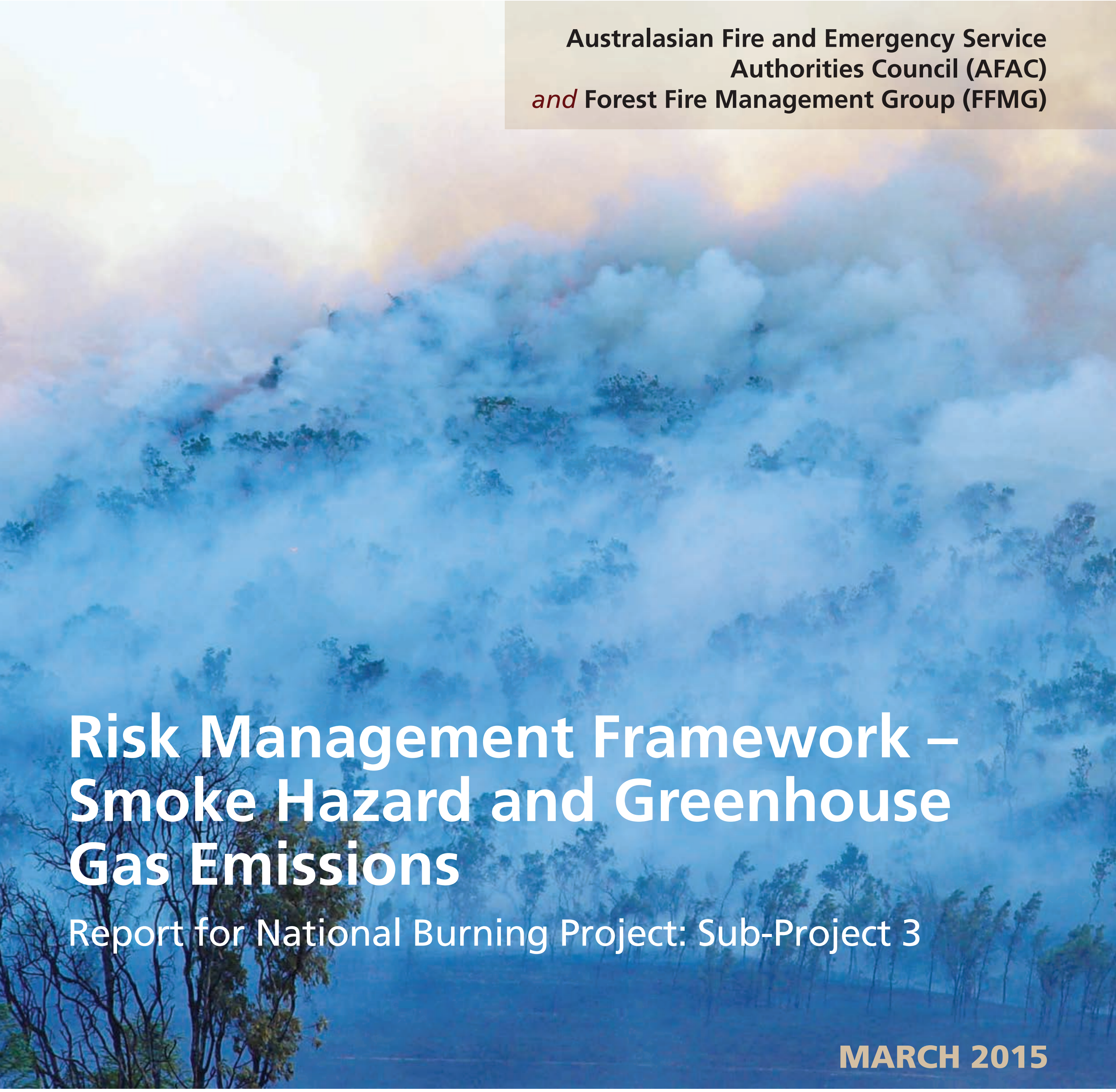
NATIONAL BURNING PROJECT

Australasian Fire and Emergency Service Authorities Council (AFAC)
and Forest Fire Management Group (FFMG)



Risk Management Framework – Smoke Hazard and Greenhouse Gas Emissions

Report for National Burning Project: Sub-Project 3

MARCH 2015

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Australasian Fire and Emergency Service Authorities Council

An Australian Government Initiative

FFMG

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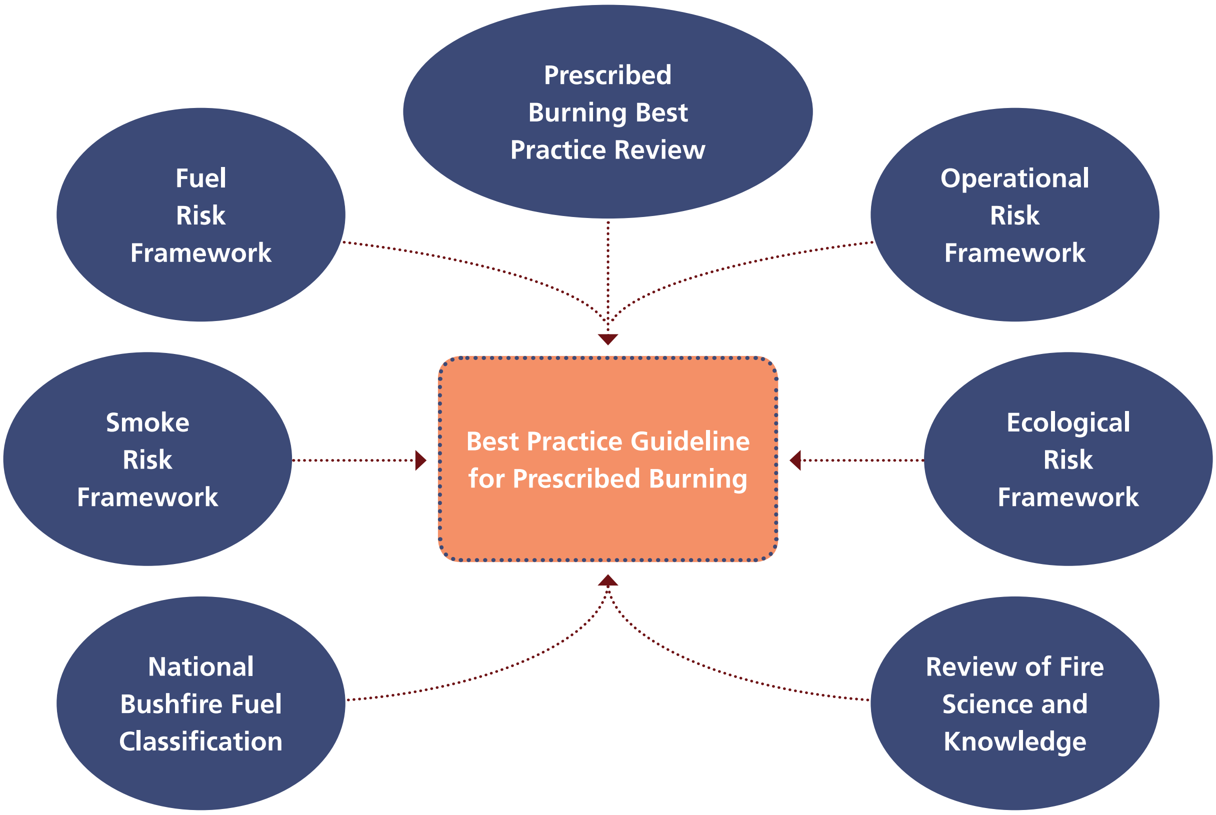
1. INTRODUCTION

The National Burning Project (NBP) has been jointly commissioned by the Australasian Fire and Emergency Service Authorities Council (AFAC) and Forest Fire Management Group (FFMG). The NBP is a multi-year project that will produce a set of national guidelines for:

- Establishing best practice guidelines for prescribed burning; and
- Ensuring greater interoperability between fire management agencies through developing common standards and approaches to prescribed burning.

A number of sub-projects are to be implemented under the NBP pursuant to developing national guidelines. The smoke risk framework development sub-project is one of the projects that will contribute to compilation of national guidelines, as depicted in Figure 1 below.

Figure 1 *National Burning Project – Framework of sub-projects*



1.1 Smoke hazard risk management and review framework development project

Prescribed burning carries a high level of inherent risk. Among others, one important suite of risks relates to the management of smoke during prescribed burning operations.

AFAC/FFMG engaged GHD to analyse and review existing risk frameworks for smoke hazard management in each jurisdiction (each of the states of Australia and New Zealand) and to develop a smoke hazard risk management and review framework.

1. INTRODUCTION

1.1.1 The need for smoke risk management

Prescribed burning is used by fire and land management agencies to reduce fuel hazards as one of a suite of bushfire risk reduction strategies, and to manage fire regimes to maintain ecosystems. Prescribed burns produce smoke, as do unplanned bushfires. Smoke can adversely impact a range of values including: public health and safety; visibility and public amenity; and smoke/visibility-sensitive infrastructure such as transport, business and crop horticultural production. Also, on-going smoke impacts can adversely affect the community's acceptance of prescribed burning programs.

The challenge for fire and land managers is to balance the community level bushfire risk management objectives of prescribed burning with local public interest objectives of protecting human health, social, economic and environmental values. Minimising the effect of smoke from prescribed burning is an essential part of using fire as a land and bushfire risk management tool. In the past, smoke management applied during prescribed burning was primarily focussed on avoiding conditions which can cause safety issues to the public and which would be objectionable to local communities. These objectives are still valid today, however over the last twenty years new demands on fire managers have emerged including requirements to comply with air quality regulations and respond to increasing community concerns about smoke.

To ensure smoke impacts are managed in an integrated and collaborative way, risk management principles should be applied to managing smoke from prescribed burning.

1.1.2 Scope of work for the smoke risk management framework development project

Within the project brief issued by AFAC/FFMG the following scope of work was specified:

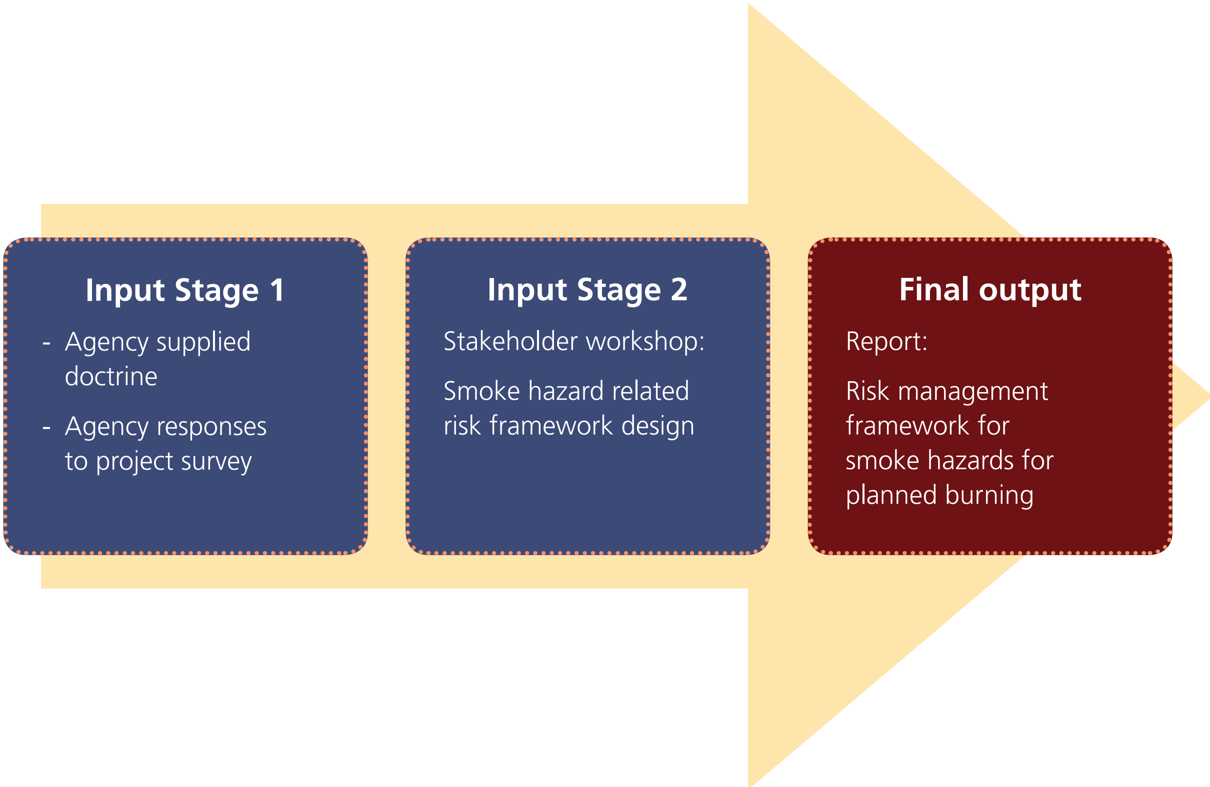
- To analyse and review existing risk frameworks for smoke hazard and carbon accounting from prescribed burning in each jurisdiction (each of the states of Australia and New Zealand);
- To provide advice on how smoke hazard from prescribed burning (for all hazard reduction, ecological and silvicultural treatment burns) compare to other air quality hazards including bushfires, how these risks can be affected by management practices, and how the risks can be measured and minimised;
- Contribute to the design of a risk framework that addresses smoke hazard risks – including risks to the amenity, prosperity, health and safety of communities and vulnerable industries affected by smoke from prescribed burning. This theme also includes the risks associated with smoke to the health of agency staff. (The operational, fuel hazard and ecological risks are the subject of other sub-projects); and
- Greenhouse Gas Emission Risks – the potential for accounting for greenhouse gas emitted from prescribed burning is a risk that is to be included in the analysis.

This report documents the findings and outcomes of GHD's analysis of prescribed burning smoke hazard related risk frameworks in participating jurisdictions, and recommends a national risk management and review framework for smoke hazard risks.

2. METHODOLOGY

GHD devised a methodology for undertaking this project for AFAC/FFMG's consideration. The proposed project methodology was discussed at the project inception meeting, agreed, and timelines developed for its implementation. An overview of the three stage methodology is provided at Figure 2 below:

Figure 2 *Three-step project methodology*



2.1 Call for agency doctrine and project survey distribution

In December 2011, GHD invited AFAC and FFMG member agencies to forward relevant doctrine relating to the management and monitoring of smoke hazard related risks, and developed a survey for agency participants to complete. To the greatest extent possible, GHD undertook web-searches to populate the survey with answers to the survey questions for each jurisdiction. This was intended to save survey participants time in completing the survey, and focus their time on validating, adding to and/or clarifying the information. Survey questions are identified in Appendix A.

2.2 Project workshop

On 7 March 2012, GHD facilitated a one day workshop in Melbourne to explore in more detail the issues, approaches and practices used by different agencies to the management and monitoring of smoke hazard related risks. A list of workshop participants is provided in Appendix C.

All AFAC and FFMG member agencies were invited to attend the workshop with invitations distributed through agency points of contact nominated by AFAC's project manager.

2. METHODOLOGY

2.3 Information analysis and project report

Pursuant to the project design agreed at the inception meeting, and further canvassed during the project workshop, GHD has structured analysis of the input received from agencies and through the workshop according to phases in prescribed burn planning.

These phases are:

- Smoke hazard and risk assessment at the level of strategic planning for prescribed burning (addressed in section 4.1 of this report);
- Smoke hazard and risk assessment at the level of tactical (program) planning for prescribed burning (addressed in section 4.2 of this report);
- Smoke hazard and risk assessment at the level of operational planning for prescribed burning (addressed in section 4.3 of this report); and
- Smoke hazard and risk assessment during prescribed burning execution (addressed in section 4.4 of this report).

Section 3 of this report discusses some general concepts of smoke hazard and risk, and discusses the nature of risk management frameworks. Specific consideration is given to the subtle changes introduced with the transition from AS 4360 to ISO 31000.

Section 5 of this report proposes a risk management and review framework for smoke hazard risks.

Section 6 of this report provides information on the types of gas considered in greenhouse gas inventories. It covers terminology used for reporting greenhouse gas emissions and how greenhouse gas emissions from bushfires and prescribed burning are calculated. A preliminary greenhouse gas emissions reduction framework is offered.

3. RISK MANAGEMENT FRAMEWORKS

In this section, some general concepts of smoke hazards and risk are briefly outlined to provide a frame of reference and context for subsequent sections.

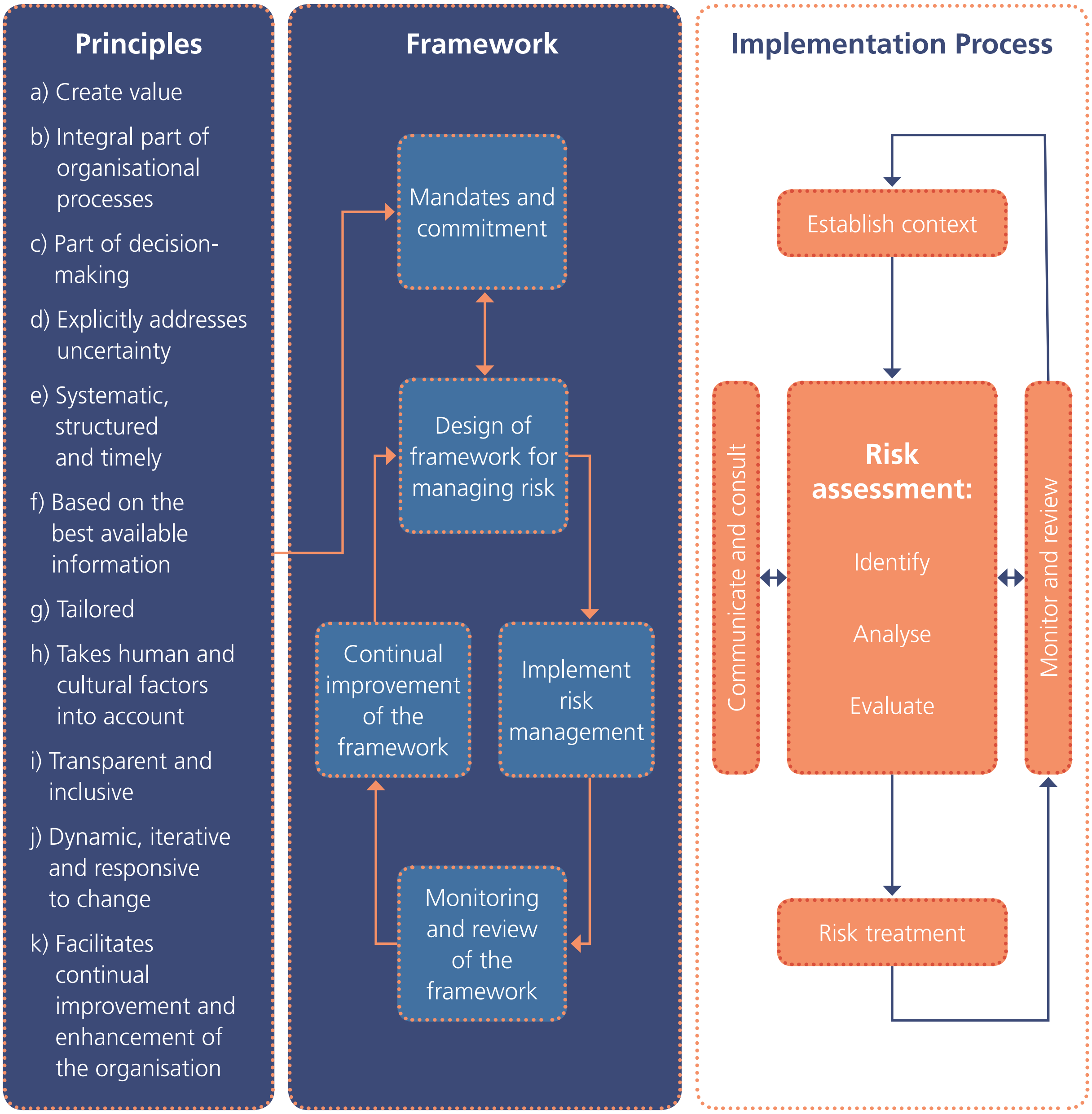
3.1 Risk management frameworks – the shift from AS/NZS 4360 to ISO 31000

In 2009 the international ISO 31000:2009 Risk Management – Principles and Guidelines usurped the AS/NZS 4360:2004 Risk Management as the primary standard on risk management in Australia and New Zealand. While ISO 31000 is founded very much on similar principles as the prior standard, there have been some subtle changes in the main points of emphasis between the two standards. Three are worth highlighting, and are listed with some commentary on the implications for developing a national risk-based framework for managing smoke from prescribed burns:

1. ***Risks are to objectives.*** The glossary of terms and the structure of the ISO 31000 standard more transparently reflect that 'risk' arises not from the occurrence of an event *per se*, but from how an event can arise and impact on an organisation and its ability to meet stated objectives. 'Risk' is defined in the standard as 'the effect of uncertainty on objectives'. Further, 'risk management' is 'a coordinated set of activities and methods… used to direct an organisation and to control the many risks that can affect its ability to achieve objectives.' Hence, while a prescribed burn will generate smoke that can result in adverse impacts for people, or to the operation of critical infrastructure (such as roads or airports) or to resources (such as grapes or clean air/visibility), the risk can relate to the possible effects on community-based needs and objectives as well. These include maintaining public health and safety, providing transport services or maintaining local economic activity. In short, articulating in a consistent way the broader objectives related to smoke management and how they relate to protecting the social, environmental and economic fabric of communities affected by prescribed burns will be a central tenet of establishing a national framework for smoke hazard management.
2. ***There are a variety of tools and methods available to perform risk assessments and inform management priorities.*** The AS/NZS 4360 standard included strong references to the use of risk assessment 'matrices' whereby qualitative descriptors of an event's 'likelihood' and 'consequences' of occurring were used to develop a risk rating of, typically, 'low', 'high' or some similar descriptor. In the bushfire risk management context, problems can arise trying to adopt the 'matrices' as an assessment tool, due to the complex and wide range of fire and smoke behaviour variability and uncertainty that can exist and that is difficult to capture. While these types of matrices can be very useful in some situations to assist with risk assessment and recording, in recent times it has become considered – in the mainstream – to be the standard tool for undertaking risk assessment, which was never the intention of the AS/NZS 4360 standard. To address this, reference to the risk matrices have been removed from the ISO 31000 standard and an accompanying document ISO 31010:2009 Risk Assessment Techniques has been created. While the risk matrices do appear in ISO 31010 as one type of tool that may be useful in risk assessment (among a list of over 30 techniques), it is emphasised that the appropriate risk assessment and communication tools should be developed with the specific context, in this case smoke risk management, in mind.
3. ***Risk management is a process of continual review and improvement, within which risk assessment is a key activity.*** The ISO 31000 generic framework for risk assessment and management is outlined below. It contains a set of principles, a risk management framework, and a risk management process, and how they inter-relate. The 'risk assessment' activities, sit within the overall risk management process. While the focus of this study is on developing a national risk assessment framework for smoke hazards management, it would be remiss to develop an approach without considering how it would be able to be conducted and subject to the continual review of the risk management approach and particularly to the principle of verifying whether the approach is producing effective and desired risk mitigation.

Further discussion relating to objective setting (Section 3.2), risk assessment considerations (Section 3.3) and the specific needs of risk assessment approaches (Section 3.4) is provided in this chapter. The concepts outlined are then used to inform the development of a recommended national framework for smoke hazard management.

Figure 3 *The ISO 31000 Risk Management Principles, Process and Framework*



3.2 Risk management objectives contextualised to prescribed burning and smoke management

In the context of maintaining community-based objectives and managing the risks due to smoke during prescribed burning, some general objectives of smoke management might include:

- Reducing the likelihood of smoke from prescribed burns causing harm to social, economic and environmental values;
- Reducing the severity of smoke impacts (exposure area, exposure duration and concentration) from prescribed burning, such that harm to social, economic and environmental values is reduced; and
- Reducing the exposure and vulnerability of social, economic and environmental values that can be harmed by smoke.

In relation to the first and second objectives, designing burns such that adverse impacts are avoided, or limited in severity and/or burning under conditions that reduce impact, can reduce the likelihood of adverse consequences arising. In regard to the third objective, managing the extent to which people or at-risk values are present within a potential smoke impact area of a burn can reduce the exposure levels of at-risk values and therefore reduce smoke impact risks. Examples include smoke-sensitive people at home near a burn, or traffic on nearby roads. When a decision has been made to implement a prescribed burn, there are some activity-based objectives to minimise the potential for adverse impacts, including:

- Attaining fire and smoke behaviour which achieves smoke density or exposure duration prescriptions;
- Limiting smoke spread to a particular direction, or within a pre-determined area; and
- Reducing the presence of smoke-sensitive people within the potential smoke-impact area of a burn, and facilitating preparedness by at-risk asset owners to reduce their vulnerability to smoke impact.

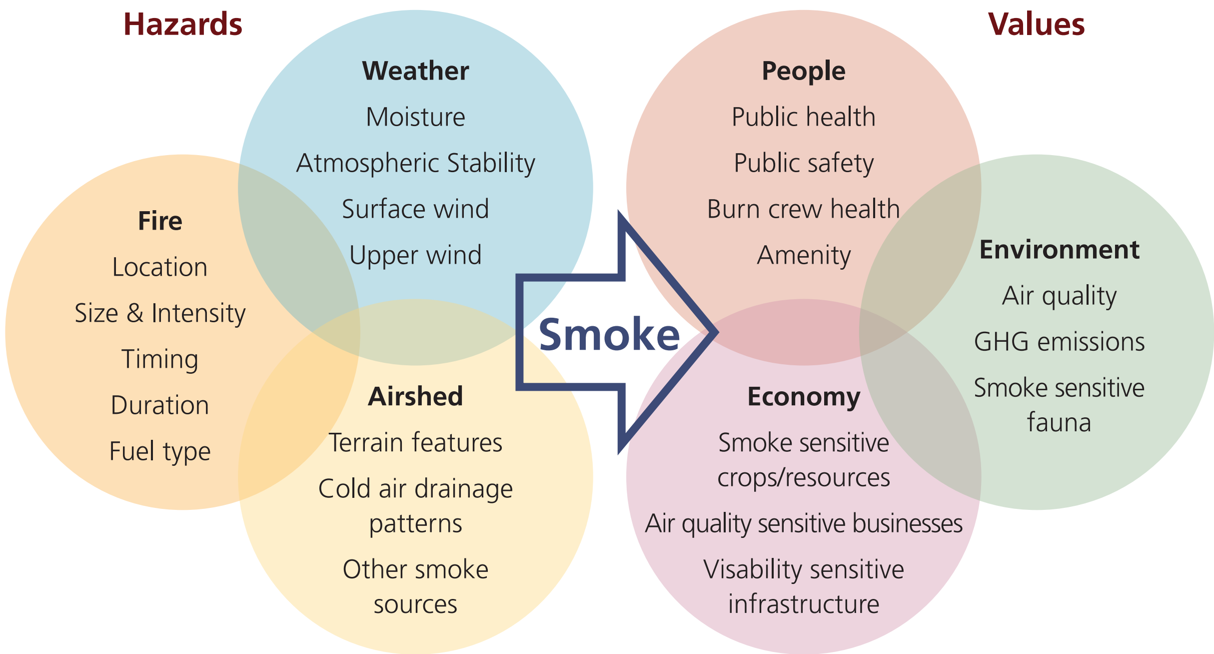
Therefore, assessing likely smoke plume characteristics and movement so that weather conditions and lighting patterns suitable to the objectives can be selected and applied, and determining appropriate consequence management strategies and resourcing requirements, will be vital.

In this report, both the prescribed burning and consequence management contexts of smoke risk management are considered.

3.3 Risk assessment considerations: Inter-relationships among hazards, values and risks

A smoke hazard, on its own, does not necessarily constitute a prescribed burning risk. Smoke must be generated in a location, quantity, density, duration and atmospheric level such that it can adversely impact values which are vulnerable and exposed to smoke.

Figure 4 *Smoke impact risk arises from the intersection of hazards with values (through smoke)*



All attributes of the hazards and values contribute to the degree of risk. The higher the hazard, and the higher the exposure and vulnerability of the values at risk, the higher the risk. The 'hazard' elements listed in Figure 4 are factors influencing the ability of smoke from a prescribed burn to be generated, spread, persist and become concentrated in an area, the 'values' listings broadly describe the things that can be at risk.

Commonly, 'risk' is considered as a combination of the likelihood of an event arising together with the consequences of the event. In this sense, values attributes may sometimes be equivalent to 'consequence' risk factors because they are factors influencing the severity of impacts arising from smoke. Hazard attributes may sometimes be referred to as 'likelihood' risk factors because they are factors influencing the likelihood that smoke will be generated in or spread to a particular place, at a particular time, and in a concentration sufficient to cause adverse outcomes. The degree of hazard factors will also influence the consequences of an event (more severe, persistent and widespread smoke events will have greater consequences than less severe, shorter duration, smaller scale events). Hence, the uses of the terms hazards and values to describe the primary drivers of risk achieves the same as considering 'likelihood' and 'consequence' but is more attuned to the focus on prescribed fire and smoke management.

3.4 Risk management considerations: Scales of assessment and prescribed burn planning phases

Risk assessment processes need to be appropriately tailored to the spatial and temporal scales being considered in planning or operations, and to the resolution of outputs required. It may not be productive or efficient to conduct fine scale analysis using high resolution data if broad landscape scale outputs in broad risk categories are required. Equally, it will be sub-optimal to use coarse resolution data and analytical methods designed to deliver broad category outputs, to support decision-making which involves fine spatial and temporal scale consideration. 'Horses for courses' risk assessment processes need to be developed and applied.

The planning phases and operating scales most commonly applied in relation to assessment of smoke risk and management are:

3.4.1 Strategic level planning at state or regional (airshed) scale

At the strategic level, smoke management planning processes typically involve identification of:

- Areas where prescribed burning operations may occur, and their seasonal timing (identifiable from strategic bushfire risk management planning);
- Values vulnerable to smoke impact in relation to prescribed burning zones (noting that potential smoke impact areas are typically much larger in extent than potential fire impact areas);
- Airshed/terrain features which, due to their physical characteristics, can exacerbate ponding or concentration of smoke at surface level and potentially also restrict smoke movement, and those airsheds which have other sources of 'background' wood smoke/particulate pollution to which prescribed burning smoke can be additive; and
- 'Acceptable residual risk' thresholds for smoke concentration/particulate pollution levels (where available).

The outcomes of smoke hazard and risk assessment at the strategic planning level typically are jurisdiction-wide or airshed-specific smoke management guidelines. These may identify matters to be considered during tactical program planning, and procedural frameworks for assessing smoke risk levels associated with prescribed burning events and practice restrictions or conditions. Strategic planning approaches in use are discussed in further detail in Section 4.1 of this report.

3.4.2 Tactical level planning for smoke management in prescribed burning programs at landscape scale, over 1 to 5 year timescales

The tactical planning processes typically take the outputs of the strategic planning phase and develop a works program identifying the locations and extents of different work types, their objectives, proposed sequence and timing.

At the tactical program planning level, smoke management considerations may be addressed through consideration of seasonality, burn scheduling (to avoid high risk periods – e.g. public holiday periods to reduce adverse tourism impacts), burn location/extent, and concurrent burning activity level restrictions. Types of burn (size, method and/or fuel type/condition) or burning activity levels that generate potential problem-level volumes of smoke can also be considered.

In some jurisdictions stakeholder consultation processes are applied at the tactical planning phase (e.g. Victoria and WA). Community group and/or individual concerns about the potential smoke risks of proposed burns may arise at this stage, before detailed smoke risk management measures for a burn, or group of burns, have been planned. The identification of such concerns can be documented and provide inputs requiring consideration during the operational planning phase.

Smoke hazard and risk assessment for the tactical program planning aspects of prescribed burning is discussed in further detail in section 4.2 of this report.

3.4.3 Operational level planning for works implementation at site-specific scale – months to weeks ahead

At the operational planning level, planning processes need to 'operationalise' the planning from the broad where, what, and approximately when level undertaken at the tactical program phase, to the how, in what conditions, and with what resources and risk management measures in place. Accordingly, the operational planning phase is usually the first stage in the prescribed burn planning process at which detail of smoke risks and the operational measures or prescriptions required to manage these are considered and documented. Consideration of smoke risks, required at the operational planning phase, normally involves both desktop assessment activities and more detailed site assessment and neighbour consultation.

Smoke management planning processes during operational planning may be broken down into the following phases:

At the ignition phase and consideration of factors such as:

- Fuel and weather conditions as this influences whether the burn can be safely undertaken and remain within containment lines;
- Fuel and weather conditions as this also influences smoke volume, smoke plume direction, smoke dispersal and smoke settling patterns;
- Occupational health and safety requirements for lighting crews, the duration of exposure and what shift change or alternative lighting patterns can be implemented to limit smoke exposure impacts; and
- Impacts of reduced visibility on airports, public roads and railways in the immediate vicinity of lighting locations, as well as those that may be impacted in the dispersal or settling phases (see below).
- Health and economic impacts associated with smoke dispersal and settling e.g. wine grapes, apiary sites, people with respiratory concerns.

During the dispersal phase and consideration of factors such as:

- Public roads potentially impacted by smoke, and the level of impact likely, and what if any smoke hazard warning and traffic management measures may be required. This factor must also be considered at the settling phase particularly if fog is forecast;
- Mass transport facilities/routes (such as airports, rail and road corridors and shipping lanes), and the level of smoke impact likely, and what if any weather prescriptions, or consequence reduction prescriptions, can be made to reduce risk to acceptable level;
- At-risk communities/facilities in which groups who have elevated smoke related health-vulnerability (elderly, young children, people with health conditions such as asthma or heart-disease/conditions); the level of smoke impact likely; and what if any weather prescriptions, or consequence reduction preparations can be made to reduce risk to acceptable levels;
- At-risk industry/business sectors (such as tourism and outdoor events), the level of smoke impact likely, and what if any weather prescriptions, or consequence reduction prescriptions can be made to reduce risk to acceptable levels; and
- Industries or facilities that have specialised ventilation or air-conditioning requirements such as underground mines or hospitals.

At the settling phase and consideration of factors such as:

- The presence of temperature inversions that may cause smoke to become trapped;
- Overnight and next morning conditions when smoke aloft produced by the burn can cool and descend to surface level after burn crews have departed the burn site and may impact on smoke sensitive values some distance away; and
- Smoke-sensitive crops, livestock, food production facilities potentially impacted by smoke settling, and the level of impact likely, the timing of impact (such as during the onset of ripening for vineyards) and what if any weather prescriptions or consequence reduction preparations can be made to reduce risk to acceptable levels.

The above processes and tasks, properly done, involve prediction of fire and smoke behaviour under the prescribed conditions. This will typically include prediction of smoke plume development during the burn and smoke dispersal afterwards. Often, the most challenging conditions are those in which there are only light and variable or negligible winds, when smoke aloft can cool and descend to the surface, sometimes becoming entrained in and exacerbating fogs, and lingering until cleared by subsequent winds.

Smoke hazard and risk assessment for the operational planning aspects of prescribed burning is discussed in further detail in section 4.3 of this report.

3.4.4 Work method tactics during burning execution to take account of fine spatial scale intra-site fuel variability and weather-driven fuel condition variability

Because operational planning may be done weeks or months ahead of when a burn takes place, such things as fire behaviour predictions and nominated lighting stages and patterns are based on assumptions about fuel attributes (often averaged across whole sites or sections of sites), and weather conditions (typically the desired weather conditions). When a burn is being implemented, fuel attributes may vary significantly across a site, and moisture content may vary significantly through the lighting period (particularly if this is over several hours or more). Therefore Operations Officers implementing burns will undertake fuel hazard, fuel moisture and weather condition assessment on an ongoing basis throughout the burn for the purpose of devising and modifying lighting tactics (e.g. lighting direction, ignition timing or rescheduling, method and spacing) and crew deployment tactics. Fuel hazard, fire and smoke behaviour assessments undertaken during burning are among the finest scale, highest resolution assessments undertaken during the burn planning and implementation end-to-end process.

Smoke hazard and risk assessment for the burning operations execution phase aspects of prescribed burning is discussed in further detail in section 4.4 of this report.

3.4.5 Post-burn monitoring of smoke hazards

After a burn is complete smoke may disperse quickly or linger for extended periods and may move from one landscape location to another. Therefore smoke impacts can occur in places not originally envisaged during the burn planning and execution phases. Good practice requires continued monitoring of smoke dispersal and movement until smoke risks have abated. Typically, this may involve:

- Monitoring of smoke plume/dispersion model outputs;
- Patrol of the burn area and areas in the airshed where smoke is known to settle and pond; and
- Advise stakeholders/residents etc. if unexpected smoke hazards arise.

4. SMOKE MANAGEMENT

GHD gathered information from fire and land management agencies regarding smoke risk management processes. An overview of the range of approaches taken is outlined in this section. Presentation of the overview is structured into the following management phases:

- Strategic planning and guidelines;
- Tactical program planning;
- Operational planning;
- Burn execution; and
- Post-burn monitoring.

4.1 Strategic Planning for smoke management – jurisdictional approaches

At the strategic planning level there is no national framework or consistent approach to classifying smoke risks. There are however some national standards and/or common approaches to how some aspects of smoke hazards are considered:

- There are national standards and measures for how levels of particulate pollution is monitored – the National Environment Protection Measure (NEPM) for PM_{10} particles is 50 micrograms/m^3 and for $PM_{2.5}$ particles is 25 micrograms/m^3;
- There is a degree of consistency in how conditions that may lead to poor smoke dispersal are considered – generally weather patterns and associated atmospheric conditions are monitored by State/Territory Environmental Protection Authorities, and a range of different approaches to restricting the amount of prescribed burning are applied in response to threshold conditions; and
- In community bushfire risk management planning, assets and values potentially vulnerable to smoke may be identified – mostly where the value at risk is human health.

Strategic level guidelines for smoke management are in place in some jurisdictions although there is little consistency in the approach and formats used.

4.1.1 NSW approach to smoke management – strategic level

The NSW Environmental Protection Authority (EPA) has a network of Air Quality Monitoring Stations (principally sited in the Greater Sydney basin and lower Hunter) at which a range of pollutants are monitored (Ozone, Nitrogen dioxide, Sulphur dioxide, Carbon monoxide, Visibility and Particles (PM_{10} and $PM_{2.5}$)). An Air Quality Index (AQI) is calculated (regionally) using worst-case index for the worst-case pollutant occurring during the measurement period. AQIs are categorised according to a six category scale.

Table 1 *Air Quality Index categories*

VERY GOOD	GOOD	FAIR	POOR	VERY POOR	HAZARDOUS
0–33	34–66	67–99	100–149	150–199	200+

An AQI of 100 corresponds to the relevant NEPM standard for criteria pollutants or the relevant NSW standard for visibility. Hence, when the AQI is reported as POOR, VERY POOR or HAZARDOUS it indicates that the determining pollutant levels have reached or exceeded the relevant standard or goal. For PM_{10} a Poor or worse index will mean the PM_{10} standard of 50 µg/m^3 has been exceeded.

Table 2 *Standards (national) for Air Quality Index pollutants*

Pollutant	Averaging period	Maximum concentration
Carbon monoxide	8 hours	9.0 ppm
Nitrogen dioxide	1 hour	0.12 ppm
Ozone	1 hour 4 hours	0.10 ppm 0.08 ppm
Sulfur dioxide	1 hour	0.20 ppm
PM_{10}	1 day	50 µg/m^3
Visibility (as Bsp)	1 hour	2.1 10^{-4} m^{-1}
$PM_{2.5}$	1 day	25 µg/m^3

ppm = parts per million by volume, i.e. parts of pollutant per million parts of air.

PM_{10} = particles less than 10 micrometers in diameter.

$PM_{2.5}$ = particles less than 2.5 micrometers in diameter.

µg/m^3 = micrograms per cubic metre, i.e. mass of pollutant per volume of air.

Bsp = coefficient of light scattering due to particles. The lower the Bsp value, the lower the level of suspended particles and the better the visibility. The DECC one-hour visibility goal, 2.1 10^{-4} m^{-1}, corresponds to a visual distance of approximately 9 kilometres.

'No burn day' declarations

- No burn days are declared (by the NSW EPA) when they deem that air pollution and meteorological conditions are unsuitable for burning (stable atmosphere with persistent low level inversion established, and negligible wind to disperse air pollution);
- Normal days (not declared no burn days) when burning is only restricted by routine open air burning regulations; and
- Where a No Burn Day is likely to be declared, fire services and land management agencies must seek exemptions for prescribed burning (coordinated through the NSW Rural Fire Service).

At-risk/smoke sensitive facility locations

In NSW, Bushfire Risk Management Plans are prepared on a Local Government Area basis (or groups of LGAs). The NSW Bushfire Coordinating Committee's Bush Fire Smoke Management Policy requires that smoke sensitive areas/locations/assets and local smoke management issues are identified in Bushfire Risk Management Plans (although the extent to which this is done is variable).

4. SMOKE MANAGEMENT

NSW Bush Fire Smoke Management Guidelines

The NSW Bushfire Coordinating Committee has issued NSW Bush Fire Smoke Management Guidelines, endorsed for application by the four NSW firefighting authorities. Strategic level guidance is largely restricted to broad guidance statements such as:

- Schedule burns so as to avoid periods of poor smoke dispersal;
- Schedule burns so as to avoid impacting significant community events (e.g. public holidays, weekends, school holidays, special community events);
- Avoid burning at times when smoke management prescriptions are unlikely to be met; and
- Where a burn has the potential to impact smoke sensitive areas, smoke management prescriptions should be used identifying desirable wind direction and fuel moisture content parameters.

4.1.2 ACT approach to smoke management – strategic level

Population levels and pollutant sources in the ACT are at much lower levels than those in Sydney with higher air quality and less necessity for air quality monitoring. While the ACT has a network of 3 air quality monitoring stations, it does not use an Air Quality Index system for public information/warning or make daily air quality monitoring results publicly accessible via the internet. The main smoke pollution issue in the ACT is smoke production from residential wood burning heaters in winter, particularly affecting the Tuggeranong Valley in winter.

However, due to the proximity of pine plantations and native bushland areas to suburban areas, and the high potential for temperature inversion formation due to the local topography, the ACT has one of the more structured smoke risk management frameworks in Australia.

The ACT approach to considering smoke risks from prescribed burning involves:

- Identification of 3 levels (low, medium and high) of 'smoke sensitivity zones' (mapped). These were devised through a semi-structured, non-quantitative process, largely on the basis of the proximity of fire-prone bushland and pine plantation areas (where prescribed burning is planned and practiced) to urban areas, and in particular to key smoke-sensitive areas including Canberra Airport, the City Centre, and the Parliamentary Triangle;
- Burns are categorised into 'small' and 'large' (being a proxy for how much smoke they are likely to produce) – see below; and

Table 3 *ACT Smoke volume category system*

Smoke Volume Class	Definition
Large	• Any burn > 5 ha, or • Any grassland burn with an area > 1 ha which has a curing < 60 %, or • Any forest burn with an area > 1 ha with a fuel moisture content > 16 %, or • Any slash (pile burn) > 200 m^2, or • Any slash (pile burn) > 100 m^2 that contains > 20% green material.
Small	Any other burn

- Atmospheric conditions are categorised using a modified Pasquil Stability Index as follows:

Table 4 *ACT Atmospheric stability category system*

Pasquil Stability Index	Description	Interpretation
A	Very Unstable	Excellent smoke dispersal and transportation.
B	Moderately Unstable	
C	Slightly Unstable	Good smoke dispersal and transportation.
D	Neutral	Marginal smoke dispersal and transportation.
E	Slightly Stable	Poor smoke dispersal and transportation.
F	Moderately Stable	Very poor smoke dispersal and transportation.
G	Very Stable	Smoke stagnates.

Using the above systems for considering 'smoke sensitivity', 'smoke volume' production potential, and 'atmospheric stability' conditions, a framework of business rules is developed which identifies:

- Those conditions (combinations of the 3 factors) in which there is considered to be little smoke impact on the community and therefore prescribed burning is allowable;
- Those conditions (combinations of the 3 factors) in which there is a likelihood of minor smoke impact on the community and therefore greater than normal caution needs to be exercised for planning and conducting a burn (e.g. potential smoke hazard advice specific to the burn issued to the community); and
- Those conditions (combinations of the 3 factors) in which major smoke impact on the community is likely to occur and therefore prescribed burning is not allowable without prior consultation with and the consent of the Environment Protection Authority.

The thresholds for burn size in relation to 'smoke volume class' are very small relative to burns conducted in other Australian jurisdictions.

4. SMOKE MANAGEMENT

Tables for calculating which level of smoke risk and precautions are required are reproduced below:

Table 5 *Tables for calculating smoke risk (ACT)*

Smoke Management Conditions

Zone 1 (High Smoke Sensitivity Zone)

Stability Class	Wind Away From Smoke Sensitive Areas		Wind Toward Smoke Sensitive Areas	
	Smoke Volume Class		Smoke Volume Class	
	Small	Large	Small	Large
A	Yes	Yes	Yes	Caution
B	Yes	Yes	Yes	Caution
C	Yes	Yes	Yes	Caution
D	Yes	Caution		
E	Caution			
F				
G				

Zone 2 (Moderate Smoke Sensitivity Zone)

Stability Class	Wind Away From Smoke Sensitive Areas		Wind Toward Smoke Sensitive Areas	
	Smoke Volume Class		Smoke Volume Class	
	Small	Large	Small	Large
A	Yes	Yes	Yes	Caution
B	Yes	Yes	Yes	Caution
C	Yes	Yes	Yes	Caution
D	Yes	Yes	Caution	
E	Caution	Caution		
F				
G				

Zone 3 (Low Smoke Sensitivity Zone)

Stability Class	Wind Away From Smoke Sensitive Areas		Wind Toward Smoke Sensitive Areas	
	Smoke Volume Class		Smoke Volume Class	
	Small	Large	Small	Large
A	Yes	Yes	Yes	Yes
B	Yes	Yes	Yes	Yes
C	Yes	Yes	Yes	Yes
D	Yes	Yes	Yes	Caution
E	Yes	Yes	Yes	Caution
F	Yes			
G				

4.1.3 Tasmanian approach to smoke management – strategic level

The Environmental Protection Authority (EPA) Tasmania have introduced a smoke pollution ‘capping’ system to manage smoke impacts from prescribed burning. A Smoke Management Working Group was established consisting of the EPA, the Forest Practices Authority, Department of Health and Human Services, Tasmanian Fire Service, the Parks and Wildlife Service and the forestry industry to develop a Coordinated Smoke Management System (CSMS) and Smoke Management Guidelines.

Under the CSMS, depending on what weather/atmospheric conditions are forecast for smoke dispersal, and what levels of current smoke pollution are observed in an air-shed, restrictions on prescribed burning will be imposed as required to ban or limit the number of burns. In this way the coordination of planned burns should minimise the risk of high concentrations of smoke within individual air sheds.

The air quality data is obtained from a state-wide smoke monitoring network known as BLANkET, which stands for Base-Line Air Network of EPA Tasmania. The network consists of air quality monitoring stations concentrated in regions and near communities likely to be impacted by smoke from planned burning. There is also a provision for a ‘no burn day’ in the system which will automatically flag days when significant further volumes of smoke should not be added to an air-shed, as determined by measurements of the current air quality and in combination with poor dispersion predictions.

Strategic elements of Tasmania’s approach to smoke management include:

- Division of Tasmania into 11 airsheds;
- Development of a ‘ventilation index’ (similar in nature to the Venting Index used in British Columbia, Canada). The Ventilation Index is a numerical value related to the potential of the atmosphere to disperse airborne pollutants, such as smoke from a prescribed fire. Index values are classified into four categories – Very Poor, Poor, Fair and Good. The index is based on both the current wind speed in the mixed layer and the mixing height. The mixed layer is the surface layer of air that is turbulent and well mixed. The mixing height is the thickness of this mixed layer. Stronger wind speeds and thicker mixed layers will produce higher venting indexes; still conditions and low mix layer depth (such as can occur during strong temperature inversions) produce low ventilation indexes; and
- Calculation of ‘allowable’ Fuel Weight Index (FWI) units, which when interpreted apply upper limits for areas allowed to be prescribed burnt in the prevailing conditions.

Table 6 *Tasmanian CSMS allowable FWI calculation table*

From BoM	Stage 1 Determined by CSMS Administrator			Stage 2 Determined by burner		Outcome in Airshed	
Ventilation Index predicted for 1600 on day of burn	FWI Base Units	Inversion height > 1500m?	Inversion height < 1500m?	Favourable dispersion	Unfavourable dispersion	Best case total FWI	Worst case total FWI
Good	15000	+5000	-5000	+33%	-33%	26667	6667
Fair	12500					23333	5000
Poor	7500					16667	1667
Very poor	2500					10000	0

Table 6 above is an extract from Forestry Tasmania's Smoke Management Guidelines. It identifies the allowable FWI's under different Ventilation Indexes (VI) and the correction factors to be applied to allow for inversion height and smoke dispersion rating.

GHD has calculated the following maximum treatment areas (hectares) are allowable under the Tasmanian CSMS:

Table 7 *Best and worst case treatment area scenarios for Ventilation Index classes*

Ventilation Index Class	Scenario	Allowable FWI	Allowable hectares*	Notes
GOOD	Best case	26667	1,778	'Best case' is triggered by the inversion height exceeding 1500m, at which wind speed of 16.9 km/hr or greater wind is required to generate a GOOD rating. Such wind speeds are not ideal for burn security – hence agencies may be reluctant to burn under Best Case Good VI conditions.
	Worst case	6667	444	
FAIR	Best case	23333	1556	On FAIR VI days with an inversion height greater than 1,500m wind speeds between 11.2 and 16.9 km/hr are required to generate the FAIR rating.
	Worst case	5000	333	
POOR	Best case	16667	1111	POOR days are commonly associated with low inversion heights, therefore Worst case scenarios are more likely on POOR days than best cases.
	Worst case	1667	111	
VERY POOR	Best case	10000	667	Inversion heights rarely exceed 1,500 m on VERY POOR VI days therefore Worst case scenarios can be expected on such days.
	Worst case	0	0	

**based on dry sclerophyll, intermediate forest and plantation fuel types*

The CSMS has been under trial since 2009, and post-season trial evaluation reports have been prepared for 2009, 2010 and 2011. While the reports do not identify the frequency of Good, Fair, Poor and Very Poor days, the reports do identify the daily 'FWI bids' received through the FWI system and the Allowable FWI for each day a bid was received. The analysis shows that it was rare for bids to exceed allowable allocation suggesting that the system is not constraining burning. There were however days on which adverse ventilation/smoke dispersion conditions resulted in no allocations and thus bids for burning allocations were not placed.

It should be noted that in Tasmania, prescribed burning levels by CSMS participants are relatively low (19,012 ha in 2009; 16,932 ha in 2010, and 32,153 ha in 2011). Burns exceeding 200 ha are relatively rare and the vast majority of burns are less than 100 ha. With burning at these levels the CSMS is unlikely to be a significant constraint to burning. If in the future Tasmanian fire and land management agencies wished to move to a larger scale burning program, particularly with a higher proportion of large burns (>1,000 ha) the current CSMS may be found to constrain burning.

The post-burn season reviews also showed that PM_{10} and $PM_{2.5}$ exceedences have been relatively rare events with the system in place, and those exceedences that have occurred did so in very poor smoke dispersal conditions when 'no burn' declarations may have avoided the exceedence (or were unrelated to prescribed burning with residential wood heater use the likely cause).

4.1.4 Victorian approach to smoke management – strategic level

The Victorian Environmental Protection Authority (EPA) maintains a network of Air Quality Monitoring Stations (13 in the Metropolitan area including Greater Melbourne/Geelong; and 2 regional stations in the Latrobe Valley). They measure the same range of pollutants and use the same Air Quality Index calculation methodology used in NSW, although Victoria only uses a five category scale (it does not have the 'Hazardous' category at the top end of the NSW scale).

Similar to the 'No Burn Day' approach applied in NSW, the Victorian EPA can declare Smoke/Smog Alert Days. These trigger a mandatory consultation process between the Department of Environment, Land, Water & Planning (DELWP) and EPA where the impact of existing and proposed burns is considered in relation to weather conditions and existing smoke/pollution levels, and an agreed course of action for proposed burns is reached (this may or may not involve postponement of particular burns). DELWP uses information assembled from its Regions regarding what burns are proposed to be ignited (gathered via a seven day schedule and daily or needs-based teleconference); existing smoke load in the atmosphere; and weather pattern/outlook and smoke dispersal advice obtained from the Fire Behaviour Analyst and BoM meteorologist in the State Control Centre.

In Victoria, DELWP prepares a Fire Operations Plan (these are tactical level plans, not strategic) in each Region annually which identifies locations and extents for proposed burns over the next 3 years. Each Fire Operations Plan (FOP) has a public exhibition/comment process, which provides a process for individual or community concerns about smoke impact to be raised. Whilst these FOPs are essentially tactical level work plans, they do incorporate strategic components in the form of designated Fuel Management Zones. Smoke management considerations can be used to inform the design of fuel management zoning arrangements. Otherwise, there appears to be no other formal method for identifying specific smoke risk areas other than applying local knowledge in planning processes.

4.2 Tactical burn program planning for smoke management – jurisdictional approaches

At the tactical program level of planning, smoke management is not considered to any significant degree. This is because most of the effort is made at the Strategic or Operational planning stages.

In Victoria, annual burning programs are placed on public exhibition with a one month period for public comment mandated. This provides the opportunity for community groups, organisations and individuals to bring concerns regard smoke (among other issues) to DELWP's attention for consideration.

In WA, seasonal burning programs (autumn and spring) are made publicly available and community groups, organisations and individuals therefore have the opportunity to bring concerns regarding smoke (among other issues) to Department of Parks and Wildlife's (DPaW's) attention for consideration.

Other jurisdictions do not publicly exhibit burning programs at the year or season ahead level, but some do have over-the-web systems for identifying where and when they will be burning once burning dates have been decided (operational planning stage).

4.3 Operational planning for smoke management – jurisdictional approaches

The operational planning stage is where jurisdictions/agencies commence site-specific identification of smoke risks and risk control measures. Typically these include such measures as identifying:

- Smoke-vulnerable values/assets in site specific burn plans;
- Relevant smoke management prescriptions in operational burn plans. This can include wind direction that will take smoke away from identified smoke-vulnerable values, conditions to avoid (inversions or particular wind directions) and in some cases minimum fuel moisture thresholds;

- Notification/public advice requirements so that potentially affected communities/ individuals can take precautions to minimise the impact of smoke;
- Specific smoke risk management measures to be applied during the burn (e.g. smoke hazard signage requirements for roads, and traffic control arrangements if deemed necessary);
- Lighting methods/patterns/timing aimed at promoting fire behaviour that results in a high proportion of smoke rising to levels where it will not later sink back to the surface (rise above radiation inversion levels); and
- Likelihood of smoke impacts at key public events.

Some agencies have Smoke Management Guidelines detailing agency operational planning requirements. Agencies typically also address smoke management aspects of operational planning in prescribe burning training modules.

4.4 Smoke management during burning operations – jurisdictional approaches

Once a burn is fully planned and preparations for burning completed, and the day of ignition identified, day-of-burn atmospheric and weather conditions are assessed to determine potential smoke impacts, and give consideration to whether it is prudent to proceed with the burn, and if so what measures are required to manage any risks identified.

For this, agencies require tools and/or sources of information and advice for determining where smoke will go (vertically and horizontally), and what severity and duration of impact is likely over the projected impact zone. Assessment of these factors is usually done on a coordinated basis by the agency (at Regional or Head Office level), although in some circumstances it may be done by Burning Operations supervisors before they go to the field to conduct operations.

4.4.1 Tools and information sources in use by agencies for smoke risk management during the burning operations phase

The following tools and information sources are used by agencies to determine operational practices or risk management measures for smoke management:

Air Quality Index (AQI)

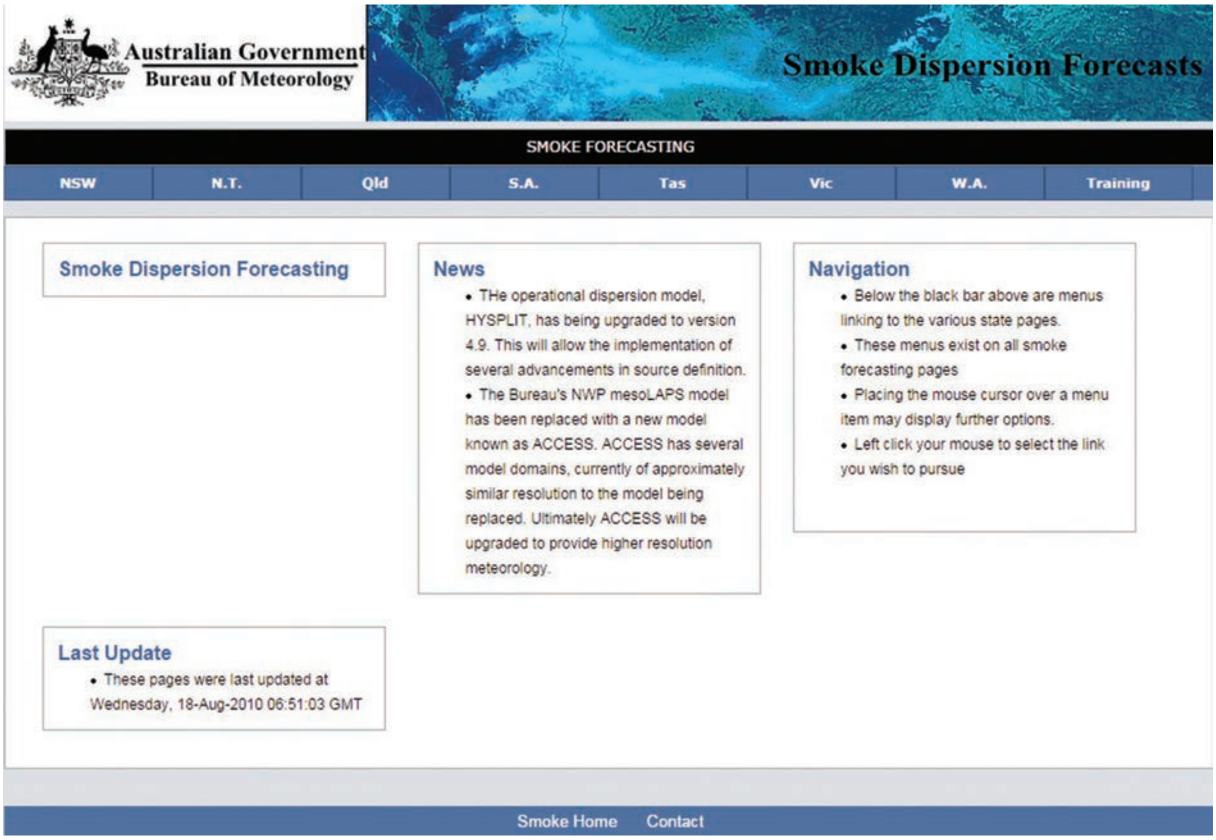
In the days immediately preceding a planned burning operation, the current and forecast AQI (issued by Environmental Protection Authorities in Victoria, Queensland and NSW only) for locations where burning is to be undertaken, are used. EPA Tasmania's website provides live air monitoring data, and indicates whether NEPM values are exceeded, but does not calculate and display an AQI. The EPA uses the AQI to support decision making regarding the declaration of 'No Burn Days' in NSW and Smoke/Smog Alert Days in Victoria. Agencies use the AQI as an input to their decision making as to whether to proceed with particular burns, and deciding what operational measures to take to manage smoke risks.

Smoke plume/dispersion models

The Bureau of Meteorology provides smoke dispersion forecasting services via its website:
http://reg.bom.gov.au/general/reg/smoke/index.shtml

Figure 5 shows a 'screen grab' from the BoM's Smoke Dispersion Forecasting home page which shows the layout and features available.

Figure 5 *BOM Smoke Dispersion Forecasting home page*



The Smoke Dispersion Forecast webpage has tabs for each State (NSW, NT, QLD, SA, TAS, VIC and WA), and each of these State pages have been customised with a number of 'Standard Locations' in consultation with Registered Users (land and fire management agencies) to routinely display smoke dispersion using a map-based format. The model output shows smoke plume development and smoke dispersion from a point source in a time lapse format. Time of ignition can be selected by the user from an ignition time menu.

The model outputs are useful to indicate what direction and how far smoke is likely to travel, and how concentrations may vary as smoke disperses. The model predictions are necessarily based on a number of model assumptions which need to be understood by those interpreting the predictions.

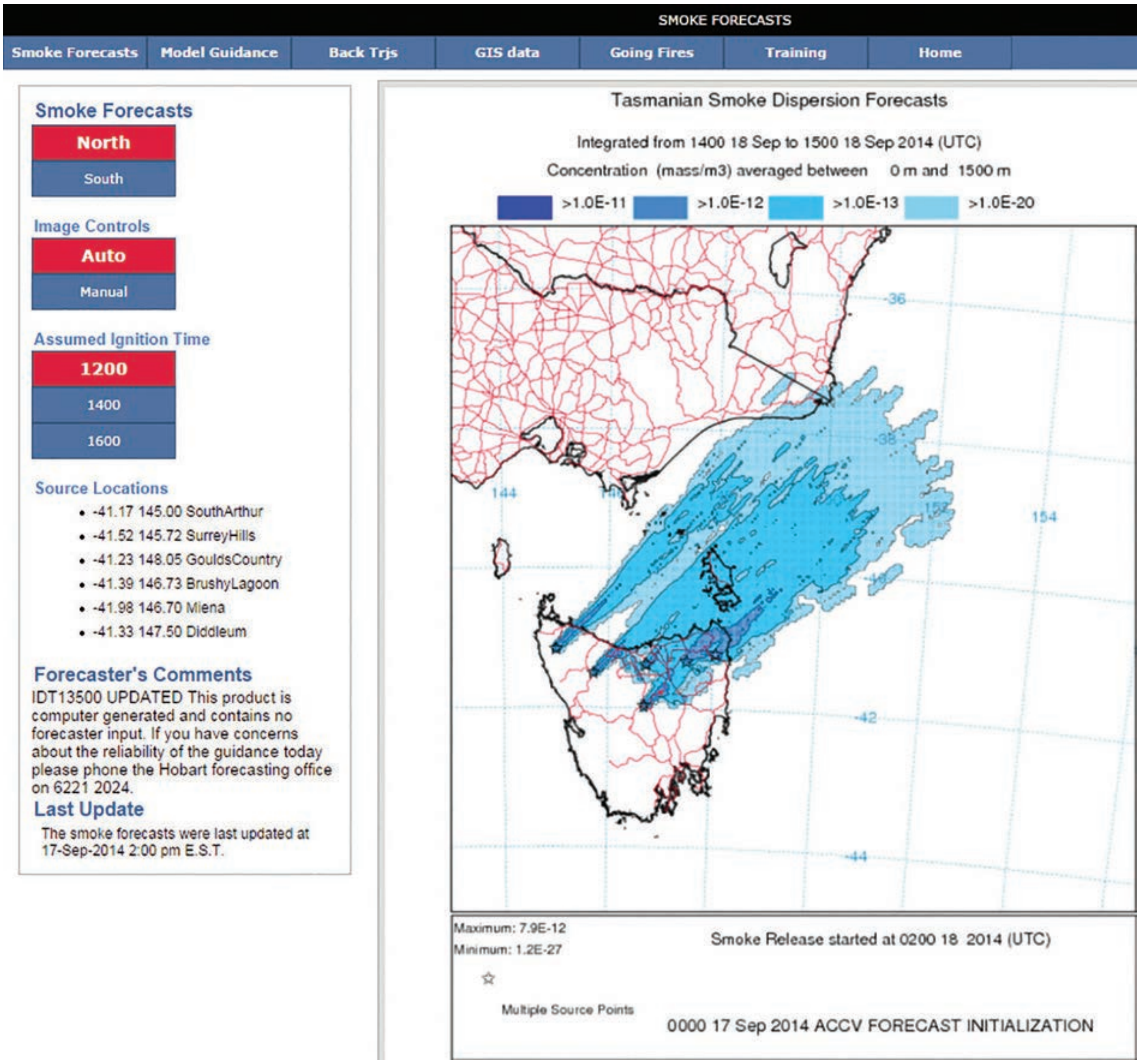
In developing model (HYSPLIT) outputs that are user-friendly and not too complex for fire-practitioner to use and interpret, a number of assumptions are incorporated:

- The model necessarily uses forecast weather data (key data being wind direction and speed), therefore if observed conditions are significantly different from forecasts, the modelled smoke dispersion will be in error to the extent of the variance;
- The modelled smoke dispersion assumes that the smoke column from a burn will reach 1500m. For burns where this does not occur (e.g. low energy release burns such as small scale burns,

burns in light fuels or burns with a high degree of smouldering) the modelled dispersion may have significant variance from what actually occurs. In such cases, users need to interpret the mapped outputs such that they 'correct' for the difference between winds at 1500m and those at the height to which smoke is actually rising;

- The model shows where the smoke that rises in the main plume will go, it does not necessarily show where low-level smoke drift (e.g. from late afternoon/overnight smouldering combustion) will go;
- Model outputs extend to 24 hrs from ignition only; and
- Model output displays smoke plume extent and concentration for 1500m (not the surface) and does not factor in smoke movement effects associated with cooling/descent or entrainment in cold air drainage. The model does not predict where smoke trapped under low level overnight inversions go.

Figure 6 *Sample of smoke dispersion forecast output (Tasmania)*



4. SMOKE MANAGEMENT

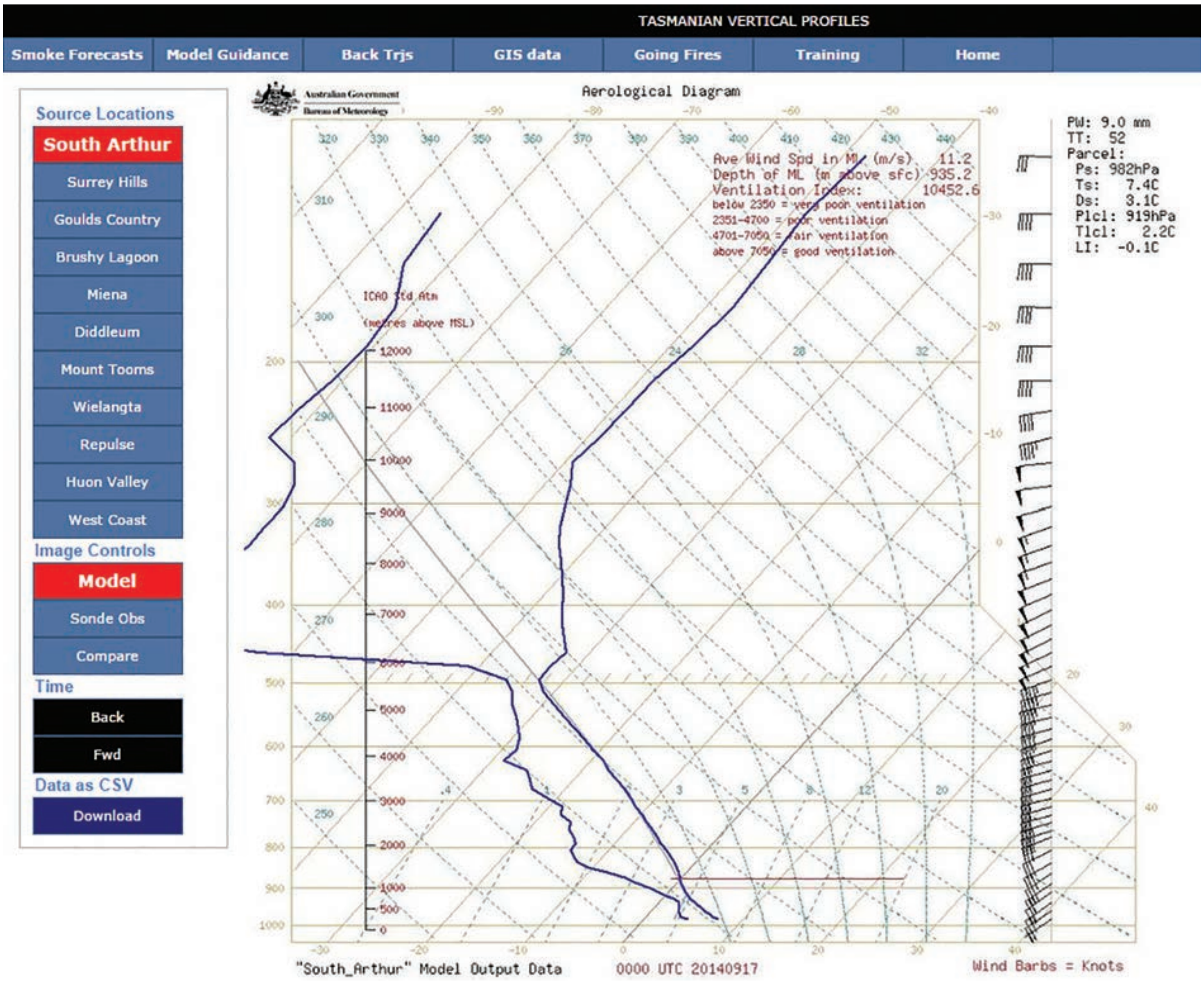
GHD understands that a three year project commenced in 2012 will incorporate a number of improvements into the smoke dispersion modelling process, potentially including allowing for the plume rise variability associated with different types/scales of prescribed burn, and allowing selection of different modelling periods (such as beyond the present 24 hour time horizon).

Aerological diagrams (modelled for specific locations)

The Smoke Dispersion Forecast webpage has tabs for each State (NSW, NT, QLD, SA, TAS, VIC and WA), and each of these State pages provide F160 aerological diagrams, modelled for specific locations as selected by local agencies.

The aerological diagrams (F160s) are customised for smoke management purposes and model the vertical column of air – in addition to showing dry bulb temperature traces and dew point temperature traces and wind direction/speed barbs with ascending altitude. The diagrams also provide mixed layer height, mixed layer average wind speed and Ventilation Index. Model aerological diagrams are available in 3 hourly increments out to 24 hours. The F160s can be interpreted by users to indicate the presence and height of temperature inversions and features such as low level wind shear. These can be interpreted by experienced users to consider smoke management risk factors such as atmospheric stability, inversion height and strength, and wind variability with increasing altitude.

Figure 7 *Aerological diagrams available through BoM Smoke Dispersion Forecast web page*



FRS Smoke Plume Model

The NSW Rural Fire Service (NSW RFS) has developed a modular tool that models smoke dispersion from prescribed burns to assist NSW fire agencies to manage smoke issues. The smoke dispersion model is a web based interface that links CSIRO's models Cubic Conformal Atmospheric Model (CCAM) and The Air Pollution Model (TAPM) to an Environmental Systems Research Institute (ESRI) based mapping module to produce mapped dispersion forecasts.

The results are visualised as interpolated plume concentration contours with both hourly and daily-averaged forecast particulate (smoke) at 10 meters in height. Maps and audio visual outputs are produced and a report is automatically generated which provides information on the forecast. The smoke dispersion particulate densities align with the Air classes set out by the NSW Environment Protection Authority (EPA).

Weather forecasts (including SPOT forecasts)

Weather forecasts information available from BoM for registered fire agencies includes a wide range of forecasts and tools including fire weather forecasts, fire danger indexes and forecasts, forest fuel dryness factor (Drought Factor), drought index and analysis charts (out to four days). These provide general wind direction/strength information and predictions that can be used by practitioners to check wind requirements against prescriptions that may be in a burn plan. They may also be used to gain a broad understanding of fuel condition.

Spot forecasts provide more detailed information including at 3 hourly time points through the day, and may include details of significant wind change events, and any specific commentary about smoke dispersal that may have been requested when the SPOT weather forecast was submitted.

Meteorologist advice

In some jurisdictions qualified meteorologists may be employed directly by agencies, or BoM meteorologists may be available through State level fire coordination/control centres, or Regional Severe Weather Sections (subject to availability) to answer questions regarding weather forecast influences on smoke dispersal.

Agency decision-support tools/procedures

Some agencies have detailed procedural guidelines and decision frameworks for making decisions not to burn, to restrict amounts of burning and to apply smoke risk management measures for burning.

Examples include:

- ACT Smoke Management Guidelines;
- Tasmania's Smoke Management Guidelines:
  - Guideline: Smoke Management Lessons Learned from the 2010 burning season;
  - Guideline: Coordinated Smoke Management System (CSMS) 2011;
  - Guideline: Minimising Smoke Nuisance #1 – The BoM F160 Aerological Diagram;
  - Guideline: Minimising Smoke Nuisance #2 – Using the BoM Smoke Dispersion Model; and
  - Guideline: Minimising Smoke Nuisance #3 – Temperature Inversions.
- DELWP Victoria's Smoke Management Guidelines; and
- NSW Bushfire Coordinating Committee's Smoke Management Guidelines.

Agency smoke guidelines typically identify operational techniques that can be applied to improve combustion efficiency (fires producing less smoke), including such measures as selecting appropriate fuel moisture content, avoiding ignition of particular fuel types or conditions, selecting times of day to optimise combustion and smoke dispersal, selecting ignition techniques that minimise smouldering combustion and avoid burning too hot/quickly with inefficient combustion.

4.4.2 Areas/tools requiring further work

Section 4.4.1 identified some of the decision support tools and information sources used by fire and land management agencies to manage smoke risk during burning implementation. Use of these tools can facilitate sound smoke risk management practice; however their use does not eliminate smoke risk. Many of the tools have only been developed in recent years, mostly within the last decade, and have significant limitations. Additionally, important information gaps are still to be addressed which limit the capacity of fire and land managers to further improve smoke management. Some key areas for improvement include:

- Fire managers do not presently have operational tools to predict how much smoke a burn will generate. Decision support tools that allow fire managers to predict how much smoke is likely to be generated from burns in different fuel types and loads, fuel moisture conditions and lighting patterns, has been suggested as a significant knowledge gap;
- Present smoke trajectory/dispersion models provide predictions of smoke movement and relative intensity at 1500 metres. The models do not provide information of smoke accumulation and movement and concentrations at other levels, and importantly not at surface level; and
- Some fire managers have indicated they need tools to predict where smoke may settle and pond in the landscape – this would be influenced by the amount of smoke produced, time of ignition, and landscape features that may influence smoke movement or ponding.

4.5 Monitoring and performance evaluation

Monitoring and performance of smoke risk management has three key levels for consideration:

Long-term program outcomes level

At the long term outcomes level, performance evaluation would normally entail evaluation of whether end-outcome level objectives of smoke management are being achieved. End-outcomes objectives, whilst not always explicitly stated, might typically include:

- Avoiding/reducing adverse public health outcomes (e.g. deaths/hospitalisations) arising from prescribed burning smoke. This may involve more monitoring of health impacts, and describing criteria for measurement and health studies of firefighters involved in prescribed burning operations;
- Avoiding/reducing adverse economic outcomes (e.g. airport closures/operations restriction, damaged crops, reduction in local tourism business etc.) arising from prescribed burning smoke; and
- Avoiding/reducing environmental harm (e.g. air pollution, greenhouse gas emission).

Measurement of indicators to identify if such performance outcomes are being achieved is problematic. The impacts occur outside of the fire and land management agency sector (e.g. deaths or hospitalisations data is not able to be recorded by fire and land management agencies – public health system data is generally at symptoms/health condition level – e.g. asthma attack – not cause). For some of the adverse outcome types, there is no structured data collection framework (e.g. economic impacts), and these can cover a wide range of business sectors.

Secondly there is the issue of determining whether or not (or the extent to which) an adverse outcome recorded is attributable to prescribed burning, because prescribed burning is not the only source of air pollution. For example, in the case of public health impacts, determining whether a hospitalisation can be directly attributed to smoke from a prescribed burn is highly problematic. The same is true for traffic accidents where smoke and naturally occurring fog are implicated and potentially also driver behaviour (not slowing down and 'driving to the conditions'). Accordingly, true long-term outcomes level objectives are not routinely evaluated as reliable data is rarely if ever available.

Intermediate program outcomes level

At the intermediate outcomes level, performance evaluation might entail evaluation of occurrence trends in the types of 'smoke events' which are assessed to be associated with adverse outcomes.

For example, National Environment Protection Measure exceedence trends might be important to monitor, keeping in mind that careful interpretation of each exceedence will be required to examine the extent to which the exceedence arose directly from prescribed burning smoke, or from other air pollution sources. NEPM's are devised in a public health context and may not be relevant to non-public health outcome level objectives (e.g. adverse tourism outcomes may be triggered at lower air pollution/visibility levels than are associated with the levels of concern for public health).

EPA agencies in each jurisdiction are the custodians of air quality monitoring network equipment and data, therefore performance evaluation of intermediate outcomes in the air quality context may be performed outside the fire and land management sector, or in partnership with it.

Fire and land management agencies can undertake performance evaluation at intermediate outcomes level if they establish appropriate accounting, monitoring and evaluation frameworks. Such frameworks might involve defining the attributes of smoke events which adversely affect outcomes for different risk dimensions (people, economic and environmental). Then using air quality monitoring data to assess occurrences and severity levels of smoke events (including consideration of the degree to which prescribed burning was involved as a pollution source). Air quality monitoring by EPA's is principally in airsheds which have major population centres. Only a small number of rural landscapes have air quality monitoring sites – these are mostly situated in areas where industrial or residential pollution sources have historically been associated with air pollution concerns. Therefore across a high proportion of landscapes where prescribed burning is carried out there are no air quality monitoring stations (and the few that may be present typically have high background levels of industrial or residential source air pollution).

The closest example of intermediate outcomes level evaluation for smoke management programs is the annual Coordinated Smoke Management System evaluation reports produced for Tasmania for the 2009, 2010 and 2011 burning seasons. Tasmania has also conducted 'lessons learnt' style reviews where adverse smoke events have occurred (such as 4 April 2012 smoke events affecting St Helens and D'Entrecasteaux Channel communities).

Input activities level

Whilst reliant to a large degree on external data for evaluation of long-term and intermediate outcomes, land and fire management agencies can internally monitor and evaluate activity inputs to smoke management programs. Such monitoring and evaluation might entail audits of the extent to which smoke risk management actions are in place, and measuring compliance against standards. Understandably, agency compliance auditing tends to be on prescribed burning procedural compliance generally, and not specifically on smoke management aspects. As there has been no consistent framework in place for how smoke risk management is undertaken, consideration of smoke management in operational compliance auditing processes is mostly absent. This project may assist in providing a structured framework for how activity level monitoring and evaluation, involving smoke risk management aspects, can be designed.

5. SMOKE RISK MANAGEMENT FRAMEWORK

From the analysis in the preceding sections, a framework for considering smoke hazard related risks for prescribed burning has been developed. The framework is depicted on the following page.

The framework identifies the following:

- The prescribed burn planning and operations sequence from strategic planning through to burning operations execution;
- The general purpose and context for smoke hazard risk assessment at each stage of the prescribed burn planning and operations process;
- Smoke hazard risk factors for consideration at each stage of the prescribed burn planning and operations process, noting that these get progressively finer in resolution as the phases of planning and operations progress; and
- Monitoring and review requirements relevant to each phase.

The value of the framework is chiefly to set out and define the key phases of the prescribed burn planning and implementation process; to identify the purpose and scale of smoke risk assessment activities at each phase; and identify the key smoke hazard attributes for assessment. It is a high-level, non-prescriptive framework (as national frameworks should be). It can be readily adopted in Australian and New Zealand jurisdictions, providing for improved alignment of approaches whilst still accommodating locally developed methodologies tailored to the different statutory and policy frameworks, institutional arrangements and agency capabilities, and operating environments in each jurisdiction.

Knowledge and systems exchange between jurisdictions, as has been conducted to various extents in the past, can promote practice improvement in different parts of the framework, particularly if considered as part of structured review and improvement processes.

Figure 8 *Smoke hazard risk management* ***framework*** *outline*

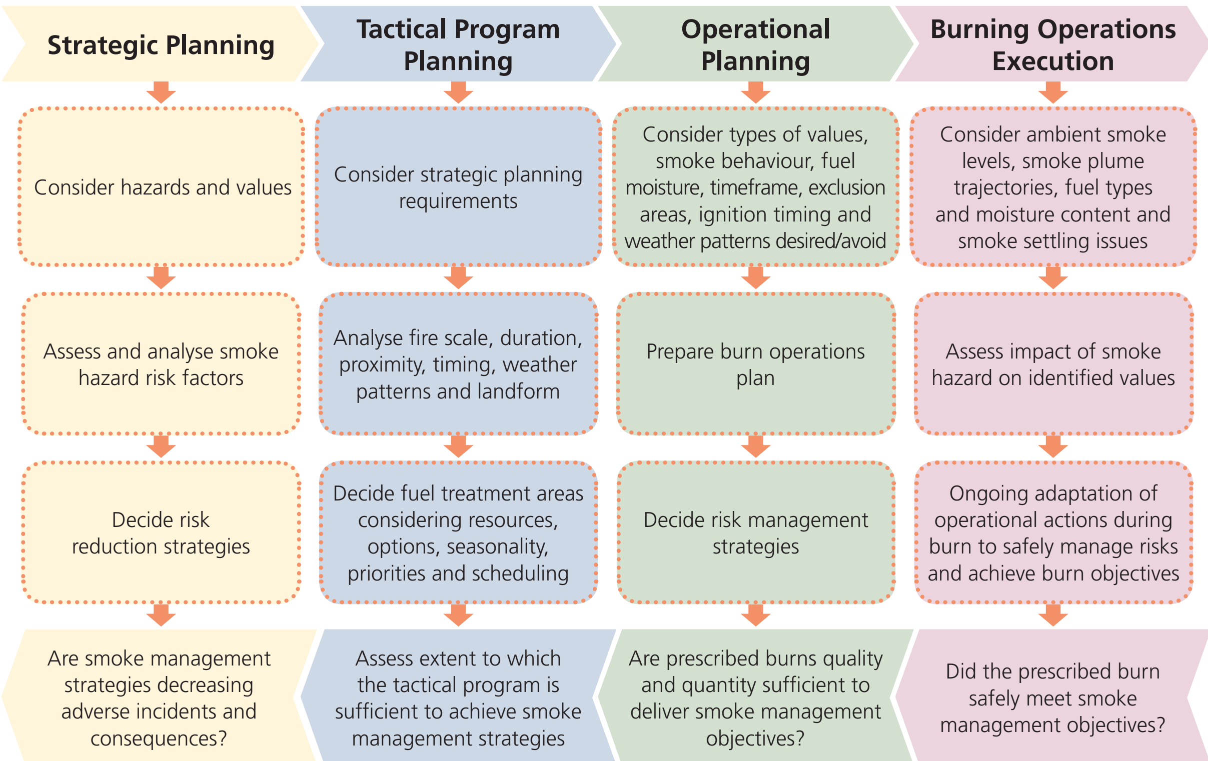
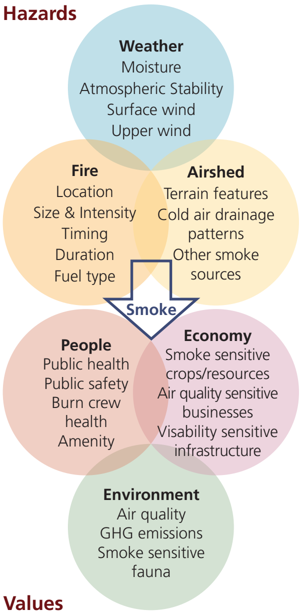


Figure 9 *Smoke hazard risk management framework for prescribed burning*

Communicate and consult

Strategic Planning → **Tactical Program Planning** → **Operational Planning** → **Burning Operations Execution**

Strategic Planning



ASSESS & ANALYSE SMOKE RISKS

Analyse where, when, how, and why problem level smoke concentrations occur and identify how potential smoke impact events/areas intersect with smoke-sensitive values.

Smoke hazard risk factors for consideration:

- Values sensitive to smoke impact (location/extent, exposure timing, and sensitivity threshold dimensions)
- Areas prone to smoke concentration/persistence (with consideration of background particulate pollution levels)
- Weather patterns conducive to poor smoke dispersal and accumulation of smoke at surface level
- Burning types/scales /times that produce problem quantities of smoke at surface level

DECIDE STRATEGIES

Smoke management strategy elements to consider:

- Weather patterns to avoid (poor smoke dispersal)
- Landscape locations requiring special/extra risk controls
- Values at-risk based burn timings/locations to avoid
- Burn activity level limits under different conditions

PUT IN PLACE CAPACITY, SYSTEMS AND TOOLS TO IMPLEMENT SMOKE MANAGEMENT STRATEGIES

Tactical Program Planning

PLAN HAZARD TREATMENT PROGRAMS

Smoke management strategies should inform tactical program planning. For example, the following smoke risk reduction strategies can influence tactical burn program planning:

- Fuel management zone types which typically involve large-scale, long-duration, burning operations can, where practicable, be placed an appropriate distance from smoke sensitive assets/values (Note: fuels closest to assets can generate the highest risks, so there are practical limitations on the extent to which smoke risk avoidance can be achieved)
- Where bushfire hazards requiring fuel reduction are in close proximity to smoke sensitive assets/values, burn programming can consider:
  - Choice of time to avoid high sensitivity exposure times, or
  - Choice of burn area dimensions to avoid high smoke exposure level events, or
  - Choice of seasonal timing/ weather pattern to maximise smoke dispersal, or
  - Choice of lighting method/ pattern to achieve rapid burn-out and therefore limit period of exposure
- Where at-risk values are vulnerable to smoke only at certain times, burn timing to avoid sensitive times can be considered
- Where particular weather patterns are conducive to poor smoke dispersal/surface level smoke concentration, burn timing to avoid such weather patterns can be considered
- Where landform features serve to concentrate smoke under particular conditions, special prescriptions might be considered

DECIDE FUEL TREATMENT AREAS, PRIORITIES AND WORK SCHEDULES

While smoke risk avoidance/ reduction strategies can be considered, conflicts between at-risk values and safe burning practice limitations may still arise where smoke risk cannot be eliminated. In these cases, smoke impact reduction measures may be limited to operational burning techniques

Operational Planning

PREPARE BURN OPERATIONS PLANS

Operational Burn Plans are prepared for each burn nominated in the tactical level program. These typically identify burn objectives and prescriptions, burning ops preparatory requirements, resource requirements and organisation, notification requirements, and operating instructions (including lighting sequence and patterns; burn inclusion and exclusion areas, and site-specific risk management measures for the burn). Importantly, they can also include operational arrangements for smoke management including:

- Types of smoke-sensitive assets/values near the burn area and their locations
- Desired smoke plume behaviour and smoke dispersal trajectories
- Desired weather parameters to achieve desired smoke behaviour and trajectory
- Desired fuel moisture conditions to minimise smoke quantity
- Desired burn-out timeframe to minimise over-night burning/smoke generation and surface smoke ponding
- Fire exclusion areas to avoid high volume smoke production (e.g. peat areas or particular vegetation types) and
- Identification of specific weather patterns or ignition timings which should be avoided

SMOKE HAZARD CONSEQUENCE PLANNING

The above measures in operational plans are designed to minimise smoke production and impact to at-risk values. All burns will generate smoke and some degree of local level impact, therefore smoke consequence management also needs to be planned. This includes:

- General warnings to local community and stakeholders (ideally incorporating smoke considerations in messaging)
- Specific notifications, especially to smoke sensitive facilities/utilities (including businesses which own smoke sensitive animals which can be relocated/sheltered)
- Smoke hazard signage and traffic control requirements
- Personal protective equipment and first aid requirements

Burning Operations Execution

SMOKE MANAGEMENT DURING BURNING OPERATIONS

Burn supervisors and burn program coordinators make numerous operational decisions in the immediate lead-up to, and during burning operations which are taken to manage smoke risks. Smoke risk assessment and management actions undertaken include:

- Assessing ambient smoke levels and current/forecast weather conditions, and/or Ventilation Index and AQI levels to determine if burning should proceed
- Assessing predicted smoke plume trajectories and concentrations in relation to smoke sensitive locations to determine if conditions are suitable for burning
- Notifying likely-to-be-impacted smoke-sensitive or vulnerable facilities/people/ businesses what impact avoidance/reduction measures they should take and when they need to take them
- Assessing/confirming the location of roads that may be impacted by smoke and making appropriate traffic management arrangements
- Assessing fuel types and their fuel moisture content to determine ignition timing and lighting patterns for optimising burn security and minimising smoke production
- Considering desirable burn-out completion timeframes so as to ensure the bulk of the smoke is produced during favourable dispersal conditions, and that residual smouldering after dispersal conditions deteriorate is minimised
- Prior to down-scaling operations, assess the current location and density of smoke, and forecast conditions overnight –revise smoke hazard signage arrangements accordingly
- If smoke aloft is considered likely to descend and pool at surface level overnight, consider which parts of the terrain this is most likely to occur in and make appropriate arrangements to check smoke conditions in the morning
- If heavy surface ponding of smoke occurs, issue appropriate warnings and notifications so smoke risk mitigation measures can be taken

OUTCOME LEVEL MONITORING (long-term) **ACTIVITY LEVEL MONITORING AND REVIEW**

Strategic Planning	Tactical Program Planning	Operational Planning	Burning Operations Execution
Are smoke management strategies decreasing adverse incident frequency, duration & severity? Are smoke impact consequences reduced? Periodic review of strategies.	Assess extent to which the tactical program is sufficient to achieve smoke management strategies. Periodically review tactical planning practices.	Assess whether standards and guidelines for incorporation of smoke management requirements in operational burn plans are relevant and effective.	Assess smoke outcomes of burns against objectives, prescriptions and risk control specifications. Record outcomes. Periodically review operating practices.

6. GREENHOUSE GAS EMISSIONS

This chapter discusses greenhouse gas emissions, legislation and accounting methods in Australia and New Zealand. Following this, greenhouse gas emissions from bushfires and prescribed burns are considered, along with opportunities and limitations in terms of generating carbon offsets.

In the savannah of Northern Australia, the potential for higher-intensity late dry season bushfire is reduced through the strategic application of lower-intensity prescribed burning. There is evidence that this process reduces emissions of greenhouse gases and a methodology to account for and claim carbon credits is available. In the forests of Southern Australia, there is uncertainty that the mitigating effect of prescribed burning on bushfire produces an overall reduction in greenhouse gas emissions, and there is no approved method to generate carbon offsets.

This chapter ends with a preliminary framework integrating current thinking on actions that may be taken by land managers to reduce greenhouse gas emissions as part of prescribed burn planning and implementation. However, this framework needs to be considered in the context of the uncertain evidence base and lack of any approved method for generating carbon offsets in forests.

6.1 Background

The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty that was established in 1992 to address increases in global average temperatures and the resulting impacts of climate change. As parties to the treaty Australia and New Zealand are required to estimate and report national greenhouse gas emissions annually.

The UNFCCC outlines the sources and sinks of greenhouse gas emissions that must be included in the national greenhouse gas inventories. Greenhouse gas emissions from bushfires and prescribed burning are included as emission sources. A distinction between anthropogenic and natural bushfires is not made in the national inventories. All bushfires are reported as it is not always possible to determine if the bushfire was deliberately lit or a result of a natural occurrence. The sequestration of carbon dioxide in grasslands and forests following a fire event is included as a greenhouse gas sink (i.e. something in which greenhouse gasses accumulate/are stored) in the national inventories. The greenhouse gas emissions from bushfires and prescribed burning are estimated annually for Australia and New Zealand. National inventory reports are available for download from http://unfccc.int/.

The Kyoto Protocol is linked to the UNFCCC and sets greenhouse emission targets for thirty-seven industrialised countries and the European Union. The same estimation methods outlined by the UNFCCC are used for assessing a country's compliance with the Kyoto Protocol. However, there are small differences regarding the emission sources and the greenhouse gases that are included in national inventories submitted to the UNFCCC and the emissions estimate used to assess compliance with the Kyoto Protocol.

The following sections provide background information on the types of greenhouses gas considered in the inventories, terminology used for reporting greenhouse gas emissions and how greenhouse gas emissions from bushfires and prescribed burning are calculated.

6.2 Greenhouse gas legislation in Australia and New Zealand

Relevant greenhouse gas legislation in Australia and New Zealand is outlined below.

6.2.1 Australia

National Greenhouse and Energy Reporting Act 2007. In the 2011 – 2012 reporting year, the National Greenhouse and Energy Reporting Scheme (NGERS) applies to facilities that emit over 25,000 t CO_2e per year or consume more than 100 TJ of energy or corporations that emit over 50,000 t CO_2e per year or consume more than 200 TJ of energy. Organisations that exceed the thresholds are required to report energy consumption, energy production and greenhouse gas emissions.

Carbon Credits (Carbon Farming Initiative) Act 2011. The Carbon Farming Initiative (CFI) has been developed to give farmers, forest growers and landholders the ability to generate accredited domestic offsets for access to domestic voluntary and international carbon markets. Offsets can be generated by the following project types, based on methodologies approved by the Domestic Offsets Integrity Committee:

- Agricultural emissions avoidance projects;
- Landfill legacy emissions avoidance projects;
- Introduced animal emissions avoidance projects; and
- Sequestration offsets projects.

Clean Energy Act 2011. This act introduced a carbon pricing mechanism that had a broad coverage from commencement in July 2012 until its repeal effective from 1 July 2014. During the two years that the scheme was active, the carbon emissions were reduced by 1% overall in sectors involved in the scheme. The carbon pricing mechanism will be replaced by a direct action climate change policy, the centrepiece of which is the Emissions Reduction Fund (EMF). Under the EMF tenders bid for funds to support projects to reduce emissions (Department of Environment 2014). Reduction estimates must be:

- Measurable and verifiable; and
- Be the result of additional measure rather than business-as-usual.

6.2.2 New Zealand

Climate Change Response Act 2002. The Climate Change Response legislation outlines the requirements of the New Zealand emissions trading scheme. The stationary energy, industrial processes and liquid fossil fuels sectors commenced on 1 July 2010. Agriculture is due to enter the scheme on 1 January 2015.

6.3 Greenhouse gases

The greenhouse gases or gas types that are reported in Australia's and New Zealand's national inventories are:

- Carbon dioxide (CO_2);
- Methane (CH_4);
- Nitrous oxide (N_2O);
- Sulphur hexafluoride (SF_6);
- Hydrofluorocarbons (HFCs); and
- Perfluorocarbons (PFCs).

These six gases are commonly referred to as the Kyoto gases, as emissions of these gases are used to assess compliance with the Kyoto Protocol. The Kyoto gases are generally used for all greenhouse gas accounting purposes.

There are a number of other gases that are classified as greenhouse gases. The gases include:

- Nitrogen trifluoride;
- Trifluoromethyl sulphur pentafluoride;
- Halogenated ethers; and
- Other halocarbons not covered by the Montreal Protocol.

These gases are generally only reported for specific industries that emit these gases.

Each greenhouse gas has a different capacity to absorb and radiate heat in the atmosphere and persists for different durations in the atmosphere. To account for these differences, the quantity of each gas is multiplied by the gases' global warming potential to convert the emission to units of tonnes of carbon dioxide equivalent (CO_2e). The global warming potential is the impact of a greenhouse gas on heat absorption and radiation in the atmosphere relative to carbon dioxide and is for a specific period of time (e.g. the 100 year global warming potential for methane is twenty-five, meaning the impact of methane is twenty-five times greater than carbon dioxide).

6.4 Greenhouse gas emissions from bushfires and prescribed burning

Prudent fire management of vegetation communities to reduce the potential for higher intensity fires through the application of low intensity fires has been suggested as a means to reduce greenhouse gas emissions. It is based around the principal that by removing fuels at lower intensity burning under milder conditions, the greenhouse gas emissions are lower than if the vegetation were to be left to burn by higher intensity bushfire. Greenhouse gas abatement methodologies are established for savannah burning but none exist for eucalypt forests, and the benefits of prescribed burning in these forests for greenhouse gas emissions reduction is uncertain (See section 6.6).

The methodologies for estimating greenhouse gas emissions from bushfires and prescribed burning are outlined in Sections 6.4.1 for Australia and 6.4.2 for New Zealand respectively.

In accordance with the requirements of the IPCC guidelines, emissions from prescribed burning of savannas are included in the agriculture section of the national reports and bushfires and prescribed burning in forests are included in the land use change section. The methodologies for estimating emissions from prescribed burning of savannas and emissions from bushfires and prescribed burning in forests are addressed separately.

6.4.1 Australia

Prescribed burning of savannas

The objective of greenhouse gas abatement through savanna burning is to carry out strategic early dry season (EDS) burning (annually before 1 July) to reduce or eliminate fuels that would otherwise burn more intensely in the late dry season, contributing greater emissions of methane (CH_4) and nitrous oxide (N_2O) than they would as EDS burns.

The methodology for estimating emissions from the prescribed burning of savannas is outlined in the Australian National Greenhouse Accounts National Inventory Report (2009)[1]. It is also defined as an approved methodology[2] under the *Carbon Credits (Carbon Farming Initiative) Act 2011* with the objective of reducing greenhouse gas emissions through early dry season savanna burning.

An outline of these methodologies, including calculations used, is provided in Appendix C: Carbon accounting methodologies for Australia and New Zealand.

Bushfires and prescribed burning of forests

The methodology for the abatement of greenhouse gasses in savannas does not readily apply to eucalypt forests owing to:

- The predictable timing and extent of annual savannah fires, and the ease at which their extent can be mapped;
- The relative simplicity of fuel types and curing assessment; and
- The greenhouse gas emissions benefit from EDS prescribed burning can easily be explained.

The greenhouse gas emissions abatement benefit of prescribed burning relative to bushfire for southern forests is yet to be established, though are considered carbon neutral in National greenhouse gas accounts (see Section 6). The methodology for estimating emissions from the bushfires and prescribed burning of forests is outlined in the Australian National Greenhouse Accounts National Inventory Report (2009)[3]. The methodologies for calculating emissions are provided in Appendix C: Carbon accounting methodologies for Australia and New Zealand.

6.4.2 New Zealand

Prescribed burning of savannas

The methodology for estimating emissions from the prescribed burning of savannas is outlined in New Zealand's Greenhouse Gas Inventory Report. Prescribed burning of savannas is outlined in Section 6.6 of the 2009 national inventory report.

CO_2 emissions are not estimated as it is assumed that all CO_2 emissions are sequestered during the following growing period. Emissions of CH_4 and N_2O are determined based on the equations outlined in Appendix C: Carbon accounting methodologies for Australia and New Zealand.

Bushfires and prescribed burning of forests

The methodology for estimating emissions from the bushfires is outlined in New Zealand's Greenhouse Gas Inventory Report. The latest published inventory report was for 2009. New Zealand does not report emissions from prescribed burning in forests as there is no data currently available and the practice is not common.

CH_4 and N_2O emissions are outlined in Section 7.3.2 of the 2009 national inventory report and are based on a default value provided by the IPCC.

1 *Volume 1, Section 6.7*
2 *Carbon Farming (Reduction of Greenhouse Gas Emissions through Early Dry Season Savanna Burning) Methodology Determination 2012*
3 *Volume 2, Appendix 7.E*

6.5 Requirements to report greenhouse gas emissions from prescribed burning

The Australian and New Zealand governments are required to estimate and report greenhouse gas emissions from bushfires and prescribed burning as part of the requirements of the UNFCCC.

Currently there are no requirements for Australian and New Zealand organisations (e.g. national park authorities, forest managers, rural fire services, private organisations) to estimate and report emissions from prescribed burning. The Commonwealth obtains information annually from State fire and land management agencies on area burnt by unplanned bushfires and by prescribed burns and derives estimates of associated greenhouse gas emissions from these.

Prescribed burning is not listed as an activity in the New Zealand emissions trading scheme and therefore excluded. There are requirements to account for emissions from fires in managed forests within the New Zealand emissions trading scheme. These requirements apply to organisations that have opted into the emissions trading scheme to generate credits from sequestration in managed forests and do not apply to prescribed burning in other forests.

6.6 Opportunities to generate carbon offsets

Within Australia, the Carbon Farming Initiative (CFI) outlines the activities allowed for the generation of carbon offsets in the land sector. The four broad activity categories are:

- Agricultural emissions avoidance projects;
- Landfill legacy emissions avoidance projects;
- Introduced animal emissions avoidance projects; and
- Sequestration offsets projects.

There is an approved CFI methodology to generate carbon offsets through shifting the burning of savannas from the late dry season to the early dry season. The methodology focuses on the change in methane and nitrous oxide emissions only as it is assumed that all carbon dioxide emissions are sequestered during the following growing period.

It is uncertain that a CFI methodology related to changing prescribed burning in forests would be approved and/or would provide sufficient returns on investments. The key requirements for methodologies to be approved are[4]:

- Abatement must be measureable and verifiable;
- Measurement methods must be supported by peer reviewed science and consistent with Australia's international accounts;
- Measurement methods must account for leakage and variability and use conservative assumptions;
- Abatement must be additional to what would occur in the absence of the project; and
- Sequestration must be permanent.

4 *Department of Environment, 2014, http://www.climatechange.gov.au/reducing-carbon/carbon-farming-initiative/carbon-farming-initiative-handbook/integrity-cfi-offsets*

Any methodology for prescribed burning in forests would need to focus on reducing methane and nitrous oxide emissions. It is assumed that all carbon dioxide emissions are sequestered during fire recovery (see Section 6.4.1) as long as there has not been a change in the land use (e.g. a forest converted to grassland). Regardless of tree mortality, if a forest is still classified as a forest and takes a significant period of time to recover, then it is assumed (under Australia's national inventory methodology) that all carbon dioxide is sequestered following the fire event. As such, a methodology focusing on reducing tree mortality in mature forests (and subsequently carbon dioxide emissions) by reducing the intensity of bushfires through prescribed burning would not be consistent with Australia's international accounts and therefore would be unable to satisfy one of the key requirements for a CFI project.

6.7 Future potential to generate carbon offsets

The potential to generate carbon offsets in the future for eucalypt forests is uncertain. Most speculation concerning potential greenhouse gas emissions reductions from prescribed burning surround the fact that prescribed burning reducing the amount of fine fuel influences the likelihood of subsequent coarse fuel ignition (from bushfire). Coarse fuels are likely to burn for a longer duration and with a greater amount of smouldering, and therefore produce more methane (Fairman *et al.* 2014).

A recent study by Fairman *et al.* (2014) considered greenhouse gas emissions at sites that had been burnt by prescribed fire and then by a bushfire three months later, as compared to long unburnt sites that were subsequently burnt by the same bushfire. They found a significant reduction in greenhouse gas emissions from the prescribed burn-bushfire sequence as compared to the bushfire alone.

An earlier report by Bradstock *et al.* (2012) argued that a high frequency of prescribed burning would be required to reduce the risk of infrequent bushfire, and therefore, the benefits of prescribed burning to reduce carbon was questionable.

6.8 Preliminary greenhouse gas risk management framework

Below, a preliminary framework is presented integrating current thinking on actions that might be taken by land managers to reduce greenhouse gas emissions as part of prescribed burn planning and implementation. This framework should be considered in the context that there is no approved method for gaining carbon offsets in forests. Greenhouse gas emissions as a result of prescribed burning of forests will require significantly greater investigation in order to demonstrate, or not, the potential for reduction in greenhouse gas emissions.

The framework identifies the following:

- Adjustments that may be considered at a strategic level of planning for prescribed burning;
- Adjustments that may be considered at a tactical (program) planning level for prescribed burning;
- Mitigations and risk management actions that may be adopted at an operational planning level; and
- Actions that may be taken at the burn operations execution level.

This framework is offered to enable agencies to consider adjustments that may be made to their prescribed burning planning and practices in the event that it is perceived that there is sufficient evidence for greenhouse gas reductions as a result of prescribed burning and/or there are opportunities to gain carbon offsets. This is already the case for prescribed burning in the savanna of Northern Australia. The actions outlined in this framework need to be considered in the context of other prescribed burning goals such as hazard management and ecological outcomes (which will likely take precedent in the event that any conflict between competing goals arises).

Figure 10 *Preliminary greenhouse gas risk management framework for prescribed burning*

Preliminary greenhouse gas (GHG) risk management framework

Strategic Planning

ASSESS GHG MITIGATION POTENTIAL, RISKS AND OPPORTUNITIES

- Analyse what aspects of fire management can be modified to minimise GHG emissions
- Monitor carbon offset policy and assess the potential for taking part in carbon offset schemes
- Be aware of the risk of bushfire producing a carbon credit deficit
- Be aware of the risk of future GHG legislation having consequences on fire management procedures and requirements for accounting

DECIDE GHG REDUCTION STRATEGIES

- In Northern Australia savanna carry out strategic early dry season (EDS) burning to reduce late season fires
- In other ecosystems consider adjustments to fire regimes that would increase the reduction of fine fuels and mitigate the extent and severity of bushfire burning coarse fuels
- Identify requirements to avoid areas of slowly accumulating GHG rich fuel (such as peat fuels)

Are strategies contributing to GHG reductions?

Tactical Program Planning

PLAN FUEL TREATMENT OPTIONS

- Consider strategic planning objectives and adjustments to fire regimes
- Consider the quantum and distribution of fuel treatment to reduce severity and extent of bushfire
- Consider seasonality issues and conditions to favour consumption of fine fuels (<6mm diameter) and avoid consumption of coarse fuels (>6mm diameter)
- Be aware of any carbon accounting requirements and maximise opportunities for offsets

DECIDE FUEL TREATMENT AREAS, PRIORITIES AND WORK SCHEDULES

While GHG emission mitigation strategies can be considered, other prescribed burning goals such as hazard management and ecological outcomes will likely take priority in the event that conflicts arise

Are tactical program plans meeting strategy objectives and any carbon offset expectations?

Operational Planning

IDENTIFY ACTIONS TO REDUCE GHG EMISSIONS

At the operational planning phase, the following GHG emission reduction options can be considered:

- Favour burn prescriptions that reduce fine fuels while leaving coarse fuels unburnt
- Identify risk management measures in situations where there is a risk of slowly accumulating and GHG rich non-target fuels types igniting (such as peat)
- Identifying suitable conditions of burning to avoid smouldering of heavy fuels, trees, logs or stags

PREPARE BURN OPERATIONS PLAN

GHG emission mitigation strategies should be balanced against other goals of planned burning

Are prescribed burns in general of a quality sufficient to address GHG mitigation measures?

Burning Operations Execution

GHG ACTIONS DURING BURNING OPERATIONS

GHG emission reduction actions that could be considered during burning operations include:

- Using conditions, ignition strategies and fire severity that targets fine fuel types but leaves coarse fuels unburnt
- Using conditions and ignition patterns that avoid ignition of unnecessary or non-target fuels
- Implementing management strategies or using conditions that avoids smouldering of coarse fuels, trees, stags or logs

Did the prescribed burn safely meet any GHG mitigation measures?

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The report was prepared by Paul de Mar and Dominic Adshead of GHD for AFAC, AGD and FFMG. The report was edited by Wayne Kington.

The content in part was generated at a workshop attended by member agency staff and key stakeholders (refer to Appendix B: Workshop Attendees List). Their contributions at the workshops are acknowledged. Other valuable contributions were received from other agency staff so thanks also goes to them.

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Project Survey Questions

Smoke hazard and risk assessment and monitoring

Through the project survey GHD sought information from AFAC/FFMG participating agencies regarding:

- What system do agencies use to classify or categorise different smoke risks within their jurisdictions?;
- How do agencies classify or categorise different smoke hazard levels within their jurisdictions?;
- What (if any) smoke management guidelines applying to prescribed burning are documented?;
- What (if any) documented smoke management operating procedures are integrated into prescribed burning training competency modules?
- What systems or tools do agencies use for determining where smoke from prescribed burning will go, the likely severity of impact on visibility and particulate pollution level, and how long the impacts are likely to persist?;
- What methodologies (if any) or systems do agencies or jurisdictions have for estimating levels of greenhouse gas emissions from prescribed burns (either at the individual burn level or whole of annual program level)?;
- What methodologies (if any) or systems do agencies or jurisdictions have for estimating levels of greenhouse gas emissions from bushfires, either at the specific fire incident level or aggregate fire season area level?;
- What methodologies (if any) or systems do agencies or jurisdictions have for estimating levels of greenhouse gas emissions from bushfires (either at the specific fire incident level or aggregate fire season area level)?; and
- What research projects (if any) have been recently completed, are underway or scheduled to begin which examine relationships between fire/burning and greenhouse gas emissions?

APPENDIX B

Workshop Attendees List

Risk Management Framework: Smoke Hazard Risks sub-project workshop

Wednesday 7 March 2012 – AFAC, 340 Albert Street East Melbourne

Craige Brown, Melbourne Water;

Tony Corrigan, ACT Emergency Services Agency;

Tim McGuffog, Forestry Corporation of NSW;

Mike Wouters, Department of Environment, Water and Natural Resources, SA;

Gary Featherston, AFAC;

Simon Heemstra, Rural Fire Service, NSW;

Phillip Timpano, Department of Environment, Land, Water & Planning, VIC;

Jim Gould, CSIRO;

Bruno Greimel, QLD Fire and Rescue Services;

Fabienne Reisen, CSIRO/Bushfire CRC; and

Eddie Staier, Parks and Wildlife Service, TAS.

Carbon accounting methodologies for Australia and New Zealand

Australia

Prescribed burning of savannas

Carbon emissions are calculated by:

CO_2 emissions are estimated using the Full Carbon Accounting Model (FullCAM) and reported as carbon stock changes as it is assumed that all CO_2 emissions are sequestered during the following growing period. Emissions of CH_4 and N_2O are determined based on the equations outlined below.

The mass of fuel burnt is estimated based on the area burnt, the fuel load (a default value for each state) and the burning efficiency:

$$M_{ij} = A_{ij} \times FL_{ij} \times Z_{ij} \times 10^{-3}$$

Where:

M_{ij} = mass of fuel burnt in fires (Gg)

A_{ij} = annual area burnt (ha)

FL_{ij} = fuel load (dry weight) (Mg/ha) (Table 6.35 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 1)

Z_{ij} = burning efficiency of fires (Table 6.36 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 1)

i = state or territory

j = activity (savanna woodland, savanna grassland or temperate grassland).

Methane emissions are calculated by:

$$E_{ij} = M_{ij} \times CC_{ij} \times EF_{ij} \times C_g$$

Where:

E_{ij} = annual emission from fires

M_{ij} = mass of fuel burnt in fires (Gg)

CC_{ij} = carbon mass fraction in fuel burnt in fires (Table 6.37 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 1)

EF_{ij} = emission factor (Table 6.38 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 1)

C_g = factor to convert from elemental mass of gas to molecular mas (Table 6.38 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 1)

i = state or territory

j = activity (savanna woodland, savanna grassland or temperate grassland).

Nitrous oxide emissions are calculated by:

$$E_{ij} = M_{ij} \times CC_{ij} \times NC_{ij} \times EF_{ij} \times C_g$$

Where:

E_{ij} = annual emission from fires

M_{ij} = mass of fuel burnt in fires (Gg)

CC_{ij} = carbon mass fraction in fuel burnt in fires (Table 6.37 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 1)

NC_{ij} = nitrogen to carbon ratio in fuel burnt in fires (Table 6.37 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 1)

EF_{ij} = emission factor (Table 6.38 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 1)

C_g = factor to convert from elemental mass of gas to molecular mas (Table 6.38 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 1)

i = state or territory

j = activity (savanna woodland, savanna grassland or temperate grassland).

Bushfires and prescribed burning of forests

Carbon dioxide

CO_2 emission are reported as a stock change to account for the emissions from fires and the sequestration of CO_2 during forest recovery following fire events. Under the Australian National Greenhouse Accounts is assumed that the debris removed during fire events recovers within five years. Based on this assumption the impacts of carbon removed from fire events recovers relatively quickly and over the long term may be carbon neutral.

The mass of fuel burnt is estimated based on the area burnt, the fuel load (a default value for each state) and the burning efficiency:

$$M_{jk} = A_{jk} \times FL_{jk} \times Z_{jk} \times 10^{-3}$$

Where:

M_{jk} = mass of fuel burnt annually (Gg)

A_{jk} = area burnt annually (ha)

FL_{jk} = fuel loading (dry weight) (Mg/ha) (See below figure)

Z_{jk} = burning efficiency of fires (burning efficiency for prescribed burning = 0.42 and bushfires = 0.72)

j = state or territory

k = activity (prescribed burning, bushfire).

Fuel Load Factors[5]

Table 7.12: Fuel load for Prescribed Burning of Forest in Australia (Mg dry matter ha^{-1})

State	ACT[a]	NSW[a]	NT[a]	QLD[a]	SA[b]	Tas[b]	Vic[a]	WA[a]
	FL_{jk} (Mg ha^{-1})							
Load	17.6	18.2	4.1	9.7	9.6	20.0	17.9	12.0

(a) State agencies, (b) Tolhurst (1994)

Table 7.13: Fuel load for Bushfires in Australia (Mg dry matter ha^{-1})

State	ACT[a]	NSW[a]	NT[a]	QLD[a]	SA[b]	Tas[b]	Vic[a]	WA[a]
	FL_{jk} (Mg ha^{-1})							
Load	35.2	36.4	7.2	19.4	19.2	40.0	35.8	33.4

(a) State agencies, (b) Tolhurst (1994)

Annual CO_2 emissions are calculated by:

$$E_{ijk} = M_{jk} \times CC_{jk} \times C_i$$

Where:

E_{ijk} = annual emission of gas i from fires (Gg)

M_{jk} = mass of fuel burnt annually (Gg/y)

CC_{jk} = carbon mass fraction in vegetation (Table 7.15 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

C_i = 3.67, factor to convert from elemental mass of gas species i to molecular mas

i = gas species

j = state or territory

k = activity (prescribed burning, bushfire).

Annual CO_2 removals are calculated by:

$$R_{ijk} = \sum (M_{jk} \times CC_{jk}) / (t \times C_i)$$

Where:

R_{ijk} = annual removals of gas i following biomass burning (Gg)

M_{jk} = mass of fuel burnt over period t

t = time required for carbon lost due to fire to be recovered (assumed to be five years)

CC_{jk} = carbon mass fraction in vegetation (Table 7.15 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

C_i = 3.67, factor to convert from elemental mass of gas species i to molecular mas

5 Table 7.12 and 7.13 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2

APPENDIX C

i = gas species

j = state or territory

k = activity (prescribed burning, bushfire).

Methane and nitrous oxide

CH_4 and N_2O emissions are outlined in Volume 2, Section 7.12 of the 2009 national inventory report and are based on the equations outlined below.

The mass of fuel burnt is estimated based on the area burnt, the fuel load (a default value for each state) and the burning efficiency:

$$M_{jk} = A_{jk} \times FL_{jk} \times Z_{jk} \times 10^{-3}$$

Where:

M_{jk} = mass of fuel burnt annually (Gg)

A_{jk} = annual area burnt annually (ha)

FL_{jk} = fuel loading (dry weight) (Mg/ha) (Table 7.12 and 7.13 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

Z_{jk} = burning efficiency of fires (Table 7.14 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

j = state or territory

k = activity (prescribed burning, bushfire).

Methane emissions are calculated by:

$$E_{ijk} = M_{jk} \times CC_{jk} \times EF_{ijk} \times C_i$$

Where:

E_{ijk} = annual emission of gas i from fires (Gg)

M_{jk} = mass of fuel burnt annually (Gg/y)

CC_{jk}= carbon mass fraction in vegetation (Table 7.15 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

E_{ijk} = emission factor for gas i from vegetation (Table 7.16 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

C_i = factor to convert from elemental mass of gas species i to molecular mas (Table 7.17 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

i = gas species

j = state or territory

k = activity (prescribed burning, bushfire).

Nitrous oxide emissions are calculated by:

$$E_{ijk} = M_{jk} \times CC_{jk} \times NC_{jk} \times EF_{ijk} \times C_i$$

Where:

E_{ijk} = annual emission of gas i from fires (Gg)

M_{jk} = mass of fuel burnt annually (Gg/y)

CC_{jk} = carbon mass fraction in vegetation (Table 7.15 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.15 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

E_{ijk} = emission factor for gas i from vegetation (Table 7.16 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

C_i = factor to convert from elemental mass of gas species i to molecular mas (Table 7.17 of the Australian National Greenhouse Accounts National Inventory Report 2009, Volume 2)

i = gas species

j = state or territory

k = activity (prescribed burning, bushfire).

New Zealand

Prescribed burning of savannas

Methane and Nitrous Oxide

Biomass burned (t dam) = area of tussock burned annually × above-ground biomass density (t dm/ha) × fraction actually burned

Carbon released from live biomass (t C) = biomass burned (t dm) × fraction that is alive × fraction oxidised × carbon content of live biomass (t C/t dm)

Carbon released from dead biomass (t C) = biomass burned (t dm) × fraction that is dead × fraction oxidised × carbon content of dead biomass (t C/t dm)

Total carbon released (t C) = carbon released from live material (t C/t dm) + carbon released from dead material (t C/t dm)

Total carbon released is then used to estimate CH_4 and N_2O emissions:

CH_4 *emissions* = total C released × emission ratio × 16/12

N_2O *emissions* = Total C released × emission ratio × N:C ratio × 44/28

APPENDIX D

National Burning Project – List of Sub Projects

The objective of the National Burning Project is to use a national approach to reduce the bushfire risk to Australian and New Zealand communities by the comprehensive management of prescribed burning at a landscape level that balances the operational, ecological and community health risks. The project will produce a series of outputs through sub-projects that together form a framework. The framework will endure long after the project and future projects will be required to add further elements to, update and refresh the framework. There are elements of the framework that are outside the scope of this project and will be delivered separately by the project partners. The current scope of the framework and the component sub-projects are listed in the table below.

#	Short Title	Long Title	Status as at 2015
1	**Review Fire Science and Knowledge**	Prepare and publish a review of the fire science, operational experience and indigenous knowledge at a national level for all fire bioregions.	Overview completed Science Review planned
2	**Analysis of Objectives**	Report on an analysis of the tools and methodologies available to balance competing objectives of burning programs and matching these to user's needs.	Planned
3	**Risk and Monitoring Framework**	Design a management and review framework to manage the major prescribed burning risks. Four risks are currently planned: • Fuel Hazard • Smoke and CO_2 emissions • Ecological • Operational (safety)	Risks 1 and 2 completed Risks 3 and 4 planned
4	**Best Practice Guideline for Prescribed Burning**	A review of the end to end processes, practices and systems of prescribed burning jurisdictions, land managers and across a range of burning objectives.	Review report completed Operational practice guideline underway. Strategic practice guideline planned.
5	**National Bushfire Fuel Classification**	Develop a best practice guide for the classification of bushfire fuels.	Underway
6	**National Position on Prescribe Burning**	A nationally agreed position is developed and communicated that outlines the principles for the use of prescribed burning.	Planned
7	**Prescribed Burning Competencies**	Define agreed standards for the tasks associated with the planning and conduct of prescribed burns.	Planned

#	Short Title	Long Title	Status as at 2015
8	**Develop Training Materials**	Develop training materials for prescribed burning for national application.	Planned
9	**Prescribed Burning Training Delivery**	Investigate the options for national training delivery and mutual recognition frameworks.	Planned
10	**Resource Optimisation**	Develop processes for the sharing of resource between prescribed burning programs.	Planned
11	**Performance Measures**	Develop performance measures for prescribed burning and design a reporting framework.	Planned
12	**National Tool Box**	Provide a set of tools that support prescribed burning activities	Planned

APPENDIX E

National Burning Project – List of Publications

The National Burning Project will progressively publish a comprehensive library of reports from the sub-project results. The list of planned publications is provided below:

Title	Description	Date of Report	Date of Publish	Authors	Contributors
Review of Best Practice for Prescribed Burning	A report to scope the development of a best practice guide for prescribed burning by reviewing current practices across Australia.	December 2013	March 2014	de Mar P, Adshead D	AFAC, FFMG, AGD, GHD
Risk Management Framework – Fuel Hazards		30-Apr-12	2015	de Mar P, Adshead D	AFAC, FFMG, AGD, GHD
Risk Management Framework – Smoke Hazards		1-Jul-12	2015	de Mar P, Adshead D	AFAC, FFMG, AGD, GHD
Scope and Framework for an Australian Fuel Classification		30-Jun-11	2015	Hollis J, Gould J, Cruz M and Doherty M	AFAC, FFMG, AGD, CSIRO
Australian Bushfire Fuel Classification – Scope and Objective.		31-Aug-12	2015	Gould J, and Cruz M	AFAC, FFMG, AGD, CSIRO
Australian Bushfire Fuel Classification – Glossary		31-Aug-12	2015	Gould J, and Cruz M	AFAC, FFMG, AGD, CSIRO
Australian Bushfire Fuel Classification – Assessment Methodology		31-Aug-12	2015	Gould J, and Cruz M	AFAC, FFMG, AGD, CSIRO
Overview of prescribed burning in Australasia.	A review of the science and practice of prescribed burning written to provide background to practitioners and information to interested members of the public.	30-Jun-12	2015	Poynter M	AFAC, FFMG, AGD, CSIRO (reviewer)

Title	Description	Date of Report	Date of Publish	Authors	Contributors
Australian Bushfire Fuel Classification – Case Study Report		2013	2015	Gould J, and Cruz M	AFAC, FFMG, CSIRO
National Position on Prescribed Burning		2013	2015		AFAC, FFMG
Prescribed Burning Competencies		2013	2015		AFAC, FFMG
Prescribed Burning Training Material – Assist with Prescribed Burn		2014	2015		AFAC, FFMG, BCRC
Prescribed Burning Training Material – Plan Simple Burn		2014			AFAC, FFMG, BCRC
Prescribed Burning Training Material – Plan Complex Burn		2014			AFAC, FFMG, BCRC
Prescribed Burning Training Material – Conduct Simple Burn		2014			AFAC, FFMG, BCRC
Prescribed Burning Training Material – Conduct Complex Burn		2014			AFAC, FFMG, BCRC
Best Practice Guide for Operational Prescribed Burning					
Best Practice Guide for Strategic Prescribed Burning					
Australian Bushfire Fuel Classification – Business Case					
Australian Bushfire Fuel Classification – Implementation					
Review of Prescribed Burn Training					
Report on the options for resource sharing in prescribed burning					
Performance Monitoring and Reporting for Prescribed Burning					

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Risk Management Framework
– Smoke Hazard and Greenhouse Gas Emissions

Report for National Burning Project – Sub-project 3

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A challenge for fire and land managers is to balance the significant benefits of prescribed burning on the one hand, with concerns surrounding smoke and emissions impacts on the other.

This document reviews the approaches undertaken by various Australian and New Zealand land and fire management agencies with regard to management of smoke and emissions. From this starting point, it builds and presents frameworks that can be used in the context of prescribed burning, to manage smoke and emissions impacts on amenity, prosperity, health and safety.

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