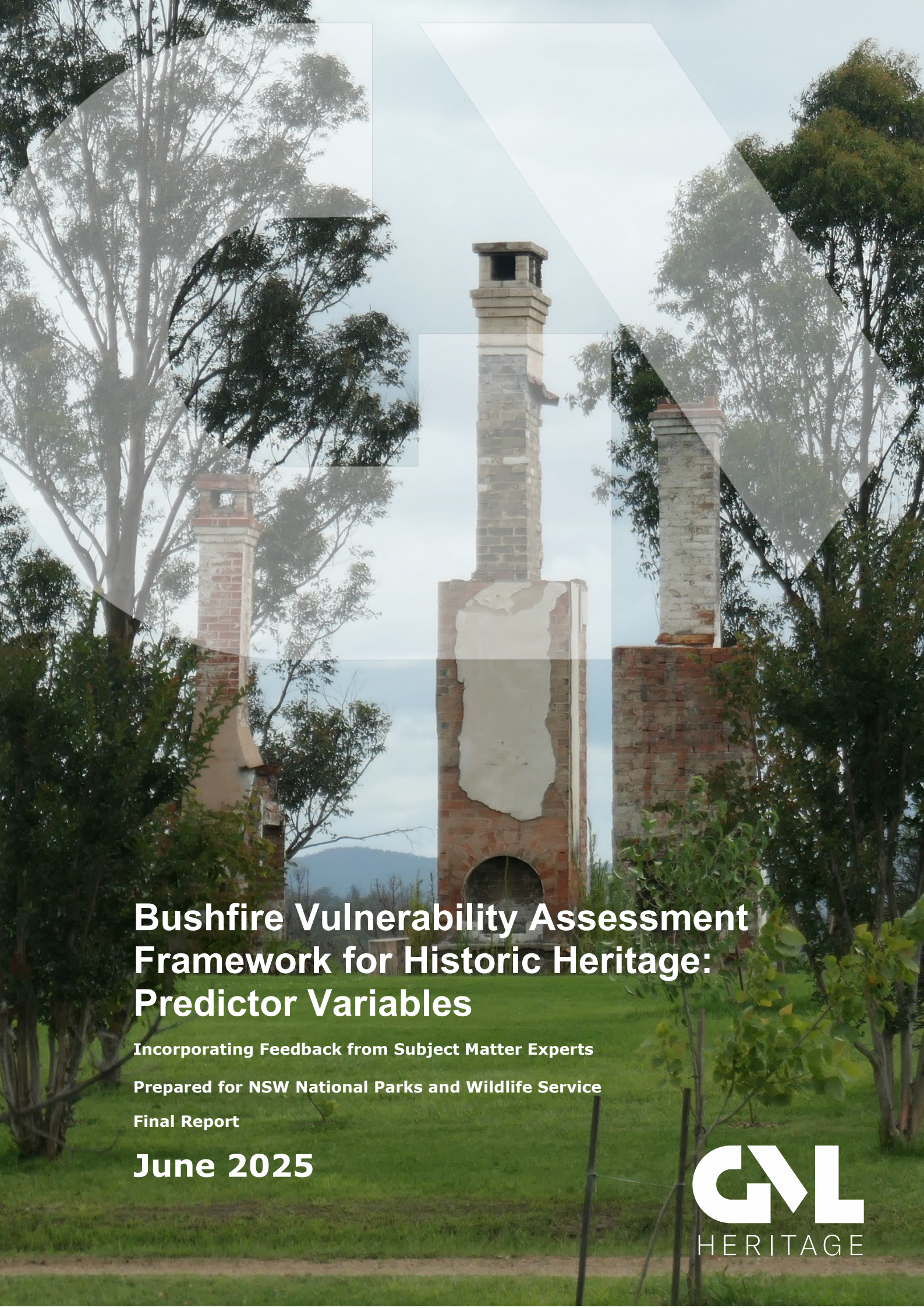

Bushfire Vulnerability Assessment Framework for Historic Heritage: Predictor Variables

Incorporating Feedback from Subject Matter Experts

Prepared for NSW National Parks and Wildlife Service

Final Report

June 2025

GML HERITAGE

Acknowledgement of Country

We respect and acknowledge the First Nations peoples of the lands and waterways on which we live and work, their rich cultural heritage and their deep connection to Country, and we acknowledge their Elders past and present. We are committed to truth-telling and to engaging with First Nations peoples to support the protection of their culture and heritage. We strongly advocate social, cultural and political justice and support the Uluru Statement from the Heart.

Cultural warning

Aboriginal and Torres Strait Islander readers are advised that this report may contain images or names of First Nations people who have passed away.

GML HERITAGE

Report register

The following report register documents the development of this report, in accordance with the GML Heritage (GML) Quality Management System.

Job No.	Issue No.	Issue Date
22-0011	1	10 March 2023
22-0011	2	5 June 2023
22-0011B	3	2 February 2024
22-0011B	4	9 December 2024
22-0011B	5	3 March 2025
22-0011B	6	June 2025

Quality management

The report has been reviewed and approved for issue in accordance with the GML quality management policy and procedures.

It aligns with best-practice heritage conservation and management, *The Burra Charter: the Australia ICOMOS Charter for Places of Cultural Significance, 2013* and heritage and environmental legislation and guidelines relevant to the subject place.

Indigenous cultural and intellectual property

We acknowledge and respect the inherent rights and interests of the First Nations peoples in Indigenous Cultural and Intellectual Property. We recognise that Aboriginal and Torres Strait Islander people have the right to be acknowledged and attributed for their contribution to knowledge but also respect their rights to confidentiality.

Executive summary

This report, prepared by GML Heritage for the NSW National Parks and Wildlife Service (NPWS), represents the first stage in the development of a Bushfire Vulnerability Assessment Framework (BFVAF) for historic heritage. The framework has been developed for the NPWS, with input from the NSW Rural Fire Service (RFS) and NSW Environment and Heritage to assist bushfire risk modelling for historic heritage assets (heritage items) located in the state of NSW. The BFVAF has been peer reviewed by subject matter experts.

Purpose

The purpose of the BFVAF is to clearly identify the attributes and conditions that make historic heritage assets/items vulnerable to bushfires. The BFVAF will be used to:

- inform development of a quantitative assessment of the vulnerability of historic heritage assets to bushfire to enable its inclusion in predictive bushfire risk modelling;
- enable the integration of historic heritage assets into Bush Fire Risk Management Plans (BFRMPs) prepared by local bush fire management committees (BFMCs) across NSW; and
- enable the integration of historic heritage assets into planning bushfire mitigation and emergency response plans.

Scope

This report identifies the vulnerability of historic heritage assets/items to bushfire and its various modes of attack, as well as its vulnerability to the mitigation measures implemented by firefighting authorities, local authorities and land managers (including property owners) before, during and after fire.

It does not provide guidance on assessing, evaluating or mitigating bushfire risk to heritage places or objects. It is intended that the BFVAF would underpin the future development of such guidance.

It does not provide guidance on assessing, evaluating or mitigating bushfire risk to Aboriginal cultural heritage assets. The BFVAF supports complementary work in this space currently under development by the NSW Department of Climate Change, Energy, the Environment and Water.[1]

[1] Department of Planning, Industry and Environment, 2022, Aboriginal cultural heritage vulnerability to bushfire and prescribed burning. State-wide data product – technical report, Department of Planning, Industry and Environment, Parramatta, NSW, Australia.

Audience

This report has been prepared for several audiences. The primary audience is:

- NSW NPWS and NSW RFS to assist them in undertaking bushfire risk modelling for heritage assets to support development of interagency Bush Fire Risk Management Plans prepared by BFMCs.

Secondary audiences include:

- BFMCs and local government to inform development of bushfire management plans and operational strategies that would reduce bushfire risk to heritage assets/places.
- property owners, site managers, and the heritage and risk management professionals who advise them, to build awareness of the vulnerabilities of different types of heritage to bushfires, to inform risk assessment and to promote implementation of appropriate protection and mitigation measures to reduce risk to heritage items/assets.

Key questions for assessing vulnerability

In assessing the vulnerability of a heritage item, key questions must be asked:

1 What type of heritage is it?

2 Is it above or below ground?

3 What materials is it made of?

4 What form does it take?

5 What is around it?

6 Is it accessible?

7 Is it defendable?

8 Is there someone on site that is trained and capable to defend it?

9 What protection or mitigation measures are in place?

Predictor variables for assessing vulnerability

This report identifies a comprehensive set of predictor variables to be considered in evaluating the bushfire vulnerability of historic heritage assets.

Predictor variables are divided into four groups and include:

1 Physical attributes/characteristics

   - Relationship to the ground plane
   - Material composition
   - Complexity of external form

- Critical points of failure
- Condition
- Presence of hazardous materials
- Archaeology type (artefacts, archaeological remains)
- Vegetation type
- Landscape layout (spacing of vulnerable elements)

2 Context

- Physical context—surrounding area
- Slope and aspect
- Immediate setting
- Condition of setting following other damaging events

3 Human capacity to protect the heritage item

- Visibility/recognisability
- Presence of road access
- Presence of defendable space
- Human presence
- Human capacity to defend
- Maintenance regime

4 Mitigation measures implemented

- Site specific bushfire management plan
- Asset protection zones
- Physical (passive) protection measures implemented
- Presence of active firefighting systems

The predictor variables best suited to evaluating the vulnerability of different types of heritage are set out in tables in Section 6 of this report.

Gaps in heritage data

Having comprehensive data on heritage places is critical to understanding their vulnerability.

Current heritage data is in many cases limited in its scope and quality. There is considerable variability across heritage inventories maintained by different agencies and at different scales (e.g. local, state, national, world heritage registers). Therefore, many of the above variables cannot currently be used for bushfire risk modelling across the state, even though they are critical to determining the bushfire vulnerability of a heritage item/asset.

Physical attributes of the heritage item should be identifiable from heritage inventory information, but this is not always the case.

Physical context is not often identified in inventory sheets and photographs. However, this information may be available through other sources such as satellite imagery and maps.

Information on the capacity of a property to be defended and the mitigation measures already implemented on a site are unlikely to be readily available. Thus, these variables cannot currently be included in risk modelling. This information, however, should be able to be gained at an individual property level and used by property owners to inform the development and implementation of site-specific bushfire management plans and mitigation measures to reduce bushfire risk.

Next steps

The current report has laid the groundwork for more accurately assessing the vulnerability of heritage items/assets to bushfires, for undertaking detailed risk modelling and risk assessments for heritage, including heritage in local BFMC BFRMPs.

Further research and testing is required to complete this work to improve the resilience of NSW's heritage to bushfire. Section 7 of this report sets out a roadmap of actions recommended in the short, medium and long term to enable the adoption and use of the BFVAF.

As a priority, the following actions are recommended:

- Identifying data entry points for NSW heritage management system to enable critical data on heritage items/assets to be collected and included in inventory sheets.
- Review and analysis of post-fire data collected by the RFS and Public Works Advisory on bushfire impacts on heritage items across the state to verify vulnerability predictor variables and identify critical variables and points of failure for heritage of different types.
- Testing the application of the vulnerability predictor variables on a sample of heritage sites of different types, including complex sites, comprising a range of heritage types (built heritage, heritage landscapes, archaeology and movable heritage), located in different contexts (bushland, rural, peri-urban) and regions of the state with different fire conditions.
- Development of a rapid vulnerability assessment tool that incorporates the critical vulnerability predictor variables identified for each heritage type to enable the integration of historic heritage assets/items into bushfire risk modelling in NSW.
- Testing the application of the vulnerability predictor variables to bushfire risk modelling in one or two Local Government Areas (LGAs) or BFMC areas to assess their efficacy and feasibility prior to rolling out their application to risk modelling across the state

- Testing the suitability of the RFS bushfire household assessment toolkit for heritage items/assets and potential for developing a similar toolkit for heritage of varying types.
- Development of bushfire risk management guidance for heritage property owners.

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1 Introduction

1 Introduction

1.1 Commission

The NSW National Parks and Wildlife Service (NPWS) has engaged GML Heritage Pty Ltd (GML) to develop a Bushfire Vulnerability Assessment Framework (the framework; the BFVAF) for historic heritage to enable its inclusion in bushfire risk modelling and bushfire risk management plans being developed by local bushfire management committees (BFMCs) across the state of NSW.

1.2 Background to the project

In an effort to improve our understanding of the vulnerability of heritage assets to fire, the NPWS Bushfire Risk and Evaluation (BR&E) Unit commissioned this independent technical report from GML Heritage.

The NPWS BR&E Unit was established in response to the 2019–20 NSW Bushfire Inquiry and leads the development and implementation of environmental and cultural risk modelling to assess and measure the potential impacts of future bushfires. These processes form a critical part of the coordinated bushfire risk assessment framework that underpins fire management in NSW. As part of this work, the BR&E Unit supports the NSW Rural Fire Service (RFS) in the rollout of the Next Generation Bush Fire Risk Management Plans, in accordance with the *Rural Fires Act 1997* (NSW). Importantly, the risk information the BR&E Unit provides is tenure-blind, ensuring consistent application at a statewide scale.

The NPWS BR&E Unit was tasked with two recommendations from the NSW Bushfire Inquiry (2020). Recommendation 19 required:

> b) prioritising implementation of revised processes for bush fire risk management planning that incorporate new modelling and methods for quantifying risk and the residual risk profile as a result of proposed hazard reduction works
>
> d) the methodology for assessing and planning for risk reduction becomes an ongoing area of research and the frameworks are formally reviewed every three years.

The BR&E Unit at NPWS has developed the statewide risk assessment methodology for environmental and cultural assets. The NPWS Project Team assists the RFS with the preparation and processing of data and has supported the RFS in the development of the Bush Fire Risk Management Policy and associated documents. The NPWS Project Team prepares an Environmental and Cultural Asset profile for each BFMC and provides advice on assets at risk.

This report provides a high-level overview of the vulnerability of different types of heritage assets to fire, with the aim of incorporating this knowledge into heritage risk modelling outputs delivered to BFMCs across NSW. NSW Environment and Heritage and the NPWS Heritage Team were consulted during the development of this report to ensure its relevance and accuracy.

We hope this report will make a valuable contribution to the conservation and protection of heritage assets in the face of a changing climate.

1.3 Purpose of the framework

The purpose of the framework is to clearly identify the attributes and conditions that make historic heritage assets/items vulnerable to bushfires.

The framework will be used to:

- Inform development of a quantitative assessment of the vulnerability of historic heritage assets to bushfire for inclusion in bushfire risk modelling.
- Enable the integration of historic heritage assets into bushfire risk management plans prepared by local BFMCs.
- Enable the integration of historic heritage assets into planning bushfire mitigation and emergency response strategies for heritage assets.

It may also be used to:

- Build awareness of the vulnerability of historic heritage to bushfires, but also the vulnerability of historic heritage to the mitigation measures used to manage bushfire risk and fight bushfires.
- Build awareness of the vulnerability of historic heritage post fire.
- Inform risk assessments for individual heritage items/assets and the development of bushfire risk mitigation strategies and site-specific bushfire risk management plans for these assets.
- Inform updates to NSW state, regional and local emergency plans, subplans and supporting plans in relation to heritage.
- Inform updates to national and state risk evaluation frameworks, disaster risk reduction frameworks, disaster preparedness frameworks, resilience and adaptation frameworks, and post disaster recovery frameworks in relation to heritage.
- Inform updates to the National Emergency Risk Assessment Guidelines (NERAG) in relation to heritage.

1.4 Who is the framework for?

The framework has been developed primarily for the NPWS, with input from the NSW Rural Fire Service (RFS) and NSW Environment and Heritage, to assist bushfire risk modelling for historic heritage assets (heritage items) located in the state of NSW.

The framework would be useful to the following groups in identifying bushfire risks to heritage places and objects of cultural significance, to inform policy, planning and decision making that will enable the state's heritage to be better protected from future bushfires:

- **NSW NPWS** (in assessing and managing bushfire risk and responding to bushfires);
- **NSW RFS** (in assessing and managing bushfire risk and responding to bushfires);
- **local BFMCs** (in assessing and managing bushfire risk to local community, community awareness building);
- **Fire and Rescue NSW** (in responding to bushfires)
- **NSW Environment and Heritage** (in identifying heritage items/assets and providing critical information to assist site specific bushfire risk management planning for heritage items/assets);
- **NSW Public Works Advisory, Emergency Engineering Management** (in post fire cleanup and recovery);
- **other state agencies** responsible for managing disaster risk, emergency response, recovery planning and building disaster resilience;
- **local government**, including planning and environmental services (in managing bushfire risk to community, advising local property owners and post fire recovery);
- **heritage professionals** (in advising heritage property owners on appropriateness of mitigation measures); and
- **heritage property owners and managers** (in managing bushfire risk to property and recovery post fire).

1.5 How could the framework be used?

The BFVAF could be used by the following groups as follows:

- **NSW NPWS** could use the framework to:
  - inform bushfire risk modelling;
  - better understand the vulnerability of historic heritage assets within the NPWS Estate; and
  - plan mitigation and response strategies for historic heritage assets within the NPWS Estate.

- **NSW RFS** could use the framework to inform:

- risk modelling;
- planning of mitigation and response strategies around heritage assets and sites to minimise the risk to heritage, and
- advice to heritage property owners through their website and community engagement programs of their local BFMCs.

- **Local BFMCs** could use the information included in the framework as a basis for:
  - identifying risks to historic heritage in their local areas;
  - incorporating historic heritage in their bushfire risk management plans (BFRMPs);
  - working with the public to build awareness of the risks to local heritage assets; and
  - assist property owners in understanding the risk to their heritage properties and to develop strategies to manage those risks.
- **Local government** could also use the framework to:
  - understand what heritage is at risk in their local government areas (LGAs) and what makes it vulnerable to bushfires;
  - promote the overlay of their bushfire maps with their heritage maps for their LGAs;
  - promote the updating of data included on their heritage inventory sheets to include critical information necessary to understanding bushfire risk to heritage items and conservation areas within their LGAs; and
  - inform adaptation, resilience, emergency and recovery planning for heritage sites and assets within their LGAs.
- **NSW Environment and Heritage** could use the framework to inform:
  - data collection and accessibility to facilitate risk modelling for heritage places and assets; and
  - data presentation on heritage inventory sheets that are made available through the NSW Heritage Management System so that it can be easily accessed and used to inform vulnerability assessments and risk modelling for heritage places and assets.
- **Australia ICOMOS, Australasian Society for Historical Archaeology and other professional organisations** within the heritage sector could use the framework to develop guidance on:
  - bushfire risk evaluation for heritage places and assets;
  - bushfire risk mitigation strategies for heritage places and assets;
  - bushfire risk management planning for heritage places and assets; and

- emergency response and recovery planning for heritage places and assets affected by bushfires.

- **Heritage property owners and managers** could:
  - be better informed of the vulnerabilities of their properties to bushfire risk;
  - develop and implement, in consultation with appropriate experts, site-specific mitigation measures and strategies to protect their heritage properties and assets; and
  - develop site-specific BFRMPs which enable property owners to be better prepared and to manage the risk to their properties before, during and after a fire.

1.6 Types of heritage included in the framework

The framework has been developed primarily for historic cultural heritage included on local, state, national and World Heritage inventories and registers, including those held by state and Commonwealth government agencies.

The framework is relevant to historic heritage places and assets including:

- **historical archaeology—**including ruins, remains and artefacts;
- **heritage landscapes—**including parks, gardens, trees, cemeteries, urban and rural landscapes;
- **built heritage—**including urban, rural, agricultural, scientific and industrial heritage, built infrastructure (e.g. bridges, culverts, tanks, towers, water/drainage systems, railways, etc), memorials and historical interiors;
- **outdoor movable heritage—**such as machinery, mining and farm equipment, vehicles, sculptures, boundary markers, and so on; and
- **indoor movable heritage and collections—**such as objects, furnishings, artworks, museum collections, historical records and archives, scientific and other equipment.

This Framework does not address items of intangible heritage (although it is recognised that heritage places and objects often have associated aspects of intangible heritage), Indigenous (Aboriginal) cultural heritage or natural heritage.

1.7 Scope of the framework

This BFVAF identifies a set of predictor variables for assessing the vulnerability of historic heritage assets/items to bushfires and the mitigation measures adopted by the NPWS, RFS, councils and property owners in managing bushfire risk to heritage assets.

Tables of predictor variables (vulnerability assessment criteria) have been compiled for different types of heritage assets—heritage structures, historical archaeology, heritage landscapes and movable heritage.

In addition, a set of key questions has been established to assist people in assessing the vulnerability of a particular type of heritage asset or a particular site using the framework.

The BFVAF is designed to enable heritage vulnerability data to be quantified and entered into a Bayesian network model for identifying bushfire risk to heritage assets. Refer to Figure 1.1.

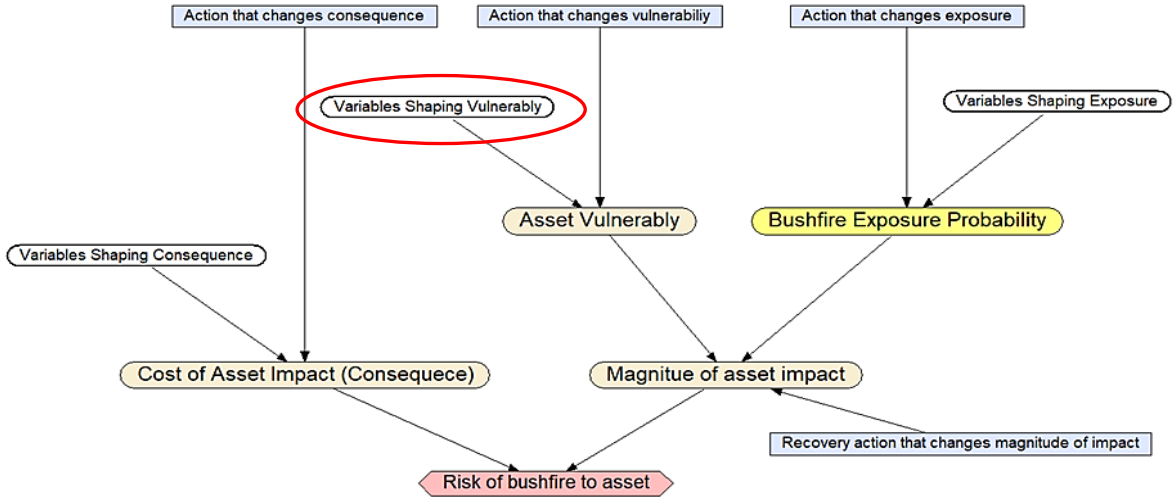

Figure 1.1 Conceptual design of Bayesian network model for quantifying bushfire risk to Historic Assets. The BFVAF identifies the vulnerability variables for inclusion in the model (circled in red) (Source: Historic Asset quantitative bushfire risk model (Version 2.0) NSW Bush Fire Management Committee Bush Fire Risk Planning)

The framework does not provide guidance on risk assessment or mitigation measures to be implemented to reduce bushfire risk to heritage. It is intended that the BFVAF would underpin the future development of such guidance.

1.8 Study methodology

The predictor variables (vulnerability assessment criteria) were initially identified:

- by heritage experts with disaster experience, including architects, engineers, archaeologists and cultural landscape specialists;
- by key personnel from NSW NPWS, NSW Environment and Heritage and the RFS;
- through a review of current local and global literature on heritage and non-heritage vulnerability to fires; and
- research into materials and fire.

The key variables identified were reviewed against existing attribute data from the Historic Heritage Information Management System (HHIMS), State Heritage Register (SHR), State Heritage Inventory (SHI) and Local Environmental Plan (LEP) heritage schedules for local heritage, to identify any gaps in critical information required to make a vulnerability assessment of a heritage asset.

The BFVAF has been reviewed by subject matter experts (SMEs).

Section 7 includes a roadmap to facilitate further development of the framework and to enable its use as outlined in Sections 1.3, 1.4 and 1.5. This includes development of a rapid vulnerability assessment for heritage to enable its inclusion in bushfire risk modelling across the state.

1.9 Terminology

Terminology associated with assessing risk is taken from NERAG.[2]

Disaster: A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic or environmental losses and impacts.

Source: *United Nations Office for Disaster Risk Reduction (UNDRR).*

Hazard: A source of potential harm or a situation with a potential to cause loss. A potential or existing condition that may cause harm to people, or damage to property or the environment. A source of risk.

Source: *Australian Emergency Manual 3: Australian emergency management glossary.*

Exposure: The elements within a given area that have been, or could be, subject to the impact of a particular hazard.

Note: Exposure is also sometimes referred to as the 'elements at risk'.

Source: *Geoscience Australia, 'Risk and impact analysis'.*

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

Source: *United Nations Office of Disaster Risk Reduction (UNDRR).*

Impact: To have a noticeable or marked effect on.

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[2] Australian Institute of Disaster Resilience (2020) National Emergency Risk Assessment Guidelines, second edition 2015 (updated 2020), Australian Disaster Resilience Handbook Collection, Australian Government, Department of Home Affairs.

Source: *Macquarie Dictionary Online.*

Consequence: The outcome of an event that affects objectives.

Notes:

- An event can lead to a range of consequences.
- A consequence can be certain or uncertain, and can have positive and negative effects on objectives.
- Consequences can be expressed qualitatively or quantitatively.
- Initial consequences can escalate through knock-on effects.

Source: *ISO Guide 73:2009 Risk management—vocabulary.*

Risk: The effect of uncertainty on objectives.

Notes:

- An effect is a deviation from the expected – positive and/or negative.
- Objectives can have different aspects (e.g. financial, health, safety, environmental goals) and can apply at different levels (e.g. strategic, organisation wide, project, product, process).
- Risk is often characterised by reference to potential events and consequences, or a combination of these.
- Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.
- Uncertainty is the state (complete or partial) of deficiency of information relating to understanding or knowledge of an event, its consequence or likelihood.

Source: *ISO Guide 73:2009 Risk management—Vocabulary.*

Risk assessment: Overall process of risk identification, risk analysis and risk evaluation.

Source: *ISO Guide 73:2009 Risk management—Vocabulary.*

Level of risk (or risk level): Magnitude of a risk or a combination of risks, expressed in terms of the combination of consequences and their likelihood.

Source: *ISO Guide 73:2009 Risk management—Vocabulary.*

Risk treatment: Process to modify risk.

Risk treatment can involve:

- avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk;
- taking or increasing risk to pursue an opportunity;
- removing the risk source;
- changing the likelihood;
- changing the consequences;

- sharing the risk with another party or parties (including contracts and risk financing); and
- retaining the risk by informed decision.

A risk treatment that deals with negative consequences is sometimes referred to as 'risk mitigation', 'risk elimination', 'risk prevention' and 'risk reduction'.

Source: *ISO Guide 73:2009 Risk management—Vocabulary.*

Residual risk: Risk remaining after risk treatment.

Notes:

- Residual risk can contain unidentified risk.
- Residual risk can also be known as 'retained risk'.

Source: *ISO Guide 73:2009 Risk management—Vocabulary.*

Risk management: Coordinated activities of an organisation or a government to direct and control risk. The risk management process includes the activities of:

- communication and consultation;
- establishing the context;
- risk assessment, which includes:
  - risk identification;
  - risk analysis;
  - risk evaluation;
- risk treatment; and
- monitoring and review.

Source: Adapted from *ISO Guide 73:2009 Risk management Vocabulary.*

Prevention: Regulatory and physical measures to ensure that emergencies are prevented or their effects mitigated.

Source: *Australian Emergency Manual 3: Australian emergency management glossary.*

Mitigation: Measures taken in advance of a disaster that aim to decrease or eliminate the disaster's impact on society and the environment.

Source: *Australian Institute for Disaster Resilience Glossary 2013.*

Preparedness: Arrangements to ensure that, should an emergency occur, all the resources and services that are needed to cope with the effects can be efficiently mobilised and deployed.

Source: *Australian Emergency Manual 3: Australian emergency management glossary.*

Response: Actions taken in anticipation of, during and immediately after an emergency to ensure that its effects are minimised, and that people affected are given immediate relief and support.

Source: *Australian Institute for Disaster Resilience Glossary 2013.*

Fuel load: The amount of flammable material.

1.10 Limitations

Current heritage data is limited in its scope and quality. Limitations include, but are not limited to the following:

- Lack of accurate mapping of heritage items and their heritage curtilages, including:
  - Accurate mapping of heritage items located within much larger sites.
  - Accurate mapping of heritage landscapes that extend beyond individual property boundaries.
  - Accurate archaeological sensitivity mapping.
- Lack of key data being included in inventory sheet descriptions.
- Lack of photographs to enable identification of the heritage item on the ground.
- Lack of information on the immediate setting of the heritage item, its current condition, occupation status, use current or bushfire protection measures already implemented.

1.11 Authors

This Framework has been developed by Catherine Forbes, GML Principal and senior heritage architect, with the assistance of Shikha Swaroop, GML Senior Heritage Consultant.

1.12 Review by subject matter experts

The draft report was reviewed by subject matter experts (SMEs) including experts in fire behaviour and bushfire management, structural engineering, heritage conservation (including architects, archaeologists, landscape specialists and conservators) and heritage management (including representatives from NSW and Victorian Government agencies). SME feedback has been incorporated into the report.

1.13 Acknowledgements

GML wishes to acknowledge the significant input and guidance given by Carrie Wilkinson and Donald Macdonald, from the Bushfire Risk and Evaluation Unit, Conservation Programs Branch, NSW NPWS. The Bushfire Risk and Evaluation Unit has developed the risk assessment methodology for environmental and cultural assets. The NPWS Project

Team also prepares an Environmental and Cultural Asset profile for each BFMC and provides advice on assets at risk.

We wish to acknowledge the input of Olwen Beazley, Shirley Goodwin and Caroline Lawrence of NSW NPWS and Stewart Watters of NSW Environment and Heritage.

Thankyous are also extended to the following SMEs who reviewed the draft BFVAF and provided expert feedback.

- Experts in different types of heritage:
  - Ari Anderson (GML Heritage)—historical cultural landscape;
  - Martin Rowney (GML Heritage)—archaeology; and
  - Victoria Pearce (Endangered Heritage)—movable heritage.
- Experts in bushfire behaviour and risk management:
  - Grahame Douglas (University of Western Sydney)—analysis of bushfire impact data;
  - Nigel Bell (Australian Institute of Architects, ECO Design Architects)—Architect, bushfire design specialist;
  - Ram Singh and Mikhail Kogan (Public Works NSW, Emergency Engineering Management)—structural engineers; and
  - Melissa O'Halloran (NSW RFS)—fire service.
- Government authorities managing heritage and risks to heritage:
  - Peter Jensen and Libby Bennett (Sydney Harbour Trust); and
  - Joanna Lyngcoln and Zoe Guthrie (Heritage Victoria, Emergency and Bushfire Recovery Program).

2 Background: Bushfire behaviour

2 Background: Bushfire behaviour

Fire has been a significant part of the Australian landscape for thousands of years.

Heritage places and assets of all types across NSW are severely threatened by bushfires—particularly those located in bushfire prone areas (mostly in bushland settings), but also those located in rural areas, country towns and on the peri-urban fringe of cities. To minimise the impacts of bushfires on the state's heritage, there is a need to understand its vulnerability to fire. To understand this, it is necessary to understand bushfire behaviour and how fires can attack and impact heritage.

2.1 Australian bushfire seasons

Bushfires in Australia are seasonal, but the seasons vary according to where you are. In NSW, most bushfires occur in the spring and summer months, beginning in the northeast of the state and moving southwards and westwards as the season progresses. The greatest danger follows a dry winter and spring. Bushfire seasons in Australia are illustrated in Figure 2.1.

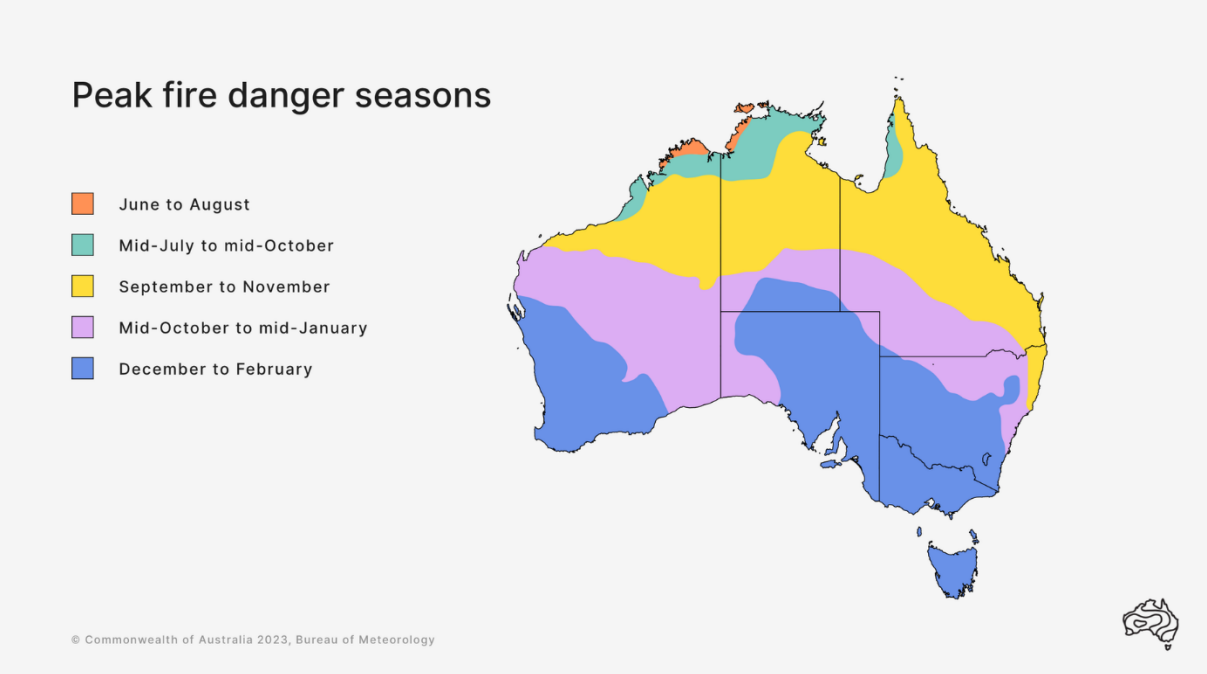

Figure 2.1 Australia's Peak Fire Danger Seasons, based on Forest Fire Danger Index. Fire seasons can extend beyond the months shown. (Source: Commonwealth of Australia, Bureau of Meteorology, 2024)

2.1.1 Climate change

Climate change is having a significant impact on our fire seasons. Rising temperatures and changing rainfall patterns are leading to longer and more intense fire seasons that are starting earlier.

The CSIRO and the Australian Bureau of Meteorology report that:

- Australia's climate has warmed on average by 1.44 ± 0.24 °C since national records began in 1910, leading to an increase in the frequency of extreme heat events.
- In the southeast of Australia there has been a decline of around 12 per cent in April to October rainfall since the late 1990s.[3]
- There has been an increase in extreme fire weather, and in the length of the fire season, across large parts of the country since the 1950s, especially in southern Australia.[4]

Refer to Figure 2.2.

It is predicted that over coming decades there will be:

- Continued increases in air temperatures, more heat extremes and fewer cold extremes.
- Continued decrease in cool season rainfall across many regions of southern and eastern Australia, likely leading to more time in drought, yet more intense, short duration heavy rainfall events.
- A consequential increase in the number of dangerous fire weather days and a longer fire season for southern and eastern Australia.
- As the climate warms, heavy rainfall events are expected to continue to become more intense.[5]

Changes in rainfall, air temperature and atmospheric moisture content exacerbate landscape drying. This affects the amount of fuel available for burning.

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[3] CSIRO and Australian Government Bureau of Meteorology (2020) State of the Climate, p 2.

[4] CSIRO and Australian Government Bureau of Meteorology (2020) State of the Climate, p 2.

[5] CSIRO and Australian Government Bureau of Meteorology (2020) State of the Climate, pp 4, 22.

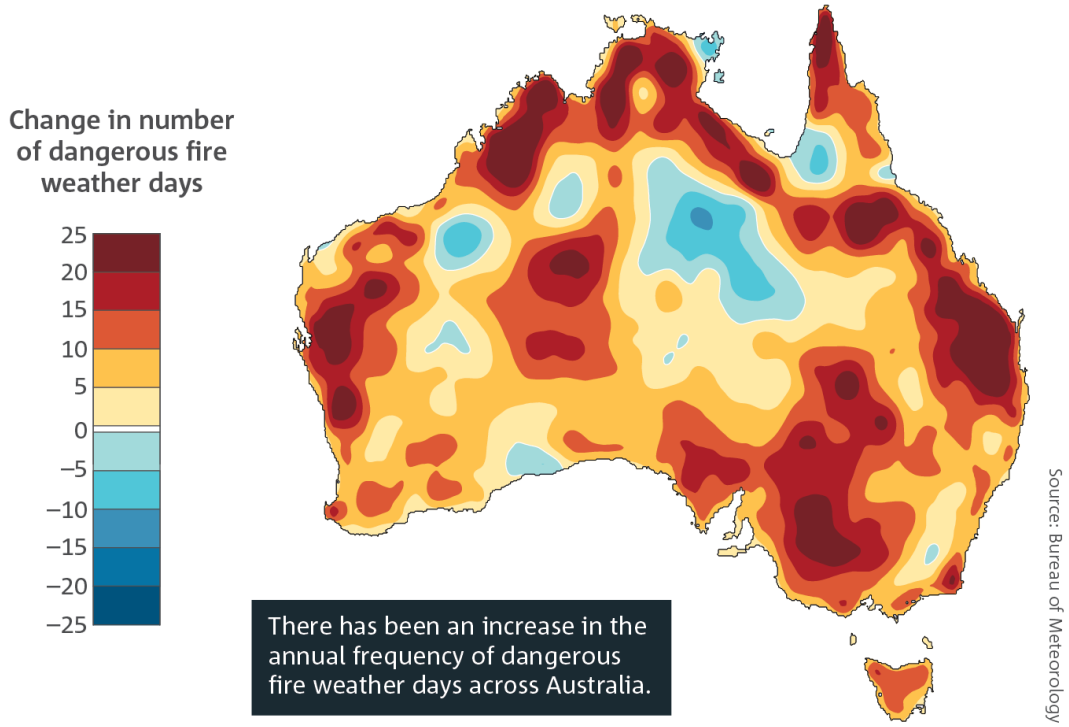

Figure 2.2 The number of days with dangerous weather conditions for bushfires has increased. (Source: CSIRO + Bureau of Meteorology, 2020[6]) © Copyright CSIRO Australia

2.2 Bushfire conditions

When bushfires occur, their behaviour is driven by three factors: weather conditions, terrain and fuel.

Prime conditions for bushfires include:

- high temperatures;
- low humidity;
- low moisture content in the soil;
- low fuel moisture;
- high fuel loads that are dry; and
- high wind speeds.

Bushfires are common during heatwaves and periods of drought.

[6] State of the Climate 2024, CSIRO and Bureau of Meteorology, © Government of Australia.

2.2.1 Ignition sources

Dry lightning strikes are the primary source of natural ignition for bushfires in National Parks (38%).[7]

The second most common ignition source is arson (18%).

However, there are many other ignition sources, most of which have a human source: e.g. sparks generated by machinery, electrical faults, fires lit by campers, fires used to burn waste, discarded cigarette butts, glass and so on. Spontaneous ignition can occur in garbage dumps due to the heat generated through decomposition of waste.[8]

2.2.2 Fuel sources

In the bush and across farmland, fuel is provided by dry vegetation growing in very dry soils, shedding bark, leaf litter and fallen timber. Where there is a lot of undergrowth and dry material on the ground, the fire can reach up into tree canopies.

In rural and residential environments, fuel sources can include rubbish heaps, wood piles, fuel canisters, fences, timber structures, garden mulch, leaves in gutters, garden plants that are not fire resistant, garden furniture, decks, doormats and buildings.

2.2.3 Topography and vegetation

Fire burns more quickly uphill due to pre-heating of fuels above the fire[9].

An uphill slope of 20 degrees will quadruple the fire's rate of spread[9]. On slopes of 26 degrees or greater the Coandă effect, or 'trench' effect becomes dominant, and the flame physically attaches to the slope due to an air pressure differential[10].

Aspect plays an important role in fire spread. In Australia, west and north-west-facing slopes are hotter and drier with enhanced fuel availability for burning leading to more intense fires. Southerly aspects are cooler and wetter with more fuel but it's generally less available for burning, leading to less intense fire.

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[7] https://www.environment.nsw.gov.au/topics/fire/fire-facts

[8] Department of Energy, Environment and Climate Action (2022). Fires at waste and resource recovery facilities. Produced by DEECA, Victoria, 3000.

[9] McArthur, A.G. (1967). Fire behaviour in eucalypt forests. Leaflet 107. Commonwealth Forests & Timber Bureau.

[10] Sharples, J.S., Gill, A.M and Dold, J.W. (2010). The trench effect and eruptive wildfires: Lessons from the Kings Cross underground disaster. (AFAC 2010 Conference, Darwin).

2.2.4 Grass fires generally burn with less intensity[11] than forested areas with a shrub layer. Shrubs act as a "near-surface" fuel that enables a fire to reach higher fuel strata[12]. This can increase the fire's rate-of-spread and intensity which can lead to crown fires and intense spotting potentially causing new ignitions in front of the fire.[13]Weather

Wind and temperature have a major influence on fires. High temperatures preheat the fuel. High winds fan the fires and cause them to spread quickly. The weather on a given day will contribute directly the level of fire risk.

In addition, large intense fires can generate their own weather systems that exacerbate fire conditions. Refer to subsections 2.3.3 and 2.3.4.

2.3 Bushfire modes of attack

To understand the vulnerability of heritage places and objects to bushfires, it is extremely important to understand a bushfire's modes of attack.

2.3.1 Ember attack

Embers start spot fires and account for 75–80% of property loss in Australia.[14]

An ember attack occurs when, during a bushfire, burning twigs, bark, moss or leaves become airborne and are carried by the wind some distance ahead of the main fire front. The distance the embers travel will depend on the conditions.

Property loss through airborne embers and firebrands that originate in nearby and distant fuel (typically less than 10 km)[15] is common Studies have demonstrated that in the most devastating fires, the main cause of house loss is from ember attack.[16]

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[11] Cheney P, Sullivan A (2008) *Grassfires, fuel, weather and fire behaviour*. 2nd Edition. (CSIRO Publishing: Collingwood).
[12] Cheney, N.P., Gould, J.S., McCaw, W.L. and Anderson, W.R. (2012). Predicting fire behaviour in dry eucalypt forest in southern Australia. *Forest Ecology and Management*. 280: 120-131.
[13] Luke, H. and McArthur, A.G. (1978). *Bushfires in Australia*. (Government Printer).
[14] Brown, D. 'How a bushfire can destroy a home', *The Conversation,* 7 February 2019,

[15] Gibbons, P., van Bommel, L., Gill, A. M., Cary, G. J., Driscoll, D. A., Bradstock, R. A., Knight, E., Moritz, M. A., Stephens, S. L., & Lindenmayer, D. B. 2012. Land management practices associated with house loss in wildfires. PLoS ONE, 7(1), Article e29212. https://doi.org/10.1371/journal.pone.0029212
[16] Leonard, J and Blanchi, R. 2003. Investigation of bushfire attack mechanisms involved in house loss in the ACT Bushfire 2003. Bushfire CRC Report, Melbourne.

Embers can enter properties through gaps, vents, weep holes, windows, doors, and open subfloor areas. They can also build up on window sills and catch in crevices (e.g. gaps in decking boards, under roof tiles, in open eaves, louvred vents) and ignite the flammable materials against which they lodge.

2.3.2 Radiant heat

Bushfires generate significant amounts of radiant heat. This is the heat released from the fire front that radiates to the surrounding environment.

Radiant heat can cause a build-up of heat inside a building. This can cause fabrics and other combustible materials to ignite, even without any embers present. Radiant heat can also damage building materials such as window glazing.[17]

Radiant heat can also impact masonry and rock surfaces, causing surface fractures and exfoliation.[18]

2.3.3 Direct flame

Bushfires burn at extremely high temperatures. They can be 1100°C at the base of the flames, 600°C at the tips of the flames and up to 1600°C inside the most turbulent flames where volatile gases are released.[19]

Direct flame attack occurs when the fire front comes into contact with, and engulfs, vegetation and structures. Direct flame is the highest level of bushfire attack.[20]

Direct flame contact places significant heat stress on all aspects of a building's construction. Flames can engulf and wrap around a building, exposing all sides and underfloor areas, as well as the roof, to overwhelming bushfire attack.

The flame front can directly contact a building if vegetation or other flammable materials (e.g. timber fences) are close to the building. In peri-urban areas, where buildings are close to each other, direct flame contact can result in fire transferring directly from one building/structure to another.

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17 https://www.yourhome.gov.au/live-adapt/bushfire-protection

18 Deal, K. *et al.* 2012, 'Wildland Fire in Ecosystems Effects of Fire on Cultural Resources and Archaeology', JFSP Synthesis Reports, 3, http://digitalcommons.unl.edu/jfspsynthesis/3

19 Sullivan, AL, CSIRO. 2015. Bushfire in Australia: understanding 'hell on Earth', ECOS Issue 214, CSIRO.

20 https://www.yourhome.gov.au/live-adapt/bushfire-protection

2.3.4 Fire-generated winds

Under extreme conditions bushfires can create their own weather conditions, which generate increased wind speeds that can be felt ahead of the fire front. Pyro convective plumes or pyro cumulonimbus clouds can be formed giving rise to high-pressure downdrafts that are strong enough to topple buildings, remove roofs, and break windows. Pyrogenic winds can markedly influence fire rate of spread and direction.[21]

Fire whirls may also occur causing debris to 'fly through the air', which can fall on roofs or damage buildings.[22] Burning branches can be blown long distances and break areas of unprotected glass.[23]

2.3.5 Fire-generated lightning strikes

Pyro-cumulonimbus clouds or firestorms, generated by the thick smoke and heat of an intense bushfire, can also create thunderstorms that produce dry lightning, potentially sparking new fires. Lightning strike distributions are largely related to local topography, with strikes occurring more frequently in higher elevation sites away from infrastructure.[24] [25]

Tall trees and structures are particularly vulnerable to lightning strikes.

2.3.6 Smoke

Smoke is an obvious aspect of bushfires. It can enter buildings, staining surfaces and significantly impacting interior furnishings and other contents, which also absorb the odour.

Smoke can also cause respiratory problems[26].

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[21] Sharples, J.S., Gill, A.M and Dold, J.W. 2010. The trench effect and eruptive wildfires: Lessons from the Kings Cross underground disaster. (AFAC 2010 Conference, Darwin).

[22] https://www.yourhome.gov.au/live-adapt/bushfire-protection

[23] Ram Singh and Mikhail Kogan, Emergency Engineering management, Public Works Advisory (SME feedback)

[24] Podur J., Martell D.L., Csillag F. 2003. Spatial patterns of lightning-caused forest fires in Ontario, 1976–1998. *Ecological Modelling* 164, 1–20.

[25] Penman, T.D., Bradstock, R.A., Price, O. 2012. Modelling the determinants of ignition in the Sydney Basin, Australia: implications for future management. *International Journal of Wildland Fire* 22(4) 469-478.

[26] Johnston, F.H., Borchers-Arriagada, N., Morgan, G.G. *et al*. (2021). Unprecedented health costs of smoke-related PM2.5 from the 2019–20 Australian megafires. *Nature Sustainability* 4, 42–47.

2.3.7 Ash

Ash, which contains the toxins from the materials burnt (including firefighting retardants), builds up on roofs and in gutters, causing surface corrosion. It also blocks drains and carries contaminants into water supplies.[27]

[27] Joanna Lyngcoln, Heritage Victoria, Emergency Bushfire Recovery Program (SME feedback)

3 Heritage vulnerability to bushfires

3 Heritage vulnerability to bushfires

The vulnerability of heritage places and assets to bushfires is determined primarily by their physical attributes and the attributes of their immediate settings. However, vulnerability is also determined by other factors such as remoteness and the capacity for the place or object to be protected.

3.1 Key questions

In assessing the vulnerability of a heritage item, the following key questions need to be asked:

1 What type of heritage is it?

2 Is it above or below ground?

3 What materials is it made of?

4 What form does it take?

5 What is around it?

6 Is it accessible?

7 Is it defendable?

8 Is there someone (trained and capable) on site who can defend it under the direction of fire authorities?

9 What protection or mitigation measures are in place?

3.2 Heritage type

Different types of heritage have different attributes and settings that contribute to their bushfire vulnerability. A brief overview of some of these differences is provided below.

3.2.1 Historical archaeology

The vulnerability of historical archaeology will vary according to its type (i.e. whether it's an artefact deposit or scatter, or a more substantial ruin), material composition and its location above or below ground.

Items buried beneath the ground would be better protected from bushfires than those sitting on or above ground. However, the level of protection would depend on how deep

the items are buried and the composition of the soil covering them—does it contain flammable organic material?

Below-ground archaeology and surface scatters may be more vulnerable to mitigation measures implemented to reduce fire risk (e.g. creation of fire breaks or containment lines) as they are not visible. Archaeology that is not easily recognisable or whose exact location is unknown is particularly vulnerable to measures that would disturb the ground surface (e.g. clearing of fire breaks).

3.2.2 Heritage structures

Buildings and other structures often comprise a broad range of materials assembled in a variety of ways into complex forms. It is very likely that the vulnerability of a structure's weakest component would strongly influence the structure's overall vulnerability to fire.

Most buildings are built above ground and are therefore highly exposed to bushfires. The vulnerability of buildings is primarily determined by their material composition, but also by their built form, their construction detailing, the texture of their surfaces and the complexity of their external features (e.g. windows, verandahs, eaves). Openings and crevices can provide places for embers to catch and ignite flammable components. Lightweight elements that are not well secured (e.g. metal roof sheeting, awnings) can be ripped off in the high winds and windows can be broken by flying debris, thereby leaving a structure open and unprotected. Tall structures may be impacted by lightning strikes.

The immediate physical environment of the heritage building/structure, including the topography, aspect, surrounding surface treatments and proximity to surrounding fuel sources, would also contribute to its vulnerability.

Structures built into or below ground would be less exposed to bushfires than those built above ground but would probably also be less vulnerable because these types of structures (e.g. retaining walls, culverts and drains) tend to be built of more durable and less flammable materials (e.g. masonry). Structures that stand above the ground or are suspended or cantilevered over it (e.g. verandahs, towers and bridges) may be more vulnerable because the fire can get underneath them and burn up through them.

3.2.3 Heritage landscapes

Heritage landscapes can merge into the broader landscape, or they can be tightly contained within a clearly defined area. They can include a single tree, a group/row of trees, a garden, a park, a cemetery, memorial plantings, market gardens, showgrounds, lookouts, urban or rural landscapes. Some landscapes can be spatially very large and complex.

Heritage landscapes may include both hard (built) and soft (plants) elements.

Many plants are highly flammable and vulnerable to fire, but not all, and their vulnerability level would increase or decrease depending on what is immediately around them or beneath them (e.g. leaf litter, mulch, tall grass, gravel, hard surfaces).

Cultural landscapes can be highly vulnerable to both bushfires and the mitigation measures implemented to manage bushfire risk (e.g. hazard reduction burns and clearing of fire breaks), particularly when the landscapes and their boundaries are not well defined.

Heritage landscapes can be extremely difficult to protect due to their often predominantly flammable nature and their high level of exposure to ember attack.

3.2.4 Movable heritage

Outdoor movable heritage is often highly exposed and highly vulnerable to fire, particularly where it is surrounded by vegetation or other flammable materials. Although it is referred to as movable heritage, it is not always movable (e.g. sculptures in the landscape, historic train carriages, heavy or dilapidated machinery).

Indoor movable heritage is often very fragile and highly vulnerable to smoke, flame and the water or retardant used to put out the fire. Indoor movable heritage, including collections, relies on the buildings that accommodate it to provide protection. If the buildings succumb to the fire, the collections are very unlikely to survive.

3.3 Physical attributes of the heritage item

The key physical attributes (inherent properties) of a heritage item that determine its vulnerability to bushfire include:

- its relationship to the ground plane (above or below ground);
- its material composition;
- its built form;
- its construction detail and features;
- its condition;
- the presence of hazardous materials;
- archaeology type/size; and
- vegetation type and layout.

These attributes or variables are discussed in more detail below and should be considered in relation to all types of heritage assets. Additional variables are proposed for landscapes and archaeological sites.

The discussion assumes that no mitigation is in place to protect the attribute/property. Mitigation is considered separately in section 3.6.

3.3.1 Relationship to ground plane

Whether a heritage item is above or below ground will affect its exposure to fire.

Items that are below ground, such as culverts and archaeological remains, will have some degree of protection from the soil layers above them, provided these are not highly flammable (i.e. do not have a high level of organic matter). The closer to the ground surface, the more likely an item will be impacted by radiant heat in very intense fires. The material composition and, to some extent, size or density of subsurface remains and artefacts will also affect their level of vulnerability.

Structures that exist above ground are much more exposed to fires. It is their materiality and built form that will determine their level of vulnerability.

The vulnerability of heritage assets as a consequence of their relationship to the ground plane is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Relationship to ground plane	Below or in ground (>500 mm below surface)	Low
	Close to surface (<500 mm below surface)	Moderate
	Above ground (<500 mm above surface)	High
	Above ground (>500 mm above surface	Very High
	Elevated above ground (e.g. tower, bridge)	Very High

3.3.2 Material composition

The material composition of the heritage item is one of the most significant attributes/ variables for determining the item's vulnerability to fire.

Some materials are highly flammable (e.g. plants, wood, paper, fabric [natural and synthetic], paint) and therefore at high risk from direct flame or ember attack. Other materials may not be flammable but may be vulnerable to radiant heat (e.g. steel buckles and loses its structural integrity at high temperatures, glass fractures and melts, masonry surfaces can crack and exfoliate, some materials can change their chemical composition and colour). Smoke can be absorbed by porous materials, and ash and soot can embed in surfaces, staining them or creating a hard crust. Compressed asbestos sheeting, although fire resistant, can become highly fibrous and disintegrate (this is discussed in more detail under Section 3.3.7 Hazardous materials).

Where items are composed of multiple materials, the material vulnerability of the item would be determined by the most vulnerable material in the item's external envelope.

For example, the vulnerability of a masonry building would be increased by the vulnerability of its timber eaves and glass windows. Refer to 3.3.5 External features and construction details.

The vulnerability of movable heritage located inside a building would be determined by the material vulnerability of the building. Whereas the vulnerability of movable heritage located in an outdoor setting would be determined by the material vulnerability of its most vulnerable components.

Appendix A includes a table setting out the vulnerability of various materials used in heritage structures or objects.

The vulnerability ranking of various materials is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Material composition	Masonry, stone, brick	Moderate
	Reinforced concrete in good condition	Low
	Reinforced concrete in poor condition	High
	Structural steel, cast iron, wrought iron with no protection	High
	Steel sheet, zincalume sheet	High
	Lead, copper, zinc, magnesium and aluminium alloys	Very high
	Terracotta	Moderate
	Ceramic	High
	Lime plaster	High
	Gypsum	Moderate
	Timber	Very high
	Wool	Moderate
	Organic materials – paper, silk, cotton, linen, hessian, etc	Very high
	Synthetic materials	Very high
	Thin heritage glass	Very high
	Thick toughened glass	Moderate
	Paint – lead, acrylic	Very high

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
	Paint - intumescent	Moderate
	Malthoid	Very high
	Plastics, PVC, acrylics	Very high
	Fibreglass	Very high
	Fibrous cement sheet	Moderate
	Asbestos	Very high

3.3.3 Built form

The built form of the heritage item can increase its vulnerability.

Complex forms with internal angles, recesses and crevices provide more places for embers to lodge. They also provide a greater surface area for flames to make contact with the structure. Verandahs, open eaves with exposed rafters and open subfloor areas are particularly vulnerable to ember attack, as are timber fretwork in gable ends and louvred vents in roofs and walls.

Simple forms that hug the ground provide far fewer opportunities for embers and flames to attack.

Low pitched and gabled roof forms with eaves are particularly vulnerable to high winds as they provide opportunities for the wind to get underneath their edges to lift them.

3.3.4 Critical points of failure

Structures are only as resilient as their weakest points.

Even though a structure may be clad in fire-resistant materials, embers can enter through gaps in the building envelope bypassing these materials.

The critical points of failure will determine the overall vulnerability of a heritage item.

3.3.5 External features and construction details

Although buildings may be of masonry construction, most will have timber-framed roofs which are exposed at the eaves. Although the walls may be fire resistant, the eaves will not be.

Window glass will fracture in extreme heat and can explode/implode when under pressure in high wind conditions. Windblown branches and other debris will also break unprotected windows, breaking through the fire-resistant skin of the building.

Leaf litter in roof gutters adds to the vulnerability of roofs. The litter is highly flammable and vulnerable to ember attack, catching alight long before any fire reaches the structure.

Lifted roof tiles, roof flashings and roof vents also provide crevices for ember attack. Sarking under the tiles may provide some ember protection.

Metal roof sheeting is vulnerable to radiant heat and high winds.

Once a roof catches fire, it is very likely that it will collapse into the structure and ignite the interiors, which usually contain highly flammable materials.

The vulnerability of heritage assets arising from their built form, external features and construction is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Built form and construction detailing	Simple form, ground hugging—no gaps or crevices, well-sealed, small number of openings, protected windows and doors, no verandahs, enclosed subfloor area.	Low
	Moderately simple form (rectangular plan, hipped roof)—boxed eaves, plain barge boards, sarking and leaf guard, moderate number of window and door openings, thick glass, no dormer windows, no chimneys, no verandahs, enclosed subfloor area.	Moderate
	Moderately complex form (more complex plan, hipped roof)—boxed eaves, plain barge boards, sarking and leaf guard, moderate number of unprotected openings, no dormer windows, capped chimneys, enclosed verandah, enclosed subfloor area.	High
	Complex form (complex plan with complex roof form including intersecting gables), decorative barges, dormer windows, large window openings, many recesses and crevices — open eaves, gables, subfloor areas, verandahs, uncapped chimneys.	Very high

Protection measures for buildings are addressed in section 3.6.3 Passive protection measures and physical interventions.

3.3.6 Condition

The physical condition of a heritage item also contributes to its vulnerability.

Old heritage structures are often fragile and in poor condition. The timber is dry, spilt, termite eaten or decaying. There are often open joints, loose elements where fixings have failed, and gaps around openings. There are many weak points that the fire can attack.

The gaps and splits provide openings for embers to catch and termite galleries and tunnels increase the surface area exposed to flame, increasing the speed and intensity of the burn.

Archaeology and movable heritage may also have decayed elements and crumbling surfaces.

Cultural landscapes may have been left to grow wild—unpruned, fallen branches left on the ground and weed infested.

Those heritage items in good condition have far fewer weak points and are less vulnerable.

The vulnerability of heritage assets arising from their condition is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Condition	Good condition—fabric intact, no decayed or loose elements, fixings sound and all gaps sealed; archaeology consolidated (not fragile); no fallen branches or leaf litter, lawns mown	Low
	Moderate condition—fabric substantially intact, some decay, fixings corroded, gaps not sealed; archaeology not consolidated; lawns mown, but leaf litter and other flammable debris present	High
	Poor condition—decay, termite damage, peeling paint, open joints, splits, loose elements, fixings failed, many gaps; vegetation growing through archaeology, foundations or walls, materials are friable; fallen branches on ground, leaf litter and weed infestation	Very High

3.3.7 Hazardous materials

Hazardous materials, such as asbestos, chemical preservatives, lead and PVC, present an additional layer of vulnerability for heritage places and assets. Prior to a fire, these materials may be embedded in the heritage items and appear to be contained, stable or not presenting an immediate risk to occupants or users. During a fire, these materials break down creating a very significant health risk to anyone in the vicinity. Some produce toxic gases (e.g. lead, PVC, plastic). Asbestos can become highly friable. The

fibres disburse into the atmosphere and embed in the surrounding surfaces and coat the surrounding landscape.

Following a fire, decontamination of sites for health and safety reasons can result in considerable loss of heritage fabric beyond that lost during a fire.

Decontamination can impact all types of heritage as it can prevent salvage and involve removal of original finishes and at least 300 mm of soil across a site.

There are many hazardous materials used in construction that can negatively impact the vulnerability of a place or item in a fire as well as human health, including fuels, gases released from burning materials and numerous toxic chemicals (e.g. copper chrome arsenate [CCA] used in treatment of timber).[28],

Mining and industrial sites also tend to be highly contaminated by chemicals used in industrial processes (e.g. arsenic, battery sands and various solvents, reactants, lubricants, coatings, dyes, colorants, inks, mastics, stabilizers, plasticizers, fragrances, flame retardants, conductors and insulators. Significant exposures to many of these chemicals can result in harmful effects to people or the environment)[29]

In the agricultural industry fertilizers, pesticides, herbicides and poisons are used and stored on site.

The vulnerability of heritage assets arising from the presence of hazardous materials is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Hazardous materials	No hazardous materials present	Low
	Hazardous materials in environment—e.g. soils contaminated by industrial waste	Moderate—structures Very high—archaeology, cultural landscape, outdoor movable heritage
	Hazardous materials stored in close proximity to heritage item—e.g. agricultural chemicals	Very high
	Hazardous materials store in heritage item—e.g. synthetic furnishing fabrics, cleaning products, paints, glues	Very high
	Hazardous materials built into heritage item—e.g. asbestos, lead, preservatives, glues,	Very high

[28] https://www.safework.nsw.gov.au/resource-library/natural-disasters/property-hazards-following-a-bushfire-fact-sheet; https://www.betterhealth.vic.gov.au/health/healthyliving/bushfire-aftermath-safety-tips#hazardous-materials-after-a-bushfire

[29] https://ipen.org/toxic-priorities/industrial-chemicals

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
	paints, dyes and fabrics that release toxic gases and fibres	

3.3.8 Archaeology type/size

The type of archaeology on a site can determine its level of vulnerability. Sites may comprise such features as standing ruins, pavements, subsurface remains, industrial remains, artefact deposits or artefact scatters. For all types of archaeology, materiality, relationship to the ground plane, form, detail and condition will strongly influence their vulnerability to fire (Refer to sections 3.3.1–3.3.6).

For artefacts, however, size can also determine their level of vulnerability. Small items heat very quickly, change their chemical composition and shatter in extreme heat.[30]

The vulnerability of heritage assets arising from their type/size is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Item size	Substantial archaeological ruin or subsurface remains of fire-resistant materials	Low
	Less substantial archaeological remains, including industrial remains	High
	Small archaeological artefacts	Very high

3.3.9 Vegetation type (plant species and habit)

The type of vegetation (plant species) used in a historical cultural landscape will largely determine the vulnerability of the landscape to bushfire.

Different types of plants have different vulnerabilities to fire. Some plants are far more fire resistant than others and reduce the risk to a landscape by not adding to the fuel load, whereas others can be explosive and increase the fire risk. Some plants can act as ember catchers and fire retardants (e.g. succulents, stiff waxy-leafed plants).

Some plants are more resilient than others and will recover from fire, regenerating from seeds, roots or beneath their bark, whereas others will burn and not recover.[31] Even fire resistant or resilient plants may not recover if a fire is too intense, or the plants have been impacted by a series of fires in quick succession.[32]

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[30] Deal, K et al. 2012, 'Wildland Fire in Ecosystems Effects of Fire on Cultural Resources and Archaeology', JFSP Synthesis Reports, 3, http://digitalcommons.unl.edu/jfspsynthesis/3

[31] https://blog.csiro.au/bushfire-impact-on-australian-plants/

[32] https://www.rbgsyd.nsw.gov.au/stories/2020/the-impact-of-fire-on-plants

Factors that influence the flammability of a plant include moisture content, branching pattern, height of branches above the ground, age, density of foliage, texture of foliage, bark type, presence of oils, waxes and resins, and retention of dead material (leaves, twigs, branches).[33]

In addition to the direct effects of fire, tall trees can also be vulnerable to high winds and lightning strikes.

The vulnerability of heritage landscapes arising from vegetation type is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Vegetation type (plant species and habit)	Fire retardant plants—do not burn easily, have high moisture content	Low
	Fire resilient plants—flammable plants that have recovery mechanisms to enable regrowth or reproduction post fire	Moderate
	Soft flammable plants—burn, but do not fuel the fire, or recover post fire	High
	Highly flammable plants—fuel fire	Very high

3.3.10 Heritage landscape layout

Heritage landscapes take many forms ranging from designed urban landscapes, to formal parks, memorial avenues, gardens and individual trees, to more informal rural landscapes, sports grounds, cemeteries and more. Landscapes often incorporate structures and pavements as well as plants and natural features (e.g. rock formations, streams). The layout of the landscape will contribute to its vulnerability.

For very complex landscapes that include structures, archaeological sites and movable heritage it will be necessary to assess the vulnerability of individual elements within the landscape using the variables discussed in sections 3.3.1–3.3.8). This section considers the layout of elements within the heritage landscape.

Open landscapes with large gaps between trees and structures are less vulnerable. It is more difficult for the fire to spread due to the lack of available fuel connecting elements. Landscapes that include complex and dense layers of plant material that are connected

[33] https://www.cfa.vic.gov.au/ArticleDocuments/447/CFA%20Landscaping%20for%20Bushfire%20(Version%203).pdf.aspx?Embed=Y

rather than separated from each other are more vulnerable. The high fuel loads contribute to the fire spread and intensity.

The vulnerability of heritage landscapes arising from their layout is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Heritage landscape layout	Individual trees, small groups of trees and/or structures separated by large distances with low fuel loads (e.g. hard pavements, mown grass) (>50 m separation between individual trees, small groups of trees and vulnerable structures)	Low
	Connected groups or rows of trees with no understorey plantings (e.g. avenue plantings) and well-separated from vulnerable structures including flammable fences (>20 m separation)	Moderate
	Trees close to vulnerable structures such as buildings and fences (10–20 m separation), but with limited understorey plantings	High
	Dense plantings with many layers, close to or overhanging structures (<10 m separation)	Very High

Landscape as a setting to a heritage item is discussed in section 3.4.8.

3.4 Physical context of the heritage item

The physical context of a heritage item will determine its exposure to fire and its vulnerability. An item can be affected by the topography of the site on which it is located and the fuel available in the landscape surrounding it. It can also be affected by its proximity to other vulnerable elements (e.g. surrounding structures, storage facilities).

3.4.1 Bushfire prone land

Bushfire hazard maps are used to identify areas that are at high risk from bushfires, based on slope, aspect and vegetation type.

Bushfire prone land is an area of land that can support a bushfire or is subject to bushfire attack, as designated on a bushfire prone land map. Bushfire prone land maps are prepared in accordance with the Guide for Bush Fire Prone Land Mapping[34] and are certified by the Commissioner of the NSW RFS under section 146(2) of the *Environmental Planning and Assessment Act 1979*. These maps are available from local councils and

[34] NSW Rural Fire Service. 2015. Guide for Bush Fire Prone Land Mapping. Version 5b.

through the NSW Planning Portal—ePlanning Spatial Viewer and are used for planning purposes. They also show buffer zones.

The zoning of land determines the level of protection that a new development must implement to be approved for construction. These measures include the use of non-flammable materials, inclusion of integrated protection measures such as fire shutters and sprinkler systems, and well-maintained settings that are designed to minimise the fuel available to approaching fires.

Historic heritage assets/items located in bushfire prone areas would almost never meet current Australian standards or building codes for construction on bushfire prone land. Site-specific protection measures would be needed to reduce their vulnerability.

3.4.2 Slope and aspect

The topography and aspect of sites directly affects the exposure of the heritage assets to bushfires.

Topography is significant in determining the rate of bushfire spread. The rate of fire spread doubles with every 10 degrees increase in slope. Assets located on slopes or at the top of slopes are highly vulnerable because fire burns very quickly uphill. Escarpments and cliffs can provide a barrier to small fires, but not to large intense fires. These will climb a rockface via any small vegetation on it.

In New South Wales, due to prevailing winds and climatic conditions, slopes with a northerly to westerly aspect tend to be much more exposed to fire than those with a southerly or north-easterly to south-easterly aspect.[35]

The vulnerability of heritage assets as a consequence of the slope and aspect of their sites is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Slope and aspect[36]	Located on flat land or at the bottom of a slope	Low
	Located on gentle slope (<10°) with north-easterly to south-easterly aspect	Low
	Located on gentle slope (<10°) with south-westerly to southerly aspect	Moderate
	Located on gentle slope (<10°) with northerly to westerly aspect	High

[35] [35] Luke, H. and McArthur, A.G. (1978). *Bushfires in Australia*. (Government Printer).
[36] Aspect is only an influential variable during non-drought conditions

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
	Located on steep slope (>10°) or at top of slope with north-easterly to south-easterly aspect	Moderate
	Located on steep slope (>10°) or at top of slope with south-westerly to southerly aspect	High
	Located on steep slope (>10°) or at top of slope with northerly to westerly aspect	Very high

3.4.3 Bushland setting

There is a close correlation between property loss and its proximity to bushland. Houses are destroyed during bushfires when exposed to flames in adjacent fuel, radiant heat from fuel within 40 m, or from airborne embers typically originating within 10 km. [37]

Properties and heritage assets located in bushland settings are highly exposed to bushfire. Bushland settings experience more intense fast-moving fires as they contain high levels of fuel and are often extremely rugged. They are also often less accessible than other areas and more difficult to defend.

Heritage assets located in bushland settings or immediately adjacent to bushland would be located within the flame zone, although they would also be exposed to all modes of bushfire attack—embers, heat, flame, high winds and smoke. Most heritage assets in this type of setting, unless they are of the most fire-resistant construction, would be highly vulnerable and at high risk of destruction. They would require the highest levels of protection.

Radiant heat is likely to ignite a wooden structure within 40 m of a fuel source[38], therefore vegetation close to or overhanging heritage assets would increase the exposure and vulnerability of those assets.

3.4.4 Rural setting

Properties and heritage assets located in rural areas where the native vegetation has been substantially replaced by pastures, crops or other development, may also be highly

[37] Gibbons, P., van Bommel, L., Gill, A. M., Cary, G. J., Driscoll, D. A., Bradstock, R. A., Knight, E., Moritz, M. A., Stephens, S. L., & Lindenmayer, D. B. 2012. Land management practices associated with house loss in wildfires. PLoS ONE, 7(1), Article e29212. https://doi.org/10.1371/journal.pone.0029212

[38] Cohen J.D. 2000. Preventing disaster: Home ignitability in the wildland-urban interface. *Journal of Forestry* 98: 15–21.

exposed to bushfire during the fire season, particularly when the conditions are hot and dry. Accessibility in these areas can be challenging and thus assets may be vulnerable.

Fires will burn across pasture. Although the fires may generally not be as intense or fast-moving as in bushland areas, they will still pose a serious threat to heritage assets/items. Heritage assets/items in rural areas would be particularly exposed to ember attack, high winds, lightning strikes and smoke, but also extreme heat and direct flame once vegetation or structures are alight in the vicinity.

Heritage items located in tall dry grass or close to trees are extremely vulnerable (e.g. fences, sheds, machinery).

3.4.5 Peri-urban fringe

Properties and heritage assets located in regional townships and on the peri-urban fringe (wildland–urban interface) are also highly exposed to bushfires. These properties/assets will be exposed to ember attack (accounting for most losses in these areas) but may also be subject to all other modes of attack, including radiant heat and/or direct flame contact once a fire is close by.

Fire can spread between buildings where they are in close proximity to one another. Large fires will easily cross over roads, endangering items located farther away from the wildland–urban interface and penetrating into the settlement/suburbs.

Vegetation, sheds, fences, mulch, woodpiles, rubbish piles, gas bottles and the like can fuel the fire and increase the vulnerability of the heritage item.

3.4.6 Proximity to high-risk facilities

Properties and heritage assets located in the vicinity of high-risk facilities may be exposed to a higher level of fire risk. Such facilities include tips and waste disposal sites which can self-ignite in high temperatures, petrol stations, industrial depots and rail corridors where volatile chemicals may be stored, and camping grounds, where there are likely to be a large number of gas bottles present.[39]

3.4.7 Predictor variables for broad physical context

As discussed above in Section 3.4.1, bushfire prone land (mostly land covered or surrounded by bushland) is mapped by local government in consultation with the RFS. The maps produced are used to identify those sites considered to be most exposed to bushfires and therefore at greatest risk as a consequence of their location and setting.

[39] Victoria Pearce, Endangered Heritage, SME feedback.

During extreme fire events, however, bushfire can spread well beyond the boundaries of bushfire prone land identified on the maps. The 2003 Canberra bushfires penetrated several blocks into the suburb of Duffy destroying more than 200 properties. There was a similar occurrence in Cobargo in early 2020. Therefore, even though heritage items may not be identified as being on or close to bushfire prone land, they may still be exposed to wildfires.

Thus, physical context/setting must be considered as a predictor variable in assessing the vulnerability of a heritage item.

Distance from the fuel source is critical in determining the level of fire exposure.

The vulnerability of heritage assets arising from the broader physical context in which they are located is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Physical context (setting)	**Urban setting** Predominantly hard surfaces—low fuel loads, a few well-spaced trees. Located several kilometres from bushland.	Low
	Suburban setting Buildings located close to each other, flammable fences between, but at least 500m away from bushland and farmland. Well-maintained parks and gardens—mown lawns, well-spaced trees with none close to or overhanging heritage items.	Moderate
	Peri-urban fringe Located within 500m of bushland or farmland with dry uncut vegetation. Flammable fences and outbuildings.	Very High
	Rural setting Grazed pasture, irrigated crops located within 500m of bushland.	High
	Rural setting Grasslands—dry and uncut located within 200m of bushland.	Very High
	Bushland setting Dense plantings with high fuel loads in the understorey, located within 100m of bushland.	Extreme
	Proximity to high-risk facilities Located within 500m of high-risk facilities.	Very High

3.4.8 Immediate setting of heritage item

This section considers the vulnerability of a heritage item (a structure, streetscape, conservation area, an archaeological site, heritage landscape or item of movable heritage) arising from its immediate setting—that is the area surrounding the heritage item, both inside and outside the item's property boundaries or heritage curtilage.

The setting of a heritage item often contributes its significance, but it can also contribute to its vulnerability.

Settings are composed of many elements. The level of vulnerability is determined by the vulnerability of the individual elements within the setting, their composition, their arrangement, relationships to each other and their relationship to the heritage item.

Hard paved or gravel surfaces, masonry walls and water features are much less vulnerable to the direct impacts of fire (depending on the intensity of the fire) than the more flammable elements such as vegetation, timber fences and structures. The hard elements can also provide some protection to the heritage item by breaking or slowing the spread of fire through a landscape.

The characteristics that contribute to the vulnerability of vegetation in a heritage landscape as discussed in Section 3.3.9 (Vegetation type) also apply to vegetation in the immediate setting of a heritage item. It is noted that some plants provide fuel to the fire while others act as fire retardants. The contribution that plants make to the vulnerability of a heritage place is also determined by their number, size, spacing and how they are grouped together within a landscape, as discussed in Section 3.3.10 (Heritage Landscape Layout).

Widely spaced trees with little in the way of under-plantings can reduce the fire's rate of spread, whereas trees with substantial under-plantings beneath will fuel the fire and increase the fire intensity and therefore the vulnerability of the place.

Neatly mown lawns can reduce vulnerability whereas mulch on garden beds can increase fuel loads and vulnerability. Trees located close to buildings or overhanging buildings and garden beds against the walls can increase the vulnerability of buildings. Although tall trees can be vulnerable to high winds and lightning strikes, trees and other vegetation (if correctly managed) can also serve as barriers against radiant heat, wind and ember attack.[40] Gibbons et al. (2012) found that modifying fuels closer to houses is an effective way to reduce house loss, with predominantly planted vegetation reducing house loss by 38%.[41]

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[40] https://research.csiro.au/bushfire/landscaping/screen-plantings/

[41] Gibbons, P., van Bommel, L., Gill, A. M., Cary, G. J., Driscoll, D. A., Bradstock, R. A., Knight, E., Moritz, M. A., Stephens, S. L., & Lindenmayer, D. B. 2012. Land management practices associated with house loss in wildfires. PLoS ONE, 7(1), Article e29212.

The vulnerability of significant trees can be increased when they are surrounded by tall uncut grass or flammable under-plantings.

Tightly clipped hedges are less vulnerable to ember attack than more open vegetation. They can provide protection to buildings and other elements within a landscape by screening embers.

The vulnerability of heritage items arising from their immediate setting is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Immediate setting	**Low fuel loads** Surrounded by broad areas of non-flammable surfaces, water features and fire barriers such as non-combustible walls and fences. Fire resistant trees are pruned and spaced well apart (>50 m). Plants are not growing close to buildings (>50 m).	Low
	Moderate fuel loads Well-maintained open or fragmented landscape setting with mown lawns and scattered trees located more than 20–50 m apart and more than 50 m from the heritage item. Landscapes characterised by scattered low plantings of fire-resistant plants, located more than 20 m from heritage items. Tall, dense well-maintained clipped hedge plantings of fire-resistant plants or non-combustible fences located around site boundaries and at least 20 m away from the heritage item, vulnerable structures and other plantings. Landscape broken by non-flammable pavements, walls and other barriers. Vulnerable structures spaced more than 20 m apart and more than 20 m from the heritage item. Plants are not growing close to the heritage item (more than 20 m away).	Moderate
	High fuel loads Vulnerable structures, including combustible fences and sheds, located 10–20 m from the heritage item.	High

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
	Trees within mulched, multi-layered garden beds, but with tree canopies more than 10m from the heritage item. Plants are not growing on or against the heritage item (>10 m separation).	
	Very high fuel loads Vulnerable structures within 10m of the heritage item. Trees, woody weeds (e.g. lantana) and garden beds growing against or overhanging the heritage item. Fuels stored on site (e.g. gas bottles, wood piles, rubbish heaps).	Very high

3.4.9 Previous events

Properties impacted by previous events such as extreme weather, flood, drought or previous bushfires can be more vulnerable due to the impacts of those events on the heritage place/item. The heritage items or their immediate settings may have been damaged by those events.

Extreme weather can cause significant damage to heritage items (landscapes, structures, archaeological sites and movable heritage) and leave a considerable amount of debris on the ground around the heritage items. Broken branches may be left hanging over heritage items.

Floods also leave considerable debris. They can also erode and expose archaeological sites or cause erosion of building foundations leaving subfloor areas more exposed than previously.

Droughts result in very reduced water supplies affecting landscape maintenance and supplies for firefighting, very low soil moisture content and very dry vegetation around the heritage items.

Previous bushfires will also leave debris, fragile trees and dry vegetation that can ignite again in the next fire.

The vulnerability of heritage items impacted by previous disaster events is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Previous events	No previous disaster event affecting site.	Low

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
	Minor impact from previous disaster event—no physical damage to heritage item, minor damage to setting.	Moderate
	Major impact from previous disaster event—physical damage to heritage item, major impact to setting—burnt, eroded, debris present.	Very High

3.5 Human capacity to protect the heritage item

3.5.1 Visibility/recognisability of the heritage item

If the heritage item is recognisable, it is easier for the community and firefighters to know what it is and that it needs protecting. If the heritage item is not recognisable, because it is invisible (e.g. below ground or hidden in long grass), not clearly identifiable due to lack of data (photographs/descriptions) or its boundaries are not well defined (e.g. a cultural landscape), its protection is much less certain.

Maps that show the location and extent of heritage items are critical to the clear identification of heritage. Property boundary maps do not show the location of specific items within their boundaries or the extent of the property's heritage curtilage. GPS and GIS point locators do not show the full extent of heritage items, although they can be useful in locating individual attributes or artefacts within large areas such as national parks or on rural properties. Site plans that clearly identify individual elements within the site, maps that show areas of archaeological sensitivity, heritage curtilage maps and maps that show the full extent of heritage landscapes, including those that merge into the surrounding landscape, are necessary to understand the heritage to be protected.

Photographs and descriptions of heritage items are also essential to being able to identify them. Where this information is missing, a heritage item is extremely vulnerable.

The vulnerability of heritage assets arising from their recognisability or lack thereof is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Recognisability from documentation	Recognisable—clearly visible, well mapped, photographed and documented, comprehensive inventory records	Low
	Difficult to recognise—partially visible, not well identified, mapped, photographed or documented, poor inventory records	High

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
	Extent of heritage item unknown—difficult to see, boundary of heritage item not identified or item merges with surrounding landscape	Very high
	Hidden from view—invisible, below ground and not well mapped or documented	Low–moderate for fire Very high for mitigation
	Not recognisable—invisible, heritage type not identified, site not mapped or documented	Very high

3.5.2 Road access

Heritage assets or items located in remote mountain areas with no road access are extremely hard to defend or protect. It is extremely dangerous for people to stay and provide protection to these items during bushfires and it is dangerous for fire services to enter these areas.

Even if the area has a single access road in good condition, this road may not be safe for fire services to travel along to defend a site because there is no alternative escape route if the road becomes impassable.

Evacuation of heritage sites with single road access would need to be undertaken early whilst conditions are safe.

Heritage sites and objects with poor access can be extremely vulnerable.

The vulnerability of heritage assets arising from their degree of road access is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Road access	Accessed by more than one sealed road, one being a major road	Low
	Accessed by only one sealed road	Moderate
	Accessed by an unsealed road or track	High
	Not accessible by road—remote	Very high

3.5.3 Defendable space

Defendable space is required around buildings/sites to enable easy access for emergency services and to provide a safe open area for firefighting. It should also provide adequate space for vehicles to turn around.[42] Barriers at the entries, or even to the rear, of

[42] https://research.csiro.au/bushfire/siting-and-design/siting-defendable-spaces/

heritage properties can restrict access for emergency services and seriously reduce their capacity to defend those properties. Such barriers may include locked gates, fences, sheds, trees, piles of rubbish, stacks of building materials, machinery and so on.

The vulnerability of a heritage item related to maintenance of a defendable space around the item is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Defendable space	Unobstructed area around heritage item greater than 20m in radius, no barriers to entry for emergency vehicles, access to all sides of heritage item	Low
	Unobstructed area around heritage item between 10 and 20m in radius, no barriers to entry for emergency vehicles, access to all sides of heritage item	Moderate
	Limited defendable space around the heritage item, restricted access to some sides of heritage item	High
	No defendable space, no access	Very high

3.5.4 Emergency evacuation

In Australia, bushfire alerts are issued to warn people of fire danger in their area.[43] Fire authorities encourage people to leave early rather than defend their property and may issue evacuation orders. Property owners and occupants must be prepared.

Evacuation of movable heritage assets and collections must also be planned for, well ahead of time.

3.5.5 Human capacity to defend

Properties that are unoccupied or have little human presence due to their remoteness are highly vulnerable because it is unlikely that anyone would be present to prepare the place for a fire or defend the place during a fire.

Even where there is a human presence, if those on site are not adequately trained, prepared and equipped, their capacity to defend a property or heritage item will be extremely limited. In fact, they will be risking their lives.

[43] https://www.rfs.nsw.gov.au/plan-and-prepare/alert-levels

On the other hand, if adequate mitigation measures have been implemented (refer to section 3.6), the presence of a well-trained, prepared and equipped team with adequate resources would reduce the vulnerability of the place.

The vulnerability of heritage items arising from their level of occupation and from the capacity of their occupants (including site managers) to defend them is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Human presence	Occupied full time	Low
	Occupied part time (e.g. most weekends)	Moderate
	Occupied part time (e.g. holidays only)	High
	Unoccupied	Very High
Human capacity to defend	Well-trained, practiced, prepared and equipped with quality personal protection, adequate firefighting resources and backup power and water (refer to section 3.6.6)	Low
	Well-trained, practiced, prepared and equipped (with personal protection, adequate firefighting resources and no backup)	Moderate
	Well-equipped, but not well-trained or practiced in use of equipment and no backup Well-trained, but not practiced and not well equipped	High
	Not trained and not equipped	Very High

3.5.6 Maintenance regime

Good maintenance is critical to reducing the vulnerability of a heritage item. This includes maintenance of the items and their immediate and broader settings.

Places that are unoccupied or have no onsite management are often not well maintained and are more vulnerable than those that are occupied.

Regular cyclical maintenance

General maintenance tasks would include ensuring that gutters on buildings and areas around buildings are kept clear of leaf litter and that the surrounding landscape is well maintained. This involves mowing, pruning, removal of overhanging branches, removal of potential fuel sources such as fibrous doormats, long grass, leaf litter and rubbish, and ensuring that wood piles, fuel (e.g. gas bottles, petrol cans) and chemicals (e.g.

fertilisers, paints) are removed from the site or located in a safe place well away from buildings or other significant heritage attributes.

Pests and insects

The presence of insects and other pests can affect the vulnerability of structures to embers, heat, flame by adding to the fuel load and increasing burn rates.

Papery wasp nests and waxy residues are flammable, termite tunnels increase the surface area facilitating flame spread, and possums, birds, bats and rodents create access holes in which embers can lodge, nests and waste (e.g. urea) that are highly flammable.

It is important that the pests and the residue from their activity is removed, and that damaged building fabric is repaired.

Basic fabric repairs

Repairs and maintenance to buildings, archaeological remains or object fabric may include tasks such as refixing of loose elements, painting, and filling gaps to prevent ember entry.

The vulnerability of heritage assets arising from the level of maintenance implemented is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Maintenance regime	**Well-maintained**—litter removed from landscape and gutters; lawns mown, trees pruned; fallen branches, rubbish, fuel sources, pests and insects removed. Damaged building/object fabric is repaired.	Low
	Maintained to a moderate standard—litter and rubbish removed from landscape and gutters; lawns mown, trees pruned. Pests removed, but pest residue (e.g. nests, waste) not removed. Fuel sources relocated, but not removed from site or stored safely. Building/object repairs partially undertaken.	Moderate
	Partially maintained—litter removed from landscape and gutters; lawns mown. Overhanging branches not pruned. Pests removed, but pest residue (e.g. nests, waste) are not removed. Fuel sources not relocated or removed from site.	High

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
	Building/object repairs not completed.	
	Not well maintained—gutters not cleared, lawn not mown, rubbish and other fuel sources not removed from site. Building/object not repaired.	Very High

3.6 Mitigation measures in place

Implementation of mitigation measures will reduce the vulnerability of a heritage place/object to bushfires and improve its resilience. Heritage items or assets that employ bushfire mitigation measures would be less vulnerable than those that do not.

Mitigation measures would include risk treatments to the heritage item (archaeological site, structure, heritage landscape, movable heritage) and/or its setting.

3.6.1 Site specific bushfire risk management strategy

A well-prepared site-specific bushfire risk management strategy (BFRMS) would identify and evaluate the risks to the heritage asset/item and include mitigation measures to minimise the risks to the item before, during and after a bushfire.

Mitigation measures to minimise the bushfire risk to a heritage item may include actions (e.g. maintenance, pre-fire preparations such as training of staff and evacuation of movable heritage/collections—refer to Sections 3.5.4, 3.5.5 and 3.5.6) or they may include physical interventions, passive (fabric based, such as introduction of ember protection and fire rated materials) and/or active (system based such as the installation of a firefighting system), that are designed to protect the heritage item from fire (refer to Sections 3.6.3 and 3.6.4).

Heritage items/assets with fully implemented bushfire risk management strategies may be considered less vulnerable than items which have not developed and implemented a BFRMP.

The vulnerability of heritage assets arising from bushfire risk management planning, or lack thereof, is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Bushfire risk management plan (BFRMP)	BFRMP developed, fully implemented, tested and regularly reviewed and upgraded as necessary	Low
	BFRMP developed and implemented, but not tested and regularly reviewed	Moderate

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
	BFRMP developed but not fully implemented, tested or reviewed	High
	No BFRMP	Very High

3.6.2 Asset protection zones

An asset protection zone (APZ) is the area of land around a building/structure/site where vegetation and other fuels are managed to reduce fire risk. The area is managed to reduce the potential for flame contact and radiant heat impacts on assets. Properties in bushfire prone areas are required to maintain APZs around them. Heritage items that do not have a well-maintained APZ around them are much more vulnerable than those that do.

Heritage landscapes and archaeological sites are not necessarily required to have APZs around them, but implementation of an APZ would reduce the vulnerability of those sites. Conflict arises where the cultural historical landscape and the surrounding bushland are integrated, contributing to the significance of the designed/historical landscape.

Movable cultural heritage within an APZ would be less vulnerable than the same heritage in an unmaintained landscape.

The vulnerability of heritage assets in relation to the space around them is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Asset protection zone	Well-maintained APZ that meets code requirements	Low
	Poorly maintained APZ	High
	No APZ, no defendable space, no access	Very high

3.6.3 Passive protection measures

Physical interventions

Passive protection measures are protection measures that are built into the fabric of the place/item. These include modifications or physical interventions to the heritage item to increase its bushfire resilience.

Passive protection measures are used to protect buildings from ember attack, extreme heat or direct flame, as well as impact damage from falling branches or flying objects thrown by the extreme winds that accompany a fire.

Protection measures may include the use of non-combustible gutter and valley guards, ember mesh to screen subfloor areas, vents and other openings/gaps, seals around windows and doors, fire shutters/screens over windows and doors, non-flammable sarking under tiled or flammable roofing and fire rated construction (e.g. fire-rated walls, eaves and ceilings).

Temporary protection

Temporary protection measures may be installed in an emergency to protect an otherwise unprotected heritage item.

One example includes the foil wrapping of structures or items located in remote areas (e.g. mountain huts, items of movable heritage) to protect them from ember attack and direct flame. In intense fires, however, foil wrapping may not protect highly vulnerable items from radiant heat. Wrapped items can spontaneously combust within the wrapping as a consequence of their material composition.

The vulnerability of heritage assets arising from physical interventions, or lack thereof, is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Physical interventions	Full suite of permanent bushfire protection measures installed on built heritage items (e.g. Non-combustible gutter guards, ember mesh, seals to openings, fire shutters or screens over windows, roof sarking, fire rated construction	Moderate
	Some bushfire protection measure installed (e.g. gutter guards and ember mesh, but no fire shutters or screens). Eaves and ceilings are not fire rated.	High
	Temporary bushfire protection measures implemented on buildings (e.g. foil wrapping	High
	No protection measures present	Very high

3.6.4 Active firefighting systems

Active on-site firefighting systems can be used to protect vulnerable heritage assets, particularly built heritage assets that are vulnerable due to their material composition, form and setting. They may also be used to protect vulnerable heritage landscapes and movable heritage.

Such systems would include external roof and wall drenchers and sprinklers inside roof spaces to extinguish embers that do enter the roof. They may also include fire hydrants and fire hoses located within the surrounding landscape. These systems require

independent water and power supply, as local supplies are likely to be over-stretched or unavailable in a major bushfire event. Adequate backup water and power are required to ensure that the systems continue to operate for long enough during a fire to protect the heritage until the fire passes.

Heritage assets without such protection would remain extremely vulnerable.

The vulnerability of heritage assets arising from active firefighting systems, or a lack thereof, is summarised below.

Predictor variable	Parameters for assessing vulnerability	Vulnerability ranking
Active firefighting systems	Active firefighting systems installed (e.g. drenchers, sprinklers, fire hydrants and hoses with independent and backup power and water supplies	Low
	Active firefighting systems installed (e.g. drenchers, sprinklers, fire hydrants and hoses with independent power and water supplies, but not back up	Moderate
	Active firefighting systems installed, but with no independent water and/or power supply	High
	No active firefighting systems installed	Very high

4 Phases of vulnerability

4 Phases of vulnerability

4.1 Vulnerability pre, during and post fire

Section 3 refers to the vulnerability of heritage assets/items to the bushfire itself and its various modes of attack.

This section highlights the vulnerability of heritage items to the mitigation measures implemented in preparation for or in response to a bushfire (e.g. mitigation measures taken on a seasonal basis, measures taken ahead of fire and those taken to fight the fire) and the vulnerability of heritage items to the deteriorated conditions that exist post fire.

4.2 Seasonal mitigation measures—pre-fire preparation

Seasonal mitigation measures are those implemented each year to reduce the risk of fire. These measures are usually planned. Therefore, where there is sufficient information about a heritage asset/item, the potential impact on those assets/items can be avoided.

4.2.1 Maintenance of asset protection zones

Asset protection zones (APZs) are used to provide open space around a property and must be maintained on a regular basis to be effective. This includes mowing, removing or thinning undergrowth, and removing fallen branches and other debris.

4.2.2 Hazard reduction burns (prescribed burns)

Hazard reduction burning is the deliberate, controlled use of fire in the landscape to reduce the amount of fuel that would feed a bushfire. Fuel reduction burning is carried out during low-risk conditions by the RFS and a variety of land managers on both public and private land.

Prescribed burns are planned well in advance, taking into account air temperatures, humidity and wind conditions. They are also closely monitored and managed to reduce the risk of their escaping and burning out of control, although this cannot be guaranteed.

When planning and implementing prescribed burns, it should be possible to avoid heritage sites or assets that are well identified.

Heritage assets or items that would be vulnerable to hazard reduction burns would include movable heritage that is concealed within long grass or other vegetation, and heritage landscapes.

Risks to other heritage assets, such as buildings, would increase when fires get out of control due to changing weather conditions.

Smoke generated by hazard reduction burns can impact heritage interiors and collections.

4.2.3 Cultural (cool) burning

The term 'cultural burning' is used to describe burning practices developed by Aboriginal people to enhance the health of the land and its people.[44]

Burns are culturally informed, seasonal and targeted, with the intention of reducing fuel loads, managing weeds, improving soil quality, biodiversity and feed for native animals. The burns are generally slower moving and cooler (i.e. of lower intensity) than hazard reduction burns and are considered to be low risk.[45]

Cultural burning is rarely undertaken close to buildings or other historic heritage assets.

The smoke generated by cultural burns is white and cleaner than that of other hazard reduction burns.

The risk to heritage assets is low.

4.2.4 Mechanical clearing

Mechanical clearing such as slashing of undergrowth has the potential to impact heritage landscapes that do not have clearly defined boundaries or that merge into the broader landscape.

The use of heavy machinery can be a threat to archaeology, especially when it is not clearly identifiable or hidden by vegetation.

4.2.5 Fire trails

The creation and maintenance of fire trails using heavy earth-moving equipment can be a threat to archaeological remains and artefact scatters, particularly those that are hidden beneath the surface or that are not well identified.

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[44] https://www.firesticks.org.au/about/cultural-burning/

[45] Guidelines for Community (Low Risk) Cultural Burning on NPWS Managed Lands https://www.aidr.org.au/media/6498/nsw-pws-guidelines-for-cultural-burning.pdf

The creation of fire breaks can also impact heritage landscapes and significant landscape settings to heritage assets/items, as well as movable heritage that is not well identified.

4.3 Emergency response measures used during a bushfire

Measures can be implemented ahead of a fire front to stop or slow its progress. These types of measures are generally implemented in an emergency and without the same level of advance planning that would occur in implementing seasonal mitigation measures prior to a fire.

To avoid and/or minimise impacts on heritage items/assets, the items/assets need to be clearly identified.

4.3.1 Containment lines and back burns

Containment lines are created ahead of a bushfire to prevent or slow its spread in a particular direction. Actions may include clearing of vegetation and creation of fire breaks using heavy equipment, and back burning. These actions can be successful, but also destructive.

Although these actions may be similar to planned mitigation measures undertaken during the cooler winter months prior to the fire season, they are often undertaken in far from ideal conditions, i.e. in hot, dry, windy conditions. They therefore carry a much higher degree of risk.

Unplanned bulldozing of containment lines can be highly destructive of the landscape and archaeological sites.

4.3.2 Fire hoses

Fire hoses are used by fire agencies and property owners with the necessary equipment to extinguish embers and flames and to wet down vegetation and surfaces to reduce their flammability.

The hoses generally operate at high pressure and can damage fragile structures and elements, erode unstable ground surfaces, dislodge artefacts, and undermine building foundations.

4.3.3 Aerial water bombing

Large quantities of water are dropped from aircraft to extinguish fires or to wet areas down between the fires and settlements or specific sites.

The water falls with immense force and can damage less robust structures and objects. It can also wash out areas, displacing ground cover and exposing previously protected or hidden sites (e.g. artefact scatters).

4.3.4 Aerial fire suppressant drops

More commonly now, fire suppressants are dropped from aircraft to stop the spread of fire. It is often dropped around buildings to reduce fire intensity as the fire reaches the site.

The chemicals have nutrient impacts on soils and water quality, and therefore affect the viability of plants in the cultural landscape.[46]

The chemicals can also have a corrosive impact on building materials.

4.4 Post-fire threats

Following a fire, the priority is on making the place safe before people return. This includes removal of hazardous materials.

Cultural heritage assets can be left exposed and vulnerable, not only as a result of the fire, but also as a consequence of the clean-up activities undertaken following the fire.

4.4.1 Vegetation loss

The loss of vegetation to fire leaves the ground unprotected and heritage sites of all types exposed to other hazards.

4.4.2 Regrowth and weed infestation

Areas burned by bushfires are highly vulnerable to weed infestation. Some weed species, such as African lovegrass and bracken, can increase the intensity of future fires.[47]

Archaeological sites exposed by the loss of vegetation need to be quickly recorded before they are hidden by the regrowth.

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[46] https://emergencyleadersforclimateaction.org.au/wp-content/uploads/2020/08/reducing-costs-impacts-bushfires-independent-bushfire-group-summary.pdf

[47] https://www.csiro.au/en/news/all/articles/2020/january/bushfire-impact-on-australian-plants

4.4.3 Rain and wind

In some circumstances areas affected by fires may then be exposed to significant rain events. The rain extinguishes the fire and any remaining embers, but it also erodes the denuded landscape because there is no vegetation to protect and contain it.

Fire damaged structures may not be weathertight and are highly vulnerable to water damage, particularly their exposed interiors (e.g. surviving floorboards and plaster finishes) and any surviving furnishings or objects within them. Mould that develops following rain presents a major issue to buildings and human health. Loose elements such as roofing are vulnerable to high winds.

Archaeological sites can be severely eroded as water flows over the sites or inundated with mud. Loose artefacts can be washed away.

Water channels can be cut through the landscape, changing the ground profile, exposing tree roots and causing landslides on steeper sites.

Fire damaged heritage places and objects are highly vulnerable to rain and extreme weather post fire.

4.4.4 Hazardous materials

Heritage assets can be contaminated by:

- the toxic materials embedded in the structures or objects prior to the fire and then released by the fire (e.g. asbestos, lead);
- chemicals used in mining activities or industrial processes (e.g. cyanide, arsenic);
- chemicals stored on site (e.g. battery acid, herbicides, pesticides); and
- the chemicals used to extinguish the fire.

Hazardous materials embedded in buildings or objects are broken down by the fires and released into the atmosphere. Asbestos fibres can coat all the surrounding surfaces inside and outside buildings, as well as impacting the surrounding environment (soils, water, vegetation). Lead will melt and coat surfaces. Other chemicals may also be carried by the water used to extinguish a fire into the surrounding environment.

4.5 Post-fire response

4.5.1 Decontamination

Hazardous material removal is a major component of post-fire clean-up.

The sites must be decontaminated to make them safe for people to return.

This can involve removal of the top 300 mm of soil, including all the artefacts within this layer, and removal of a large portion of the heritage fabric of a fire damaged building. Affected objects and other movable heritage are also removed.

Heritage places are highly vulnerable to the decontamination process. In some cases, decontamination is more damaging than the fire itself.

4.5.2 Make safe works

Fire damaged structures may be demolished and trees removed as part of the making safe process and recovery works. A rapid assessment of their stability would be made by an engineer, who may not be aware of a place's significance or cultural value. The priority will be on human safety and the need to retain a place for cultural reasons may not be considered.

Stabilisation of a heritage structure or site is needed to protect it from further damage or loss, and to allow a more detailed damage assessment to be undertaken. This would also allow salvage of materials and artefacts and detailed documentation of the place to facilitate recovery.

Heritage assets are highly vulnerable to the decision-making processes around making a place safe.

4.5.3 Clean-up and salvage

There is often an imperative to address post fire actions in the initial stages of fire clean-up works.

The clean-up may not be undertaken by the property owners themselves, but rather by paid contractors or volunteers who do not necessarily value the place or objects as the owner would. Consequently, much can be removed from a site that may otherwise have been kept.

Salvage of damaged components is critical to the complete restoration or reconstruction of heritage places (i.e. recovery of heritage values). Therefore, heritage places/objects are highly vulnerable during the post-fire clean-up.

The use of heavy machinery to clear sites from sites can pose a threat to heritage sites, particularly archaeological sites.

4.5.4 Security

Bushfires expose sites and present opportunities to access remote and previously difficult to access sites.

Looting and vandalism can be an issue post fire. Heritage places and archaeological sites often contain valuable artefacts or objects that need to be secured.

Once emergency teams have left the site, site security becomes the responsibility of the property owner.

4.6 Vulnerability of heritage types during bushfire and mitigation phases

Different types of heritage have different vulnerabilities at different phases of the bushfire, including implementation of mitigation measures and response treatments.

These are summarised in the following table.

Hazards (threats)	Type of heritage				
	Historical archaeology	Historical cultural landscape	Built heritage (Structures)	Historic interiors + collections	Outdoor movable heritage
Pre-fire mitigation—asset owners					
Hazard reduction burns	Low	Moderate	Low	Low	High
Clearing of vegetation (asset protection zones)	Moderate	High	Low	Low	High
Earthworks (fire breaks)	High	High	Low	Low	High
Bushfire hazard—fire attack mechanisms					
Ember attack	Low	High	High (timber, complex forms, tiled roofs, subfloors, verandahs, eaves) Moderate (steel) Low (masonry)	High (through openings)	High
Direct flame	Low	High	High (timber) Low (masonry, steel)	High	High (timber) Low (masonry, steel)

Hazards (threats)	Type of heritage				
	Historical archaeology	Historical cultural landscape	Built heritage (Structures)	Historic interiors + collections	Outdoor movable heritage
Radiant heat	Moderate	High	High (timber, complex forms, tiled roofs, subfloors, verandahs, eaves) Moderate (steel) Low (masonry)	High	High (timber) Moderate (steel) Low (masonry)
Smoke and ash	Low	Low	Moderate	High	Low
High winds	Low	High	High (roofs, verandahs, awnings)	High (through openings)	Moderate (depends on weight and fixing)
Lightning strike	Low	High	High (tall structures)	Low	Low
Bushfire response—RFS and NPWS					
Fire hoses	Low	Low	Low	Moderate	Low
Water bombing	Low (if below ground)	Moderate	Moderate	Low (if sealed)	Moderate
Fire retardant	High	High	Moderate	Low (if sealed)	High
Containment lines (earthworks)	High	High	Low	Low	High
Back burning	Moderate	High	Moderate	Moderate	High
Post-fire hazards					
Vegetation loss	High	Very High	Moderate	Low	High
Weeds	High	High	Moderate	Low	High
High intensity rain	Moderate	Moderate	High (if damaged) Low (if sound)	High (if roof or windows damaged) Low (if structure sound)	Low

Hazards (threats)	Type of heritage				
	Historical archaeology	Historical cultural landscape	Built heritage (Structures)	Historic interiors + collections	Outdoor movable heritage
Landslides, mudslides	High (slopes, bottom of slopes following loss of vegetation) Low (on flat ground)	High (slopes, bottom of slopes following loss of vegetation) Low (on flat ground)	High (if on sloping ground or at bottom of slope following loss of vegetation) Low (on flat ground)	High (if structure vulnerable) Low (if structure sound)	High (slopes, bottom of slopes following loss of vegetation) Low (on flat ground)
Erosion	High	High	High (if close to water course, top of embankment) Low (on flat ground)	High (if structure vulnerable) Low (if structure sound)	High (if close to water course, top of embankment) Low (on flat ground)
Contamination—hazardous materials	High (mining and industrial sites) Low (except in proximity to hazardous materials)	Low (except in proximity to hazardous materials)	High (if built before 1987)	High (if structure damaged and built before 1987) Low (if structure sound and no hazardous materials present)	High (if hazardous materials present) Low (otherwise)
Looting	High	Moderate (sculptures) Low	Very High	Very high (if building not secure) Moderate (if building secure)	High (if newly exposed) Low (if damaged)
Post-fire response					
Decontamination	High	High (if unidentified) Moderate (exposure of roots from removal of soil)	High (if built before 1987)	High (if structure damaged and built before 1987) Low (if no hazardous materials present)	High (if hazardous materials present) Low (otherwise)

Hazards (threats)	Type of heritage				
	Historical archaeology	Historical cultural landscape	Built heritage (Structures)	Historic interiors + collections	Outdoor movable heritage
Make safe measures (demolition / removal of trees and structures)	High (if unidentified and heavy equipment used) Low (otherwise)	High (burnt significant trees)	High (severely damaged structures)	High (in severely damaged structures)	Low (unless deemed dangerous)
Clearing of debris (heavy machinery)	Very high	Very high	High (damaged structures)	High (damaged structures)	High (if unidentified) Low (if remote)

5 Data availability and quality

5 Data availability and quality

5.1 Heritage data

5.1.1 Heritage inventories and databases

Data on heritage items across NSW is kept in a range of inventories and databases, the major one being the NSW State Heritage Inventory (SHI).

NSW statutory heritage lists (identified and managed under NSW legislation) include:

- NSW State Heritage Register (SHR);
- NSW SHI—includes heritage items and conservation areas identified on Local Environmental Plans (LEPs);
- NSW NPWS Historic Heritage Inventory Management System (HHIMS);
- Section 170 Heritage and Conservation Registers of NSW Government departments (s170);
- State Environmental Planning Policies (SEPPs); and
- Regional Environmental Plans (REPs).

The NSW Heritage Management System is gradually gathering all the heritage data from the various lists covered by NSW heritage legislation into a centralised system. It does not include heritage protected under Commonwealth Government legislation or heritage lists held by non-government organisations such as the National Trust of Australia, the Australian Institute of Architects and Engineers Australia.

Commonwealth statutory heritage lists (identified and managed under Commonwealth legislation) include:

- Australia's National Heritage List; and
- Commonwealth Heritage List.

The World Heritage List is held by UNESCO.

Non-statutory heritage lists are held by many non-government organisations. These include, but are not limited to:

- National Trust of Australia (NSW) Heritage List;
- Australian Institute of Architects Register of Significant 20th century buildings; and
- Engineering Heritage Register.

5.1.2 Heritage mapping

Mapping of heritage is essential to identifying where heritage is located. The NSW Heritage Management System includes mapping of all heritage sites for which geospatial information is available.

The mapping extends to property boundaries and includes clearly defined heritage conservation areas and heritage landscapes. The mapping does not include heritage curtilages that extend beyond property boundaries or across multiple properties, although some sites will have heritage curtilage maps included with their listing data. Nor does it always identify where a heritage asset is located on a very large site, such as a rural estate or parkland. Archaeological potential or sensitivity mapping is also excluded.

Examples of heritage maps at both large scale and small scale are included below.

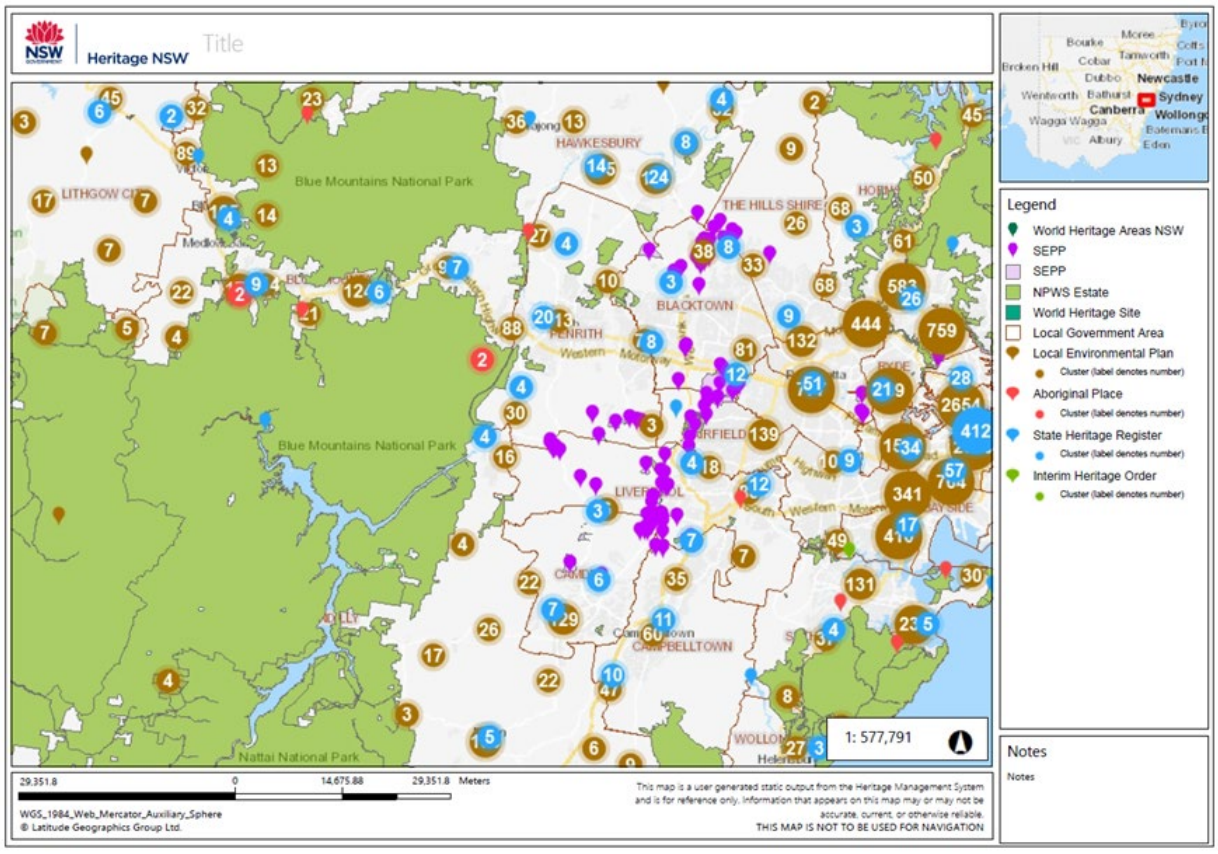

Figure 5.1 SHI map of the Greater Sydney region and the Blue Mountains, showing LEP, SEPP and SHR items, designated Aboriginal Places, and the NPWS Estate. (Source: NSW Heritage Management System)

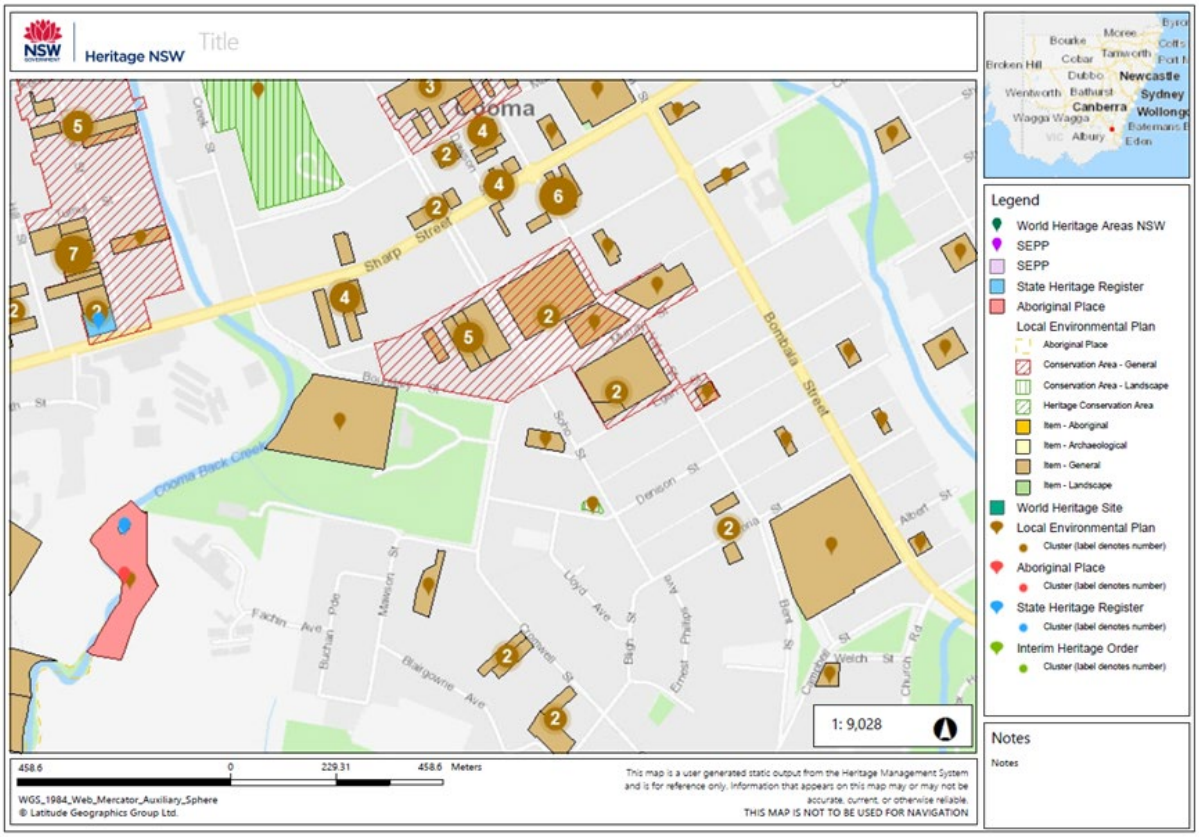

Figure 5.2 SHI map of Cooma showing heritage items and conservation areas on the LEP, SHR items, and designated Aboriginal places over the Department of Planning and Environment base map. (Source: NSW Heritage Management System)

5.1.3 Inventory data

The data included in the inventories is qualitative in nature and includes item descriptions, site maps and photographs (but not always).

For some sites the data is comprehensive, but for many it is not. It can also be out of date.

Content is entered under a common set of headings and significance assessment criteria. The structure and format of the information is designed to identify a place and its significance. It is not designed to facilitate the vulnerability assessment of a heritage item. Critical information can be hard to find within the inventory sheet or may even be missing from the inventory sheet. Many item descriptions lack critical information, such as the type of heritage (building/landscape/archaeology), materials, setting (immediate or broader setting), heritage curtilage, archaeological potential or photographs.

5.1.4 Gaps in heritage data

Database content is not consistent or comprehensive across all sites in NSW. Many listings do not include the data needed to undertake a vulnerability assessment using all the vulnerability predictor variables identified in Section 3 of this framework.

There are some key gaps in information:

- The heritage type is not always identified (rare).
- No description or photograph is included for some sites.
- Descriptions do not always list/describe all the significant attributes of the place (e.g. house, garden, interior, archaeology, outbuildings, movable heritage).
- Materials are not necessarily included in the description (e.g. brick or timber walls, tile or metal roof). Often when the materials are included it is deep within the description or towards the end, making them hard to find.
- The physical context beyond the site boundary is very rarely identified.
- Information on use, occupancy, preventative or mitigation measures in place is not included.
- Areas of archaeological sensitivity are not mapped.
- Accurate mapping of many heritage landscapes, such as avenues of trees or large landscapes that straddle multiple sites, is lacking.
- Mapping is not nuanced to show the location of an asset within a property. This can be an issue for very large sites.

5.1.5 Minimum listing requirements for a heritage vulnerability assessment

To assess the vulnerability of historical heritage across NSW, the following data is required as a minimum:

- type of heritage;
- photograph to enable identification;
- significant attributes clearly identified in description and on a site map;
- materials of attributes clearly identified; and
- heritage curtilage.

To assist in locating critical information, it would be helpful if inventory sheets had specific data entry points for this information (e.g. list of significant attributes, construction materials).

5.2 Vulnerability predictor variables

5.2.1 Key predictor variables for assessing the vulnerability of historic cultural heritage items

Key predictor variables that could, in most cases, be identified through currently available heritage inventory data include:

- Location—name, address, and inventory item number;
- type of heritage (mostly identified);
- relationship to ground plane (may not be available—requires description and photographs);
- material composition (mostly identified—requires description and photographs);
- form (sometimes identifiable—requires description and photographs);
- immediate setting (sometimes identifiable—requires description and photographs); and
- condition (often identified, probably out of date).

Key information that is not available through the heritage databases, but may be accessed by other means, would include:

- physical context (via aerial photography, topographic and vegetation maps);
- road access (via maps); and
- APZs (via satellite imagery, local council and RFS maps).

5.2.2 Predictor variables for more detailed site-based vulnerability assessments

Predictor variables for which there is likely to be insufficient data available through publicly accessible information sources include:

- presence of hazardous materials;
- landscape setting, unless it is described as part of a significant heritage landscape;
- human presence on site—whether the place is occupied (full or part time) or unoccupied;
- capacity of the occupants to defend the place;
- barriers to emergency service access;
- maintenance regime;
- bushfire mitigation measures implemented on site; and
- history of other damaging events (e.g. storms and floods) affecting the condition of the place and its context.

This type of information would need to be sought at site level through consultation with owners and occupants. The variables would be very useful for undertaking site-specific vulnerability and risk assessments and for developing and implementing site-specific bushfire risk management plans or strategies.

5.2.3 Grouping of vulnerability predictor variables

There may be some potential for grouping vulnerability predictor variables or selecting a small number of critical variables for undertaking rapid vulnerability assessments or high-level risk assessments for heritage items distributed across large areas. For example, type of heritage and materiality are critical indicators to understanding the overall vulnerability of heritage assets. Other critical variables relate to the context in which the heritage item is located. The most reliable grouping of vulnerability predictor variables for this type of study needs to be further investigated and tested.

For preparing site-based risk assessments for heritage items, however, it is important to understand the full range of vulnerability predictor variables that make the asset/place vulnerable (as identified in this report) so that each variable can be addressed by the property owner in the development of suitable bushfire risk management strategies, thereby reducing the bushfire risk to the heritage item/property.

6 Quantifying vulnerability

6 Quantifying vulnerability

To enable the historic heritage bushfire vulnerability assessment framework to be integrated into the predictive risk modelling being undertaken by NPWS, RFS and the University of Melbourne, the qualitative assessment of vulnerability predictor variables must be converted to a quantitative one.

6.1 Converting qualitative data to quantitative

6.1.1 Limitations

To date very little independent research has been undertaken to provide accurate quantitative data that can be applied to assessing and evaluating the vulnerability of heritage assets to bushfires using the vulnerability predictor variables identified in Section 3 of this report. Nor is there research that would enable the ranking of predictor variables.

Therefore, a very simplistic approach has been adopted for this report.

It is anticipated that as more research becomes available, a more accurate numerical assessment of vulnerability will be possible.

6.1.2 Numerical values applied to qualitative rankings

A very simple approach has been adopted for allocating numerical values to the bushfire vulnerability rankings identified against each of the assessment parameters for the vulnerability predictor variables identified in Section 3 of this report.

Vulnerability ranking	Vulnerability value
Low	1
Moderate	2
High	3
Very high	4
Extreme	5

To date, the 'Extreme' vulnerability ranking has only been applied to the physical context (setting) variable for heritage items located in bushland. As more information becomes available, this may be extended to other critical vulnerability predictor variables (e.g. material composition) or points of critical failure.

6.2 Vulnerability of heritage items to fire

6.2.1 Vulnerability values applied to predictor variables for historical archaeology

The following table highlights the predictor variables identified as the most appropriate for assessing the bushfire vulnerability of historical archaeology. Each assessment parameter is allocated a vulnerability value. Predictor variables for which it is unlikely that sufficient information exists in heritage database inventory sheets, satellite imagery or other easily accessible information sources have been shaded grey. Data for these predictor variables could, however, be collected at the site level, to enable property owners or managers to assess the risks to the individual heritage item/asset. For more detail on each of the parameters identified for each predictor variable refer to Section 3 of this report.

Predictor variables for historical archaeology			
Predictor variable	**Vulnerability assessment parameters**	**Vulnerability ranking (from Section 3)**	**Vulnerability value**
Relationship to ground plane	Below ground	Low	1
	Close to surface	Moderate	2
	Above ground (<500mm high)	High	3
	Above ground(>500mm high)	Very high	4
Material composition	Masonry, stone, brick, mass concrete (no steel)	Moderate	2
	Reinforced concrete—good condition	Low	1
	Reinforced concrete—decayed/corroded	High	3
	Structural steel, cast iron, wrought iron	High	3
	Steel sheet, zincalume sheet	High	3
	Lead, copper, zinc, magnesium, aluminium alloys	Very high	4
	Terracotta	Moderate	2
	Ceramic	High	3
	Timber	Very high	4

Predictor variables for historical archaeology			
	Organic materials – paper, fabrics	Very high	4
	Synthetic materials	Very high	4
	Thin heritage glass	Very high	4
Form and construction detailing	Simple	Low	1
	Moderately simple	Moderate	2
	Moderately complex	High	3
Hazardous materials	No hazardous materials present	Low	1
	Hazardous materials in environment	Very High	4
Archaeology type and size	Substantial ruin or subsurface remains	Low	1
	Less substantial remains including industrial remains	High	3
	Small artefact	Very high	4
Immediate setting (within site boundaries)	Low fuel loads—hard surfaces, earth, sparse vegetation, away from archaeology	Low	1
	Moderate fuel loads—fire resistant vegetation, spaced apart, away from archaeology	Moderate	2
	High fuel loads—flammable vegetation, close to archaeology	High	3
	Very high fuel loads—highly flammable vegetation, woody weeds, against/over archaeology	Very high	4
Broader context	Urban setting	Low	1
	Suburban setting	Moderate	2
	Peri-urban setting	Very High	3
	Rural setting	Very high	4
	Bushland setting	Extreme	5
	Close to high-risk facilities	Very high	4
Slope and aspect	Located on flat land or bottom of a slope	Low	1

Predictor variables for historical archaeology			
	Located on gentle slope (<10°) with north-easterly to south-easterly aspect	Low	1
	Located on gentle slope (<10°) with south-westerly to southerly aspect	Moderate	2
	Located on gentle slope (<10°) with northerly to westerly aspect	High	3
	Located on steep slope (>10°) or at top of slope with north-easterly to south-easterly aspect	Moderate	2
	Located on steep slope (>10°) or at top of slope with south-westerly to southerly aspect	High	3
	Located on steep slope (>10°) or at top of slope with northerly to westerly aspect	Very high	4
Maintenance regime	Well-maintained—lawns mown, drains cleared, leaf litter and rubbish removed	Low	1
	Poorly maintained—uncut grass, woody weeds rampant, litter and rubbish left on site	Very high	4
Previous events	No previous disaster event affecting site	Low	1
	Minor impact from previous disaster event—no physical damage to heritage item	Moderate	2
	Major impact from previous disaster event—physical damage to heritage item and/or setting—burnt, eroded, debris present.	Very High	4
Recognisability (vulnerability to implementation fire protection measures rather than vulnerability to fire)	Archaeology visible, well documented	Low	1
	Archaeology partially visible, poorly documented, full extent unknown	High	3
	Archaeology invisible, but well documented	Moderate	2
	Archaeology invisible, not well documented, extent unknown	Very high	4

6.2.2 Vulnerability values applied to predictor variables for heritage landscapes

The following table highlights the predictor variables identified as the most appropriate for assessing the vulnerability of heritage landscapes. Each assessment parameter is allocated a vulnerability value. Predictor variables for which it is unlikely that sufficient information exists in heritage database inventory sheets, satellite imagery or other easily accessible information sources have been shaded grey. Data for these predictor variables could, however, be collected at the site level, to enable property owners or managers to assess the risks to the individual heritage item/asset. For more detail on each of the parameters identified for each predictor variable refer to Section 3 of this report.

Predictor variables for heritage landscapes			
Predictor variable	**Vulnerability assessment parameters**	**Vulnerability ranking (from Section 3)**	**Vulnerability value**
Vegetation type	Fire retardant plants—do not burn easily	Low	1
	Fire resilient plants—flammable, but able to recover	Moderate	2
	Flammable plants—do not fuel fire or recover	High	3
	Flammable plants—fuel fire	Very high	4
Material composition—built elements	Hard landscape elements (e.g. masonry walls, paths)	Low	1
	Mown and watered lawns	Low	1
	Water features	Low	1
	Masonry structures	Moderate	2
	Steel structures	High	3
	Timber, brush and glass structures	Very high	3
Landscape Layout	Trees spaced apart, no understorey plantings, mown lawn, hard surfaces	Low	1
	Connected groups of trees, no understorey plantings, well-separated from vulnerable attributes	Moderate	2
	Multi-layered plantings (trees, shrubs and garden beds), mulched, separated from vulnerable attributes	High	3
	Dense multi-layered plantings, close to or overhanging vulnerable attributes	Very high	4

Predictor variables for heritage landscapes			
Slope and aspect	Located on flat land or bottom of a slope	Low	1
	Located on gentle slope (<10°) with north-easterly to south-easterly aspect	Low	1
	Located on gentle slope (<10°) with south-westerly to southerly aspect	Moderate	2
	Located on gentle slope (<10°) with northerly to westerly aspect	High	3
	Located on steep slope (>10°) or at top of slope with north-easterly to south-easterly aspect	Moderate	2
	Located on steep slope (>10°) or at top of slope with south-westerly to southerly aspect	High	3
	Located on steep slope (>10°) or at top of slope with northerly to westerly aspect	Very high	4
Immediate setting (beyond site boundaries)	Low fuel loads—hard surfaces, earth, elements well separated (>50m)	Low	1
	Moderate fuel loads—open fragmented landscape, clipped hedges, walls, other barriers, separation 20m–50m from heritage landscape	Moderate	2
	High fuel loads—multilayered landscape, woody weeds, close to heritage landscape	Very High	3
Broader context	Urban setting	Low	1
	Suburban setting	Moderate	2
	Peri-urban setting	Very High	3
	Rural setting	Very high	4
	Bushland setting	Extreme	5
	Close to high risk facilities	Very high	4
Hazardous materials	No hazardous materials present	Low	1
	Hazardous materials in environment	Very High	4
Maintenance regime	Well-maintained—lawns mown, drains cleared, leaf litter and rubbish removed	Low	1
	Partially maintained— lawns mown, leaf litter on ground, weeds prevalent, trees	High	3

Predictor variables for heritage landscapes			
	and shrubs overhanging vulnerable elements not pruned		
	Poorly maintained—uncut grass, woody weeds rampant, litter and rubbish left on site	Very high	4
Previous events	No previous disaster event affecting site	Low	1
	Minor impact from previous disaster event—minor damage to heritage landscape	Moderate	2
	Major impact from previous disaster event—major damage to heritage landscape—burnt, eroded, debris present.	Very High	4
Recognisability (vulnerability to implementation fire protection measures rather than vulnerability to fire)	Boundaries of landscape well defined, significant attributes identifiable, documented and mapped	Low	1
	Landscape elements identifiable, but not clearly mapped	Moderate	2
	Boundaries of landscape merges with surrounding landscape, not well documented, attributes identifiable but not mapped	Very high	4

6.2.3 Vulnerability values applied to predictor variables for heritage structures (built heritage)

The following table highlights the predictor variables identified as the most appropriate for assessing the vulnerability of built heritage. Each assessment parameter is allocated a vulnerability value. Predictor variables for which it is unlikely that sufficient information exists in heritage database inventory sheets, satellite imagery or other easily accessible information sources have been shaded grey. Data for these predictor variables could, however, be collected at the site level, to enable property owners or managers to assess the risks to the individual heritage item/asset. For more detail on each of the parameters identified for each predictor variable refer to Section 3 of this report.

Predictor variables for heritage structures (built heritage)			
Predictor variable	**Vulnerability assessment parameters**	**Vulnerability ranking (from Section 3)**	**Vulnerability value**
Relationship to ground plane	Below ground	Low	1
	On ground	High	3

Predictor variables for heritage structures (built heritage)			
	Elevated with open subfloor or understorey	Very high	4
Material composition	Masonry, stone, brick	Moderate	2
	Reinforced concrete in good condition	Low	1
	Reinforced concrete in poor condition	High	3
	Structural steel, cast iron, wrought iron with no protection	High	3
	Steel sheet, zincalume sheet	High	3
	Lead, copper, zinc, magnesium and aluminium alloys	Very high	4
	Terracotta	Moderate	3
	Ceramic	High	3
	Lime plaster	High	3
	Gypsum	Moderate	4
	Timber	Very high	4
	Wool	Moderate	2
	Organic materials – paper, fabrics	Very high	4
	Synthetic materials	Very high	4
	Thin heritage glass	Very high	4
	Thick toughened glass	Moderate	2
	Paint – lead, acrylic	Very high	2
	Paint – intumescent	Moderate	4
	Malthoid	Very high	2
	Plastics, PVC, acrylics	Very high	4
	Fibreglass	Very high	4
	Fibrous cement sheet	Moderate	4
Built form and construction detailing	Simple form, ground hugging—no gaps or crevices, well-sealed, small number of openings, protected windows and doors, no verandahs, enclosed subfloor area.	Low	1
	Moderately simple form (rectangular plan, hipped roof)—boxed eaves, plain barge boards, sarking and leaf guard,	Moderate	2

Predictor variables for heritage structures (built heritage)			
	moderate number of window and door openings, thick glass, no dormer windows, no chimneys, no verandahs, enclosed subfloor area.		
	Moderately complex form (more complex plan, hipped roof)—boxed eaves, plain barge boards, sarking and leaf guard, moderate number of unprotected openings, no dormer windows, capped chimneys, enclosed verandah, enclosed subfloor area.	High	3
	Complex form (complex plan with complex roof form including intersecting gables), decorative barges, dormer windows, large window openings, many recesses and crevices—open eaves, gables, open subfloor areas, open verandahs, uncapped chimneys.	Very high	4
Condition	Good condition—fabric intact, no decay, loose elements or gaps	Low	1
	Moderate condition—fabric substantially intact, some decay, loose elements and gaps	High	3
	Poor condition—decayed, dilapidated, termite damage, many gaps	Very high	4
Hazardous materials	No hazardous materials present	Low	1
	Hazardous materials in environment—soils	Moderate	2
	Hazardous materials stored on site—chemicals, paints, glues	Very high	4
	Hazardous materials within heritage item—structure or furnishings	Very High	4
Immediate setting (within site boundary)	Low fuel loads—Surrounded by hard surfaces, fire resistant vegetation, scattered trees >50 m from heritage item	Low	1
	Moderate fuel loads—fragmented open landscape—trees spaced apart, open grassland, no understorey plantings, clipped hedges—vegetation >20 m from heritage item	Moderate	2

Predictor variables for heritage structures (built heritage)			
	High fuel loads—vegetation and vulnerable structures 10–20 m from heritage item	High	3
	Very high fuel loads—Trees overhanging structures, garden beds / woody weeds against structures	Very high	4
Slope and aspect	Located on flat land or at the bottom of a slope	Low	1
	Located on gentle slope (<10°) with north-easterly to south-easterly aspect	Low	1
	Located on gentle slope (<10°) with south-westerly to southerly aspect	Moderate	2
	Located on gentle slope (<10°) with northerly to westerly aspect	High	3
	Located on steep slope (>10°) or at top of slope with north-easterly to south-easterly aspect	Moderate	2
	Located on steep slope (>10°) or at top of slope with south-westerly to southerly aspect	High	3
	Located on steep slope (>10°) or at top of slope with northerly to westerly aspect	Very high	4
Broader context	Urban setting	Low	1
	Suburban setting	Moderate	2
	Peri-urban setting	High	3
	Rural setting	Very high	4
	Bushland setting	Extreme	5
	Close to high-risk facilities	Very High	4
Recognisability (vulnerability to implementation fire protection measures rather than vulnerability to fire)	Recognisable—Attributes known, well documented, photographed and mapped	Low	1
	Difficult to recognise—Attributes visible, but not clearly recognisable as significant, poorly recorded through inventory data, photographs or mapping	High	3
	Extent of heritage item unknown, boundaries unclear—large complex sites	Very high	4

Predictor variables for heritage structures (built heritage)			
	Not recognisable—not identified, mapped or documented	Very high	4
Maintenance regime	Well-maintained—gutters and drains cleared of leaves, lawn mown, rubbish removed from grounds, building repairs undertaken when needed	Low	1
	Moderately well maintained—gutters and drains cleared, lawn mown, rubbish removed from grounds, building repairs not completed when needed	Moderate	2
	Partially maintained—gutters and drains not cleared regularly, overhanging branches not pruned, fuel sources left on site and not safely isolated, building not repaired as needed	High	3
	Poorly maintained—gutters and drains not cleared, lawn not mown, rubbish and fuel sources left around heritage item, building elements not repaired	Very high	4
Human presence	Occupied most of the time	Low	1
	Occupied part of the time (most weekends)	Moderate	2
	Occupied part of the time (holidays only)	High	3
	Unoccupied	Very high	4
Human capacity to defend	Well-trained, practiced, prepared and equipped with quality personal protection, adequate firefighting resources and backup power and water	Low	1
	Well-trained, practiced, prepared and equipped (with personal protection, adequate firefighting resources), but limited backup water and power	Moderate	2
	Well-equipped, but not well-trained or practiced in use of equipment, and no backup water and power Well-trained, but not practiced and not well equipped	High	3
	Not trained and not equipped	Very High	4
Road access	Easily accessible by emergency services—more than one sealed road;	Low	1

Predictor variables for heritage structures (built heritage)			
	no obstacle to site entry or area around heritage item		
	Moderately accessible—at least one sealed road; access to site unhindered	Moderate	2
	Difficult access—dirt track; locked gates and other obstacles	High	3
	No access by road	Very high	4
Defendable space	Unobstructed area around heritage item greater than 20 m in radius, no barriers to entry for emergency vehicles, access to all sides of heritage item	Low	1
	Unobstructed area around heritage item between 10 and 20 m in radius, no barriers to entry for emergency vehicles, access to all sides of heritage item	Moderate	2
	Limited defendable space around the heritage item, restricted access to site and some sides of heritage item	High	3
	No defendable space, no access	Very high	4
Site specific bushfire risk management plan (BFRMP)	BFRMP developed, fully implemented, tested and regularly reviewed and updated as necessary	Low	1
	BFRMP developed and implemented, but not tested or regularly reviewed and updated	Moderate	2
	BFRMP developed but not fully implemented, tested or reviewed	High	3
	No BFRMP	Very High	4
Asset protection zone	Well-maintained APZ that meets code requirements	Low	1
	Poorly maintained APZ	High	3
	No APZ, no defendable space, no access	Very high	4
Bushfire protection measures—physical interventions	Full suite of permanent bushfire protection measures installed on built heritage items (e.g. gutter guards, ember mesh, seals to openings, fire shutters or screens over windows, roof sarking, fire rated construction	Moderate	1

Predictor variables for heritage structures (built heritage)			
	Some bushfire protection measures installed (e.g. gutter guards and ember mesh, but no fire shutters or screens). Eaves and ceilings are not fire rated.	High	3
	Temporary bushfire protection measures implemented on buildings (e.g. foil wrapping)	High	3
	No protection measures present	Very high	4
Bushfire protection measures—Active firefighting systems installed	Active firefighting systems installed (e.g. drenchers, sprinklers, fire hydrants and hoses) with independent and backup power and water supplies	Low	1
	Active firefighting systems installed (e.g. drenchers, sprinklers, fire hydrants and hoses) with independent power and water supplies, but no back up	Moderate	2
	Active firefighting systems installed, but with no independent water and/or power supply	High	3
	No active firefighting systems installed	Very high	4

6.2.4 Vulnerability values applied to predictor variables for historic interiors and indoor collections

The following table highlights the predictor variables identified as the most appropriate for assessing the vulnerability of historic interiors and collections. Each assessment parameter is allocated a vulnerability value. Predictor variables for which it is unlikely that sufficient information exists in heritage databases have been shaded grey. Data for these predictor variables could, however, be collected at the site level, to enable property owners or managers to assess the risks to the individual heritage item/asset.

For interiors and collections, if the structure that contains them fails, the interiors and collections are likely to be lost as well. Therefore, it is important that an interior or collection is assessed within the context of what is housing it. Reference should be made to predictor variables for heritage structures (built heritage) in Section 6.2.3. It is also possible for interiors and collections housed within buildings to be damaged even if the structure is not, especially where smoke and ash can enter the building through cracks in the building's envelope, or by water used to protect the building.

The predictor variables below relate to furnishings and collections housed or stored within buildings.

Predictor variables for historic interiors and collections			
Predictor variable	**Vulnerability assessment parameters**	**Vulnerability ranking (from Section 3)**	**Vulnerability value**
Structure containing historic interior/ collection (refer to Table in Section 6.2.3)	Fire resistant, gaps sealed	Low	1
	Non-fire resistant, but with protection measures in place, gaps sealed	Moderate	2
	Non-fire resistant, but with some protection measures in place, gaps not sealed	High	3
	Non-fire resistant, poorly maintained, with no protection, gaps in building envelope	Very High	4
Material composition	Masonry, stone, brick	Moderate	2
	Reinforced concrete in good condition	Low	1
	Reinforced concrete in poor condition	High	3
	Structural steel, cast iron, wrought iron with no protection	High	3
	Steel sheet, zincalume sheet	High	3
	Lead, copper, zinc, magnesium and aluminium alloys	Very high	4
	Terracotta	Moderate	2
	Ceramic	High	3
	Lime plaster	High	3
	Gypsum	Moderate	2
	Timber	Very high	4
	Wool	Moderate	2
	Organic materials – paper, silk, cotton, linen, hessian, etc	Very high	4
	Synthetic materials, resin	Very high	4
	Thin heritage glass	Very high	4
	Thick toughened glass	Moderate	2
	Paint – lead, acrylic	Very high	4
	Paint – intumescent	Moderate	2

Predictor variables for historic interiors and collections			
	Malthoid	Very high	4
	Plastics, PVC, acrylics	Very high	4
	Fibreglass	Very high	4
	Fibrous cement sheet	Moderate	2
Hazardous materials	No hazardous materials present	Low	1
	Hazardous materials present in heritage item—e.g. synthetic furnishing fabrics, cleaning products, paints, glues	Very high	4
	Hazardous materials built into structure housing heritage item—e.g. asbestos, lead, preservatives, glues, paints, dyes and fabrics that release toxic gases and fibres	Very high	4

6.2.5 Vulnerability values applied to predictor variables for outdoor movable heritage

The following table highlights the predictor variables identified as the most appropriate for assessing the vulnerability of outdoor movable heritage, including machinery. Each assessment parameter is allocated a vulnerability value. Predictor variables for which it is unlikely that sufficient information exists in heritage databases have been shaded grey. Data for these predictor variables could, however, be collected at the site level, to enable property owners or managers to assess the risks to the individual heritage item/asset.

Predictor variables for heritage structures (built heritage)			
Predictor variable	**Vulnerability assessment parameters**	**Vulnerability ranking (from Section 3)**	**Vulnerability value**
Relationship to ground plane	Below ground	Low	1
	Above ground	High	3
	Elevated above ground	Very high	4
Material composition	Masonry, stone, brick, mass concrete (no steel reinforcement)	Moderate	2
	Reinforced concrete in good condition	Low	1
	Reinforced concrete in poor condition	High	3
	Structural steel, cast iron, wrought iron with no protection	High	3

Predictor variables for heritage structures (built heritage)			
	Steel sheet, zincalume sheet	High	3
	Lead, copper, zinc, magnesium and aluminium alloys	Very high	4
	Terracotta	Moderate	2
	Ceramic	High	3
	Lime plaster	High	3
	Gypsum	Moderate	2
	Timber	Very high	4
	Wool	Moderate	2
	Organic materials – paper, silk, cotton, linen, hessian, etc	Very high	4
	Synthetic materials	Very high	4
	Thin heritage glass	Very high	4
	Thick toughened glass	Moderate	2
	Paint – lead, acrylic	Very high	4
	Paint - intumescent	Moderate	2
	Malthoid	Very high	4
	Plastics, PVC, acrylics	Very high	4
	Fibreglass	Very high	4
	Fibrous cement sheet	Moderate	2
	Asbestos	Very high	4
Form and Detail	Simple, ground hugging, no openings/crevices	Low–moderate	2
	Complex—many components, angles and crevices	Very high	4
Hazardous materials	No hazardous materials present	Low	1
	Hazardous materials in environment—e.g. soils contaminated by industrial waste	Very high	4
	Hazardous materials built into heritage item—e.g. asbestos, lead, preservatives,	Very high	4

Predictor variables for heritage structures (built heritage)			
	glues, paints, dyes and fabrics that release toxic gases and fibres		
Immediate setting (within site boundary)	**Low fuel loads** Surrounded by hard surfaces, water	Low	1
	Moderate fuel loads Surrounding by well-maintained open landscape—trees spaced apart, broken by hard non-flammable surfaces, walls and other barriers such as tightly clipped hedges	Moderate	2
	High fuel loads Surrounded by vulnerable structures, including combustible fences and sheds, located 10–20 m from the heritage item. Tree canopies are more than 10m from the heritage item. Plants are not growing on or against the heritage item (>10 m separation).	High	3
	Very High fuel loads Surrounded by dense multi-layered vegetation, leaf litter/mulch on ground, tall uncut grass/weeds and other flammable elements	Very high	4
Slope and aspect	Located on flat land or at the bottom of a slope	Low	1
	Located on gentle slope (<10°) with north-easterly to south-easterly aspect	Low	1
	Located on gentle slope (<10°) with south-westerly to southerly aspect	Moderate	2
	Located on gentle slope (<10°) with northerly to westerly aspect	High	3
	Located on steep slope (>10°) or at top of slope with north-easterly to south-easterly aspect	Moderate	2
	Located on steep slope (>10°) or at top of slope with south-westerly to southerly aspect	High	3
	Located on steep slope (>10°) or at top of slope with northerly to westerly aspect	Very high	4

Predictor variables for heritage structures (built heritage)			
Broader context	Urban setting	Low	1
	Suburban setting	Moderate	2
	Peri-urban setting	High	3
	Rural setting	Very high	4
	Bushland setting	Very high	4
	Located within 500m of high-risk facilities	Very High	4
Maintenance regime	Well-maintained: lawns mown, trees pruned, litter removed, no overhanging branches, no fuel sources present.	Low	1
	Partially maintained: lawns mown, litter removed. Overhanging branches not pruned.	High	3
	Not well maintained: lawn not mown, rubbish and other fuel sources not removed from site.	Very High	4
Damage from previous disaster events	No previous disaster event affecting site.	Low	1
	Minor impact from previous disaster event: minor damage to heritage item and/or setting.	Moderate	2
	Major impact from previous disaster event on item and/or setting: burnt, eroded, debris present.	Very High	4
Recognisability from documentation	Items are clearly visible and identifiable, well-documented, photographed and mapped	Low	1
	Items are visible, but not identified as heritage, photographed and mapped	High	3
	Items are not visible, not documented and mapped	Very high	4

6.3 Calculating vulnerability

For this bushfire vulnerability assessment framework, a very simple approach has been adopted for calculating the vulnerability of heritage assets or items.

The vulnerability of a heritage asset or item is calculated as an average of the sum of several predictor variables as shown in the following equation.

Vulnerability score of heritage asset = sum of vulnerability values for predictor variables / number of predictor variables

The larger the vulnerability score, the higher the level of vulnerability. For the following examples, the following vulnerability levels are used.

Vulnerability score	Overall level of vulnerability
1–<1.5	Low
1.5–<2.5	Moderate
2.5–<3.5	High
3.5–<4.5	Very high
4.5–>4.5	Extreme

Several examples using this method of calculating vulnerability are provided below. These include examples for historical archaeology, built heritage, heritage landscapes and outdoor movable heritage. Only a small range of variables have been selected for the following examples, but this could be expanded. The examples are not exhaustive, but rather selected to illustrate the methodology adopted for calculating vulnerability.

6.3.1 Example 1: Historical archaeology

Vulnerability of an item of historical archaeology can be calculated as the sum of the vulnerability values identified for each of the predictor variables that are relevant to that type of heritage asset (e.g. location in relation to ground plane + material + form + setting) divided by the number of predictor variables used for the calculation.

a) **Bushfire vulnerability of a stone ruin in a bushland setting** may be calculated using the following predictor variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Location in relation to ground plane	Above ground	High	3
Material composition	Stone	Moderate	2
Form	Simple	Low	1
Size/Type of archaeology	Structural ruin	Low	1
Setting	Bushland	Extreme	5
Total			**12**

Bushfire vulnerability score of the stone ruin

$$= \frac{3 + 2 + 1 + 1 + 5}{5} = \mathbf{2.4}$$

Using the vulnerability score table included at the beginning of section 6.3, the stone ruin would be assessed as having a **moderate** level of bushfire vulnerability.

b) **Bushfire vulnerability of the stone ruin to mitigation measures** that may be implemented during a fire (e.g. creation of fire breaks) includes a variable for recognisability.

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Location in relation to ground plane	Above ground	High	3
Material composition	Stone	Moderate	2
Form	Simple	Low	1
Size/Type of archaeology	Structural ruin	Low	1
Setting	Bushland	Extreme	5
Recognisability	Visible and well documented	Low	1
Total			**13**

Bushfire vulnerability score of stone ruin to bushfire mitigation measures (including variable for recognisability) $= \frac{3 + 2 + 1 + 5 + 1 + 1}{6} = \mathbf{2.17}$

From the vulnerability score table in section 6.3, the stone ruin would also be assessed as having a **moderate** level of vulnerability to mitigation measures implemented during a bushfire.

c) **Bushfire vulnerability of buried artefacts in the same setting** as the stone ruin may be calculated using the following predictor variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Location in relation to ground plane	Below ground (close to surface)	Moderate	2
Material composition	Ceramics and glass	High to very high	3-4 (use higher number)
Form	Simple	Low	1

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Size/Type of archaeology	Small artefacts	High	3
Setting	Bushland	Very high	5
Total			**15**

Bushfire vulnerability score of buried artefacts = $\frac{2 + 4 + 1 + 3 + 5}{5}$ = **3**

The small artefacts would be assessed as having a **high** level of vulnerability to bushfire.

d) **Vulnerability of the same artefacts to mitigation measures** undertaken prior to or during a fire would be calculated including a predictor variable for recognisability:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Location in relation to ground plane	Below ground (<500 mm)	Moderate	2
Material composition	Ceramics and glass	Very high	4
Form	Simple	Low	1
Size/type of archaeology	Small artefacts	High	3
Setting	Bushland	Extreme	5
Recognisability	Invisible and not documented	Very high	4
Total			**19**

Vulnerability score of buried artefacts to mitigation measures

$$= \frac{2 + 4 + 1 + 3 + 5 + 4}{6} = \mathbf{3.1}$$

The vulnerability of the small artefacts to bushfire mitigation measures would also be assessed as **high**, as the artefacts are not visible to those implementing the mitigation measures.

6.3.2 Example 2: Built heritage

e) Using the same methodology, **bushfire vulnerability of a well-maintained and occupied brick house** with timber-framed tiled roof and complex detailing **in a peri-urban area** with no protection measures in place may be calculated using the following predictor variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Location in relation to ground plane	Above ground	High	3
Material composition	Brick	Moderate	2
Built form + envelope detail	Complex	Very high	4
Setting	Peri-urban	Very high	4
Occupancy	Fully occupied	Low	1
Protection measures	None	Very high	4
Maintenance level	Well-maintained	Low	1
Total			**19**

Bushfire vulnerability score of brick house = $\frac{3 + 2 + 4 + 4 + 1 + 4 + 1}{7}$ = **2.71**

The bushfire vulnerability of the brick house in a peri-urban setting is assessed as **high**.

If occupancy, protection measures and maintenance level are unknown, the calculation may be as follows (these parameters are removed from the calculation):

Bushfire vulnerability score of brick house (calculated with limited variables)

$$= \frac{3 + 2 + 4 + 4}{4} = \mathbf{3.25}$$

The bushfire vulnerability score for the brick house would increase, but the vulnerability of the house would continue to be assessed as **high**.

Alternatively, by allocating the highest level of vulnerability to each of the unknown parameters (shaded grey), the calculation would be as follows:

Bushfire vulnerability score of brick house

$$= \frac{3 + 2 + 4 + 4 + 4 + 4 + 4}{7} = \mathbf{3.57}$$

The bushfire vulnerability of the brick house would be assessed as **very high**.

f) **Bushfire vulnerability of a timber house** in similar circumstances to the brick house would be calculated using the following predictor variables (assuming all are known):

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Location in relation to ground plane	Above ground	High	3
Material composition	Timber	Very high	4
Built form + envelope detail	Complex	Very high	4
Setting	Peri-urban	Very High	4
Occupancy	Fully occupied	Low	1
Protection measures	None	Very high	4
Maintenance level	Well-maintained	Low	1
Total			**21**

Bushfire vulnerability score of a well-maintained timber house in a peri-urban setting, assuming all variables are known,

$$= \frac{3 + 4 + 4 + 4 + 1 + 4 + 1}{7} = \mathbf{3}$$

The bushfire vulnerability of the well-maintained timber house in a peri-urban area would be higher than the brick house but would still be assessed as **high** (refer to bushfire vulnerability score table at the beginning of section 6.3).

Following example (e) above, where information is only available for a limited range variables (ie. occupancy, protection measures and maintenance levels are unknown and omitted from the calculation), the vulnerability score of the timber house

$$= \frac{3 + 4 + 4 + 4}{4} = \mathbf{3.75}$$

The bushfire vulnerability of a timber house in a peri-urban area, where predictor variables are unknown, is now assessed as **very high**.

If the highest vulnerability rankings are applied to each of the unknown variables, the vulnerability score of the same house

$$= \frac{3 + 4 + 4 + 4 + 4 + 4 + 4}{7} = \mathbf{3.86}$$

The bushfire vulnerability of a timber house increases and continues to be assessed as **very high.**

g) **Vulnerability of a poorly maintained timber house**, similar to that in example (f), but **in a bushland setting** and only occupied intermittently (e.g. weekends or holidays) would be calculated using the following predictor variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Location in relation to ground plane	Above ground	High	3
Material composition	Timber	Very high	4
Built form + envelope detail	Complex	Very high	4
Setting	Bushland	Extreme	5
Occupancy	Occupied sometimes	High	3
Protection measures	None	Very high	4
Maintenance level	Not well-maintained	High	3
Total			**26**

Vulnerability score of the unmaintained timber house in bushland

$$= \frac{3 + 4 + 4 + 5 + 3 + 4 + 3}{7} = \mathbf{3.71}$$

The bushfire vulnerability of a timber house in a bushland setting which is only occupied intermittently is assessed as **very high**.

6.3.3 Example 3: Heritage landscape

h) Using the same methodology, the **bushfire vulnerability of a public park** with mown lawns, deciduous and evergreen trees and shrubberies, **in an urban setting** may be calculated using the following predictor variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Material composition	Flammable plants—do not fuel fire or recover	High	3
Layout	Trees spaced apart, no understorey plantings, lawn or hard surfaces	Low	1
Immediate setting (beyond site boundaries)	Low fuel loads—hard surfaces	Low	1
Broader context	Urban setting	Low	1

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Recognisability	Attributes and extent of landscape known, photographed and mapped	Low	1
Maintenance regime	Well-maintained: lawns mown, drains cleared, leaf litter and rubbish removed	Low	1
Total			**8**

Bushfire vulnerability score of public park in an urban area is calculated as

$$= \frac{3 + 1 + 1 + 1 + 1 + 1}{6} = \mathbf{1.33}$$

The bushfire vulnerability of the public park is assessed as **low.**

i) **The bushfire vulnerability of a well-maintained garden** with mown lawns, deciduous and evergreen trees and shrubberies, **in a peri-urban setting** on the edge of bushland may be calculated using the following predictor variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Material composition	Flammable plants—do not fuel fire or recover	High	3
Layout	Multi-layered plantings (trees, shrubs and garden beds), mulched	High	3
Immediate setting	High fuel loads—flammable trees and shrubs within 10-20m of heritage landscape boundaries	High	3
Broader context	Peri-urban / bushland setting	Very high–Extreme	4-5 (use higher)
Recognisability	Attributes and extent of landscape visible and known, photographed and mapped	Low	1
Maintenance regime	Well-maintained: lawns mown, drains cleared, leaf litter and rubbish removed	Low	1
Total			**16**

Bushfire vulnerability score of a well-maintained garden in a peri-urban/bushland setting is calculated as

$$= \frac{3 + 3 + 3 + 5 + 1 + 1}{6} = \mathbf{2.67}$$

The bushfire vulnerability of the garden is assessed as **high.**

j) **The bushfire vulnerability of a memorial avenue of trees in a rural setting** may be calculated using the following predictor variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Vegetation type	Flammable plants—do not fuel fire or recover	High	3
Layout	Trees spaced 10-20 m apart	High	3
Immediate setting	Very high fuel loads—woody weeds and grasses around trees	Very high	4
Broader context	Rural setting—grasslands	High	3
Recognisability	Attributes and extent of landscape not obvious, well documented or mapped	Very high	4
Maintenance regime	Poorly maintained—uncut grass, weeds rampant, litter and rubbish left on site	Very high	4
Total			**21**

Bushfire vulnerability score of a memorial avenue of trees in a rural setting that is not well-maintained is calculated as

$$= \frac{3 + 3 + 4 + 3 + 4 + 4}{6} = \mathbf{3.5}$$

The bushfire vulnerability of the memorial avenue of trees is assessed as **very high.**

k) **The bushfire vulnerability of an historic urban landscape in a rural setting** (e.g. country town) may be calculated using the following variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Material composition	Timber, brick, trees Hard surfaces	Low–Very high	4 (use highest vulnerability value)

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Layout	Buildings close together (<10 m apart) Trees spaced 10-20 m apart	Very high High	3–4 (use highest value)
Immediate setting (beyond site boundaries)	Low – high fuel loads—hard surfaces, grass and gardens	Low–High	1–3 (use highest value)
Broader context	Peri-urban, surrounded by rural	Very high	4
Recognisability	Known and recognisable	Low	1
Maintenance regime	Variable (sheds, equipment, wood piles in rear yards)	Low–Very high	1–4 (use highest value)
Total			**20**

Bushfire vulnerability score for an historic urban landscape of a country town in a rural setting is calculated as

$$= \frac{4 + 4 + 3 + 4 + 1 + 4}{6} = \mathbf{3.33}$$

The bushfire vulnerability of an historic urban landscape of a country town is assessed as **high.**

6.3.4 Example 4: Movable heritage

l) Using the same methodology, the **bushfire vulnerability of movable heritage** (e.g. historic farm equipment) **in a rural setting** may be calculated using the following predictor variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Material composition	Steel Timber	High Very high	3 4
Immediate setting	Very high fuel loads—woody weeds and grasses	Very high	4
Broader context	Rural—grasslands	Very high	4
Recognisability	Hidden and not well documented or mapped	Very high	4
Maintenance regime	Very poor	Very high	4

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Total			**20**

Bushfire vulnerability score of farm equipment in a rural setting is calculated as

$$= \frac{4 + 4 + 4 + 4 + 4}{5} = \mathbf{4.8}$$

The bushfire vulnerability of the farm equipment is assessed as **extreme.**

m) **The bushfire vulnerability of movable heritage** (e.g. mining equipment or historic rail rolling stock) **in a bushland setting** may be calculated using the following predictor variables:

Predictor variable	Assessment parameter	Vulnerability ranking	Vulnerability value
Material composition	Steel	High	3
Immediate setting	Very high fuel loads—woody weeds and grasses	Very high	4
Broader context	Bushland	Extreme	5
Recognisability	Hidden and not well documented or mapped	Very high	4
Maintenance regime	Very poor	Very high	4
Total			**20**

Bushfire vulnerability score of mining equipment in a bushland setting is calculated as

$$= \frac{3 + 4 + 5 + 4 + 4}{5} = \mathbf{4.8}$$

The bushfire vulnerability of the mining equipment is also assessed as **extreme.**

6.3.5 Weighting of variables

To provide a more accurate assessment of vulnerability, some predictor variables (those that will have the greatest influence on the vulnerability of the heritage item) may be given greater weight.

For example, variables such as material composition, may be given a higher weighting than all other variables. This may be achieved by increasing the vulnerability ranking for the variable by a factor of 2.

6.3.6 Example 5: Increased weighting given to materiality

In the following examples, the predictor variable of material composition is weighted by a factor of 2.

n) The following examples are adapted from examples (e) and (f) in 6.3.2.

The bushfire vulnerability of a fully occupied and well-maintained brick house with timber-framed tiled roof and complex detailing in a peri-urban setting with no protection measures in place is calculated with a weighting given to material composition:

Bushfire vulnerability score for brick house without weighting of predictor variable for material composition (example (e) equation)

$$= \frac{3 + 2 + 4 + 4 + 1 + 4 + 1}{7} = \mathbf{2.71}$$

Vulnerability of brick house with weighting given to material composition predictor variable

$$= \frac{3 + \mathbf{2x2} + 4 + 4 + 1 + 4 + 1}{7} = \mathbf{3}$$

The vulnerability of the brick house in the peri-urban setting in both cases is assessed as **high,** but the vulnerability score has increased with the weighting of the predictor variable for composition.

Bushfire vulnerability score of a well-maintained timber house in the same circumstances and same peri-urban setting (example (f) equation)

$$= \frac{3 + 4 + 4 + 4 + 1 + 4 + 1}{7} = \mathbf{3}$$

Vulnerability of timber house with weighting given to material composition predictor variable

$$= \frac{3 + \mathbf{4x2} + 4 + 4 + 1 + 4 + 1}{7} = \mathbf{3.57}$$

By weighting the predictor variable for material composition, the assessed vulnerability of the timber house has increased from **high** to **very high**. It also provides greater differentiation between the vulnerability of the brick house and the vulnerability of the timber house.

A range of variables may be considered for prioritisation or weighting with prioritisation given to the weakest components. Examples would include material composition and vegetation/vulnerable elements in immediate setting (relevant to all types of heritage), critical points of failure (particularly relevant to built heritage) and landscape layout (for heritage landscapes).

6.3.7 Predictor variables for prioritisation

Feedback from subject matter experts identified the following predictor variables as those most critical to assessing the vulnerability of different types of heritage. Consideration may be given to giving these predictor variables more weight when calculating the overall vulnerability of a heritage item.

Heritage type	Historical archaeology	Built heritage	Heritage landscape	Movable heritage
Critical variables	Material composition	Material composition	Vegetation type	Material composition
	Relationship to the ground plane	Critical points of failure (built form and detail)	Landscape layout	Immediate setting
	Immediate setting	Immediate setting	Immediate setting	Broader context

Some predictor variables, such as slope and aspect, are also critical, but are likely to form part of the hazard exposure assessment used for risk modelling. Even though these variables may not be used for vulnerability assessment, it is important that property owners understand how they contribute to the bushfire risk to their heritage items.

6.3.8 Lack of data

The effectiveness of the bushfire vulnerability assessment is dependent on data being available. It may not be possible to assess some critical predictor variables due to a lack of available information in readily available sources (i.e. heritage databases). In this case, the highest vulnerability ranking/value anticipated for the missing variable for the particular heritage type should be allocated. For example, if the immediate setting is unknown, then it could be assumed that the setting is flammable with a very high vulnerability ranking. This is illustrated in examples (e) and (f).

6.4 Vulnerability assessment for inclusion in risk modelling

6.4.1 Core predictor variables for vulnerability assessment

The predictor variables that can be used to calculate bushfire vulnerability for risk modelling purposes are constrained by the information available in existing heritage databases. Taking into consideration the critical variables identified by subject matter experts (section 6.3.7) and the information available in heritage databases, the predictor variables that could currently be used for determining the bushfire vulnerability of heritage items would include:

- **type of heritage**;
- **relationship to ground plane** (below, above, elevated above ground);
- **material composition** (the composition of the external shell of the item—structure, archaeology or movable heritage; vegetation type for heritage landscape);
- **form** (complexity of form and detail; type/layout for heritage landscape).
- **layout** (heritage landscapes and large complex sites)

This core group of predictor variables could be extended, if data is available through other publicly accessible sources such as satellite imagery and maps, to include the following:

- **context** (from satellite imagery and maps); and
- **access** (from maps).

6.4.2 Missing data

Information on the full range of predictor variables affecting the vulnerability of heritage items/assets (e.g. critical points of failure, condition, maintenance, occupation, fire protection measures in place) will in many cases be very difficult to obtain from heritage inventory sheets, databases or maps. Consequently, these variables cannot currently be used for calculating bushfire vulnerability for risk modelling purposes. As more detailed information becomes available, these predictor variables could be added to the calculations.

Although not available for current bushfire vulnerability calculations and risk modelling, this type of data would be very useful for property owners and managers undertaking detailed risk assessments for individual heritage properties/items to enable the development of site-specific bushfire risk management strategies/plans.

6.4.3 Grouping of variables

More research and testing needs to be undertaken to determine how heritage items/assets and predictor variables may be grouped or aggregated to simplify the bushfire vulnerability assessment process and risk modelling.

However, the full range of predictor variables should be retained for the preparation of more detailed vulnerability assessments for individual heritage items. This would enable the development of site-based bushfire mitigation measures to address specific issues or weaknesses and to improve the bushfire resilience of the heritage items.

6.4.4 Cultural heritage risk

The risk to cultural heritage assets is divided into Aboriginal cultural heritage assets and historic heritage assets. The Aboriginal cultural heritage assets are also divided into known sites and predicted sites.

6.5 Significance

Significance is not identified as an attribute contributing to vulnerability. Most heritage assets are vulnerable to bushfire to varying degrees and need protection. Their level of significance does not alter their level of vulnerability.

An item's level of significance may be used to establish priorities in determining the level of protection that is given. For example, an item of World Heritage significance may be given a higher level of protection than an item of local significance. It is noted, however, that a local heritage item can be as important to a local community and its recovery as a state, national or World Heritage item.

7 Next steps

7 Next steps

This report, which completes stages 1 and 2 in developing a BFVAF for historic heritage in NSW, identifies predictor variables for use in assessing the vulnerability of historic heritage to bushfires and the mitigation measures adopted by the RFS, NPWS, councils and property owners to minimise risk and the disastrous impacts of bushfires on the state's natural and cultural heritage assets.

The variables identified in this report have been reviewed by subject matter experts, but still need to be tested prior to their adoption for incorporation in bushfire risk modelling currently being undertaken by NPWS, RFS and the University of Melbourne.

This report also identifies gaps in critical information and highlights the types of data that could still be gathered to ensure that the BFVAF adequately assesses the vulnerability of the state's historic heritage, to enable its integration into risk modelling and BFRMPs prepared by local BFMCs.

The following tasks/actions are recommended.

7.1 Immediate—short term (12 months)

- Review the range of predictor variables identified with subject matter experts, the parameters used for each variable to assess the vulnerability of different types of heritage, and the proposed method of calculating vulnerability.
- Review and analyse post fire impact data gathered by RFS, Bushfire and Natural Hazards Cooperative Research Centre, NSW NPWS and Public Works Advisory on heritage losses and damage.
- Through a pilot study, use the existing heritage data to test the viability of the draft BFVAF for historic heritage. The study should include all types of historic heritage and heritage identified as being of local, state, national and world heritage significance.
- The study should enable:
  - Confirmation of the most appropriate predictor variables to be used in bushfire vulnerability calculations for heritage.
  - Confirmation of whether specific variables should be ranked/prioritised?
  - Confirmation of the range of variables (based on available heritage data) that can be used now for calculating bushfire vulnerability to enable heritage to be included in bushfire risk modelling.
  - Confirmation of whether the available data is adequate for a full bushfire vulnerability assessment of historic heritage assets/items to be undertaken.
  - Identification of critical data that still needs to be gathered.

- Confirmation of the approach to be taken where data is not available.

- Discuss the potential for updating inventory sheets with NSW Environment and Heritage.
- Develop entry data points/categories for critical information to be entered into inventory sheets, e.g. materials.

7.2 Medium term (2 years)

- Update the SHI database to include the data entry points identified so that the critical information needed to undertake a bushfire vulnerability assessment of a heritage item can be added.
- Identify other sources for gathering critical information where there are gaps in the heritage data (such as local sources, field investigations, ground-truthing).
- Following completion of the pilot study, review and update the draft BFVAF for historic heritage, including the range of predictor variables used and the methods used for calculating vulnerability.
- Develop a range of functional groups of assets and variables that can be used to simplify the BFVAF for historic heritage.
- Retest the BFVAF using the functional groups.
- Integrate the vulnerability data into the bushfire risk modelling being undertaken by University of Melbourne, RFS and NPWS.
- Request RFS to review BFVAF and risk modelling for historic heritage to ensure it works for the RFS and meets its needs.
- Refine the predictor variables and the BFVAF.
- Develop a rapid bushfire vulnerability assessment tool for historic heritage that will enable its integration into bushfire risk modelling.
- Integrate historic heritage into BFRMPs prepared by local BFMCs.
- Build awareness of issues for historic heritage among BFMCs.
- Review the current household bushfire assessment tool and its potential adaptation to heritage.

7.3 Long term (5 years)

- Update BFRMPs as more information becomes available.
- Work with industry groups to develop bushfire risk management guidelines for historic heritage.
- BFMCs to build community awareness of risks to heritage and the mitigation measures required to reduce the risk.

- Adapt the rapid bushfire vulnerability assessment tool for historic heritage to enable property owners and managers to better understand and respond to the vulnerabilities of their heritage assets and develop appropriate risk mitigation strategies.

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8 Appendices

8 Appendices

Appendix A

Material Vulnerability—Identifying Bushfire Risks to Historic Heritage and Risk Management Options

Appendix A: Material Vulnerability

Material	Vulnerability to flame	Vulnerability to heat	Vulnerability to smoke	Vulnerability to ash	Vulnerability ranking
Stonework	Non-flammable	Extreme heat can cause change in colour, crazing, exfoliation of surface, factures	Staining	Staining, surface decay, crust on surface	Moderate
Brickwork	Non-Flammable	Extreme heat can cause change in colour, dehydration of mortar and loss of mortar strength, fractures	Staining	Staining, surface decay, crust formation on surface	Moderate
Earth – adobe, pise	Non-flammable	Extreme heat can cause dehydration of earth and loss of strength, fractures, discolouration	Staining	Staining, surface decay, crust formation on surface	High
Mass concrete	Non-flammable	Extreme heat can cause fractures	Staining	Saining, surface decay, crust formation on surface	Low
Reinforced concrete – good condition, adequate cover to steel reinforcement	Non-flammable	Extreme heat can cause surface damage	Staining	Staining, surface decay, crust formation on surface	Low
Reinforced concrete – poor condition, lacks cover to steel reinforcement	Non-flammable	Extreme heat can cause expansion of steel reinforcement and fracturing of concrete	Staining	Staining, surface decay, crust formation on surface	High

Material	Vulnerability to flame	Vulnerability to heat	Vulnerability to smoke	Vulnerability to ash	Vulnerability ranking
Structural steel – exposed	Non-flammable	Extreme heat can cause loss of strength and buckling		Corrosion, crust formation on surface	High
Cast Iron	Non-flammable	Extreme heat causes thermal cracks, fractures, loss of strength and deformation		Corrosion, crust formation on surface	High
Wrought Iron	Non-flammable	Extreme heat causes thermal cracks, fractures, loss of strength and deformation		Corrosion, crust formation on surface	High
Galvanized steel sheet	Non-flammable	Heat can cause loss of strength and buckling	Staining	Corrosion, crust formation on surface	High
Colourbond steel sheet	Non-flammable	Heat can cause loss of strength and buckling, crazing of bonded finish, discolouration	Staining	Surface decay of bonded finish, corrosion of steel	High
Zincalume sheet	Non-flammable	Heat can cause loss of strength and buckling, crazing of bonded finish, thermal cracks	Staining	Oxidization of zincalume, surface of bonded finish	High
Aluminium	Flammable	Extreme heat causes melting, deformation, discolouration	Staining	Oxidization, surface decay, crust formation on surface	Very high
Aluminium alloys	Flammable	Extreme heat causes	Staining	Oxidization, surface	

Material	Vulnerability to flame	Vulnerability to heat	Vulnerability to smoke	Vulnerability to ash	Vulnerability ranking
		melting, deformation, discolouration		decay, crust formation on surface	

Material	Vulnerability to flame	Vulnerability to heat	Vulnerability to smoke	Vulnerability to ash	Vulnerability ranking
Magnesium alloys	Flammable	Extreme heat can cause spontaneous ignition	Staining	Oxidation, surface decay, crust formation on surface	Very high
Zinc	Flammable	Extreme heat can cause melting, spontaneous ignition	Staining	Oxidation, surface decay, crust formation on surface	Very high
Copper	Non-flammable	Extreme heat causes melting, deformation	Staining	Crust formation on surface	Very high
Lead	Non-flammable	Extreme heat causes melting, volatization	Staining, emits toxins in smoke	Crust formation on surface	Very high
Sarking (woven glass fabric with aluminium foil laminate)	Non-flammable at low temperatures, flammable at high temperature	Extreme heat can cause melting	Staining		High
Malthoid (bituminous flashing)	Flammable	In extreme heat produces thick smoke and emit toxic gases	Emits toxins in smoke		Very high
Terra cotta	Non-flammable	Extreme heat can cause change in colour, crazing of glaze, dehydration and loss of strength,	Staining	Staining, surface decay, crust formation on surface	Moderate

Material	Vulnerability to flame	Vulnerability to heat	Vulnerability to smoke	Vulnerability to ash	Vulnerability ranking
		fractures, discolouration			
Porcelain	Non-flammable	Extreme heat can cause change in colour, crazing of glaze, fractures, shattering	Staining	Staining, surface decay, crust formation on surface, discoloration	High
Timber	Flammable Charring of surface of large section timbers (300mm x 300mm)	Extreme heat can cause dehydration, spontaneous ignition	Staining, infuses smoky smell	Staining, crust formation on surface	Very high

Material	Vulnerability to flame	Vulnerability to heat	Vulnerability to smoke	Vulnerability to ash	Vulnerability ranking
Lime Plaster	Non-flammable	Extreme heat can cause dehydration, separation from masonry ground, cracks	Staining, infuses smoky smell	Staining, crust formation on surface	High
Lathe and plaster	Wooden battens behind plaster are flammable	Extreme heat can cause dehydration, spontaneous ignition of timber battens, crack, peel layer of plaster	Staining, infuses smoky smell	Staining, crust formation on surface	High
Gypsum Plasterboard	Paper surface is flammable	Extreme heat can cause dehydration, deformation, cracks	Staining, infuses smoky smell	Staining, surface decay, formation of crust layer on surface	Moderate

Material	Vulnerability to flame	Vulnerability to heat	Vulnerability to smoke	Vulnerability to ash	Vulnerability ranking
Asbestos sheet	Non-flammable	Extreme heat can cause fractures and disintegration of surface	Staining, asbestos fibres dispersed through smoke	Staining, surface decay, formation of crus layer on surface	Very high
Fibrous cement sheet	Non-flammable	Extreme heat can cause fractures and disintegration of surface	Staining, fibres dispersed through smoke	Staining, surface decay, formation of layer on the surface	Moderate
Fibreglass	Non-flammable	Extreme heat can cause fractures, disintegration of surface, melting, deformation	Staining, glass fibres dispersed through smoke	Staining, surface decay, formation of layer on the surface	Very high
Glass – 3mm to 5mm	Non-flammable	Heat will cause fractures, melting	Staining	Staining, surface decay, formation of crust layer on surface	Very high
Glass - toughened	Non-flammable	Extreme heat can cause shattering into small pieces	Staining	Staining, surface decay, formation of crust layer on surface	Moderate

Material	Vulnerability to flame	Vulnerability to heat	Vulnerability to smoke	Vulnerability to ash	Vulnerability ranking
Natural fabrics – cotton, silk, linen, hessian	Flammable	Heat will cause spontaneous ignition	Staining, infuses smoky smell, discolouration	Staining, infuses smell, discolouration	Very high
Natural fabric – wool	Flame resistant, smoulders	Heat resistant	Staining, infuses smoky smell, discolouration	Staining, infuses smell, discolouration	Low

Material	Vulnerability to flame	Vulnerability to heat	Vulnerability to smoke	Vulnerability to ash	Vulnerability ranking
Synthetic fabrics – polyester, etc	Flammable	Heat will cause melting	Staining, infuses smoky smell, discolouration	Staining, decay of surface, discolouration	Very high
PVC	Non-flammable	Heat will cause melting, deformation	Staining, emits toxic gas in smoke	Surface decay, discolouration	Very high
Plastic	Flammable	Heat will cause melting, deformation	Staining, emits toxic gas in smoke	Surface decay, discolouration	Very high
Paper	Flammable	Heat will cause spontaneous ignition	Staining, infuses smoky smell	Staining, discolouration, infuses smell	Very high
Paint – acrylic	Non-flammable	Heat will cause pealing, melting, change in colour	Staining	Staining, surface decay, discolouration	Very high
Paint - lead	Non-flammable	Heat will cause pealing, melting, change in colour	Staining Emits toxic gas in smoke	Staining, surface decay, discolouration	Very high
Paint – intumescent (fire retardant paint)	Non-flammable	Creates a barrier against fire by forming a foaming char layer above surface materials such as timber, steel or plaster	Staining	Staining, surface decay, discolouration	Moderate