Incorporating Bushfire Impacts into Road Design

Literature Review Report (v1.0)

Author/s:

Georgia O'Connor, Peter Dwyer, Melissa Lyons, and Zia Rice

ARRB Project No.:

016847/016920

A JOINT INITIATIVE BY

WARRIP
WESTERN AUSTRALIAN ROAD RESEARCH AND INNOVATION PROGRAM

NACOE
NATIONAL ASSET CENTRE OF EXCELLENCE

BROUGHT TO YOU BY

mainroads WESTERN AUSTRALIA

Queensland Government

arrb YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Final Report Approval

Project Title: **Incorporating Bushfire Impacts into Road Design**

Project Number: **016847/016920**

TMR Project Leader	**WARRIP Project Manager**	**ARRB Project Leader**
Name: Ellyse Sheridan	Name: Louis Bettini	Name: Melissa Lyons
Position/Title: Project Manager	Position/Title: Project Manager	Position/Title: Project Leader
Signature:	Signature:	Signature:
Date: 29 / 08 / 2022	Date: 29/ 08 / 2022	Date: 28 / 06 / 2022
OK to publish? ☒ Yes ☐ No	OK to publish? ☐ Yes ☐ No	

TMR Quality Manager	**ARRB Quality Manager**
Name: Type name	Name: Karen Cogo
Position/Title:Type full title/position	Position/Title: Quality Manager Principal Professional Leader – Community Safety and Resilience
Date: / /	Date: 30 / 6 / 2022

Publication Approval

Commercial in confidence: ☐ Yes ☐ No

Recommended to publish on NACOE and WARRIP Websites:		☒ Yes ☐ No	
Name: Narelle Dobson	Name: Natalie Lockwood	Name: Desiree Hamann	Name: Joe Grobler
Position/Title: **TMR Agreement Manager**	Position/Title: **WARRIP MRWA Agreement Manager**	Position/Title: **WARRIP ARRB Agreement Manager**	Position/Title: **NACOE ARRB Agreement Manager**
Signature:	Signature:	Signature:	Signature:
Date: 23 / 05 / 2023	Date: 25/05/2023	Date: 25/05/2023	Date: 26 / 06 / 2023

Version Control

Report version no.	Date	Released to client by	Nature of revision
1	28 October 2021	Melissa Lyons	Draft Report
2	22 December 2021	Melissa Lyons	Updated Report
3	30 June 2022	Melissa Lyons	Literature review for publication

Summary

There is growing uncertainty regarding climate variability and the impact this will have on the frequency and intensity of bushfire events. Currently, it is understood that the Queensland Department of Transport and Main Roads (TMR) and Main Roads Western Australia (Main Roads WA) planning, design and construction practices for infrastructure projects do not actively consider bushfire risk.

This project, a joint initiative being undertaken by the National Assets Centre of Excellence (NACOE) through TMR, and the Western Australian Road Research and Innovation Program (WARRIP), through Main Roads WA, aims to develop a framework which imbeds the consideration of bushfire prevention, preparedness, response and recovery into the planning, design, construction and maintenance of transport infrastructure in addition to recommending updates to TMR and Main Roads WA practices and documentation to reflect best practice.

The literature review undertaken as the first phase of this project aimed to examine how to assess the risk and vulnerability of transport infrastructure when impacted by a bushfire event, and what best practice is for bushfire management in the road corridor.

As a result, the first recommendation is the adoption of the Prevention, Preparedness, Response, Recovery (PPRR) framework, which the literature review has been based around. The PPRR includes the following areas for consideration:

- importance of undertaking a risk assessment (references are provided to assist with the risk assessment process)
- prevention through risk avoidance and risk reduction strategies
- preparedness through overall policy strategic objective solutions
- response strategies for disaster management
- recovery strategies for improvement in post-disaster recovery.

Acknowledgements

The authors would like to acknowledge the collaborative input of the Queensland Department of Transport and Main Roads and Main Roads Western Australia officers. In particular, the authors would like to thank the following contributors: Ellyse Sheridan, Louis Bettini, and Julian Butler. In addition, the authors would like to acknowledge the contribution of Karen Cogo as Quality Manager.

Contents

Tables

Figures

1 Introduction

Over the recent decade, bushfires have increased in both frequency and severity, due to an increase in fire danger weather – caused by climate change. Currently, it is understood that the Queensland Department of Transport and Main Roads (TMR) and Main Roads Western Australia (Main Roads WA) planning, design and construction practices for infrastructure projects do not actively consider bushfire risk. *Incorporating Bushfire Impacts into Road Design*, a joint initiative being undertaken by the National Assets Centre of Excellence (NACOE) through the TMR, and the Western Australian Road Research and Innovation Program (WARRIP), through Main Roads WA aims to review existing infrastructure processes required to ensure the capacity and capability of TMR and Main Roads WA to consider and manage bushfire risk are enhanced.

1.1 Background

Unprecedented bushfire events across Australia during the 2018 to 2020 period have highlighted the fact that roads and associated infrastructure are critical enablers of bushfire prevention, preparation, response and recovery activities. However, these bushfire events have also highlighted the vulnerability of road infrastructure and the travelling public during and after a bushfire event. For example, the closure of the Genoa-Mallacoota Road in Victoria during late December 2019 resulted in the isolation of residents and visitors within the township of Mallacoota, Victoria. Evacuation of these individuals was only possible with the assistance of air and naval resources from the Australian Defence Force. Further, bushfire events in Queensland during 2019–20 caused the closure of major urban highways, including the Sunshine Motorway, and caused damage to critical access roads into remote communities, including Binna Burra Road. Similarly, in 2019, bushfires caused major damage to key assets along the Great Southern Highway in Western Australia.

Western Australia has a high number of timber bridges across the state road network which are at significant risk and vulnerable to bushfire events. In recent years, several bridges have been extensively damaged creating disruption for local communities and emergency services during and after bushfire events. Additionally, WA's geographic spread compounds disruption from bushfire events if access is obstructed on critical freight routes due to the lack of potential alternative routes.

Road agencies generally incorporate consideration of the disaster management framework through design, construction and maintenance doctrine and specifications. For example, flood immunity is considered during strategic planning, project planning and design, construction management and asset maintenance. In this regard, consideration of flooding is mature, incorporated into core business and is recognised as a business-as-usual function of road network management. Comparatively, bushfire management is considerably less mature and is generally not considered during strategic planning, project planning and design, construction management or asset maintenance. This is likely due to the scale at which flooding will occur, when compared with other natural disasters such as a bushfire. Flooding can often be predicted by considering real time rainfall information in conjunction with terrain and other data, whereas bushfires are often unpredictable.

1.2 Objectives

Currently, TMR and Main Roads WA planning, design and construction practices for infrastructure projects do not actively consider bushfire risk in the same way that flooding risk is considered. Therefore, the objective of this project is to incorporate best practice bushfire management into TMR and Main Roads WA infrastructure planning, design, construction, and asset maintenance practices to ensure:

- bushfire risk is considered in transport network planning
- design considerations and standards address bushfire risk to the asset (including roadside stopping areas), travelling public and operation of the network and ensure impact to the transport network level of service is minimised in a bushfire event
- the ability for rapid recovery of the transport network level of service post bushfire event.

Specifically, TMR and Main Roads WA are seeking the development of a fit-for-purpose framework which imbeds the consideration of bushfire prevention, preparedness, response and recovery into the planning, design, construction and maintenance of transport infrastructure. This includes consideration for both greenfield and brownfield road networks.

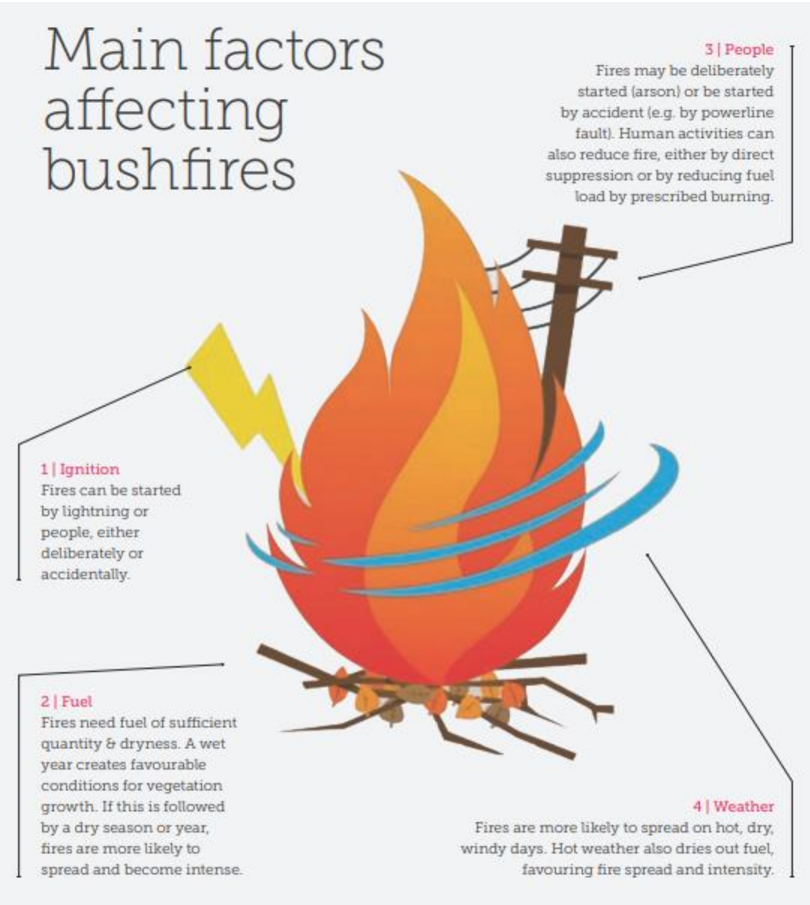
2 Bushfires

Bushfires are characterised as a natural disaster or natural hazard, due to the way in which they can progress through landscapes, and at what intensity/severity. This progression is influenced by general characteristics of:

- ignition, location and timing
- vegetation fuel loads, arrangement and continuity
- topography
- weather conditions including humidity, temperature
- wind speed (Country Fire Authority 2007; cited in March et al. 2020).

The main factors affecting bushfires are shown in Figure 2.1.

Figure 2.1: Main factors affecting bushfires



Source: Climate Council (2015).

Climate change has had an impact on both bushfire frequency and severity. Researchers have shown the potential influence of climate change on the more severe and longer fire seasons around the globe (Dowdy 2008, cited in March et al. 2020; Setunge et al. 2021). The impacts of this are:

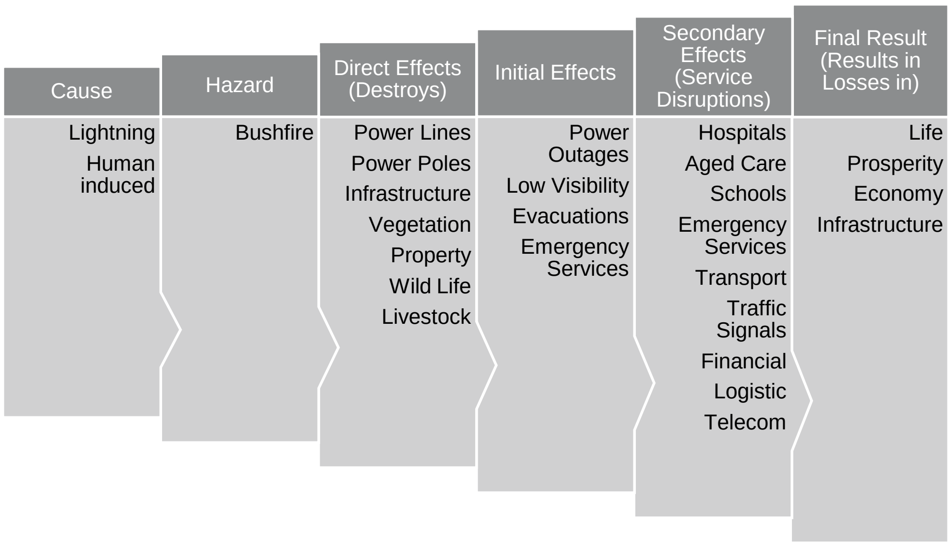
- Longer seasons leave less time for hazard reduction.
- Hotter conditions are also leading to more extreme hot days and longer heatwaves.
- Hotter conditions lead to more dangerous bushfires.
- There is an increased risk of bushfires in bushfire-prone areas and regions not previously prone to bushfires.

- Lower levels of rainfall, lead to more dry days, allowing for the build-up of dry soils and vegetation which can act as fuel for bushfires.
- There are more lightning storms, where lightning can be a major cause of bushfire events.

Fire weather seasons have lengthened by 18.7% globally since 1979 to 2013 (Setunge et al. 2021). In addition, rapid urbanisation, population decentralisation, ongoing settlement growth and urban sprawl across Australia have increased the size of the Wildland Urban Interfaces (WUI) or the urban/rural fringe – leaving more communities and infrastructures vulnerable to bushfires (Allen 2018, cited in March et al. 2020; Setunge et al. 2021). The intensity, duration and scope of bushfires during the Australian 2019–20 summer highlighted this. The severity of these bushfires was exacerbated by the fact that the fires were occurring near population settlements, such as housing and other structures, that were in too close proximity to flammable vegetation (March et al. 2020).

Severe bushfires have the potential to produce numerous economic, social and environmental impacts, which can range from short-term inconveniences to long-term life-changing impacts (Stephenson 2010). An example of the cascading destructive effects of bushfires is provided in Figure 2.2.

Figure 2.2: Impact of bushfires on critical infrastructure and society



Source: Adapted from Stephenson (2010).

2.1 Australian Context

The 2019–20 Black Summer bushfire season burnt almost 19 million hectares, destroyed over 3,000 houses, and 35 people perished across New South Wales, Australian Capital Territory, Queensland, Victoria, and South Australia (Australian Institute of Disaster Resilience (AIDR) 2020). NSW was severely impacted with several mega-fires creating a total burnt area larger than any fire season experienced in the past 20 years. One of these mega-fires was the largest recorded forest fire in Australian history (AIDR 2020). Within this same bushfire season, Victoria recorded the highest number of bushfires, the largest area burnt, and the second highest number of houses lost across the season. South Australia had the highest number of houses lost in the last 20 years (Filkov et al. 2020).

Queensland and Western Australia have experienced a growing number of bushfire impacts over the decade, 2011 to 2021. The 2019–20 Black Summer bushfire season caused 6.6 million hectares of damage in Southeast Queensland, in addition to destroying 49 houses, 68 sheds and 5 commercial buildings. In 2018, bushfires in Eastern Queensland caused damage across Gladstone, Rockhampton and Mackay. This included damage to 1.4 million hectares of land, 1 fatality, with 9 homes destroyed, and significant damage to crops and pastures. In 2011, there were 345 bushfires burning across 42 government areas in southwestern Queensland.

Western Australia has also endured several major bushfires over the recent decade. In 2015, Esperance experienced two major bushfire events which led to a total damage area of 140,000 hectares. These fires caused 4 fatalities and destroyed 3 homes and 16 non-residential structures. Approximately 500,000 tonnes of grain were burnt, leading to a vast economic and social impact. In 2016, bushfires in Waroona-Yarloop damaged 69,000 hectares of land, caused 2 fatalities and destroyed the small township of Yarloop and associated 181 houses. In 2014 in Parkerville and Perth Hills, a small bushfire impacted 650 hectares of land, resulted in one fatality, but destroyed 52 homes due to the area being more densely populated.

As can be seen from this information, bushfires have been increasing in both frequency and severity over recent decades. This can be attributed to an increase in extreme heat events, caused by climate change. However, climate change will not affect all of Australia equally. For example, areas with a historically low bushfire threat might have to adapt the most to changing conditions. Queensland may see a ‘new’ fire danger environment which will need to be managed whereas, Western Australia is more likely to see an exacerbation of an already high risk. This spatial distribution of impacts also needs to be taken into account when developing management practices. It is important to consider not only the current risk but how this risk will change over time.

2.2 Social Impacts

Research has shown that bushfires can have significant ongoing impacts for communities. These impacts include:

- community members becoming isolated during the immediate threat of a bushfire
- physiological stress associated with property damage and property loss
- health impacts associated with smoke inhalation
- damage or destruction of cultural heritage assets, for example, aboriginal spiritual sites (Stephenson 2010).

One of the most pivotal social impacts of bushfires is the loss of human life. In the 2019–20 bushfire season 33 people perished, and over 3,000 houses were destroyed (Filkov et al. 2020). In the 2009 Black Saturday bushfires in Victoria, 173 people perished, 414 people were injured, 7,562 people were displaced, and 2,100 homes were destroyed (Bushfire ABC n.d.; Victorian Bushfires Royal Commission 2010).

2.3 Economic Impacts

Bushfires cause significant economic impacts, due to their effect on infrastructure, economic production, property and government services. In addition to roads, other infrastructure related services which can be disrupted during or after a bushfire include damage to power lines causing electricity disruption, the loss of communication equipment, and damage to potable water supplies.

Furthermore, the disruption to local business in regional areas can cause significant reductions in economic production. During a severe bushfire, losses of between 50 and 100% of turnover are common. For agricultural and forestry industries, businesses can face ongoing losses due to the loss of their products and produce (i.e. timber, livestock, etc.) (Stephenson 2010).

Table 2.1 provides the average annual cost of bushfires by state and territory between 1967 and 2005. Bushfires comprised 8.2% of Australia’s costs due to natural disasters from 1967 to 2005.

Table 2.1: Average annual cost of bushfires by state and territory, 1967 to 2005

State/Territory	Cost ($min 2005 Australian dollars)
NSW	23.9
Vic	36.7
Qld	0.7
SA	13.0

State/Territory	Cost ($min 2005 Australian dollars)
WA	4.6
Tas	11.5
NT	0.0
ACT	9.7

Note: These figures exclude the cost of death and injury.

Source: BITRE (2008 cited in Setunge et al. 2021).

More recent data has shown between 2019 and 2020, New South Wales, Queensland, Victoria and South Australia had $2.32 billion worth of insurance losses. Additionally, $93 million worth of damage was accrued in the Perth Hills region from 2020 to 2021 (Insurance Council of Australia 2021).

The Victorian Department of Primary Industries estimated that in the 2009 Black Saturday bushfires, 11,800 head of livestock were lost, 6,200 hectares of grazing pasture was lost, and 3,200 tonnes of hay and silage were lost. 'The Insurance Council of Australia reported that as of August 2010, $1.2 billion in insurance claims' had been made, 84% for property and 16% for vehicles. The Bushfires Royal Commission stated that the cost of the damage on Black Saturday was $4.4 billion, which did not include the agricultural losses (Bushfire ABC n.d.).

Internationally, catastrophic wildfires between 2015 and 2020 have caused damage to the Californian Department of Transportation (Caltrans) road network in 81 separate wildfire events. This cost Caltrans over $590 million to repair highway assets (Thorne et al. 2021).

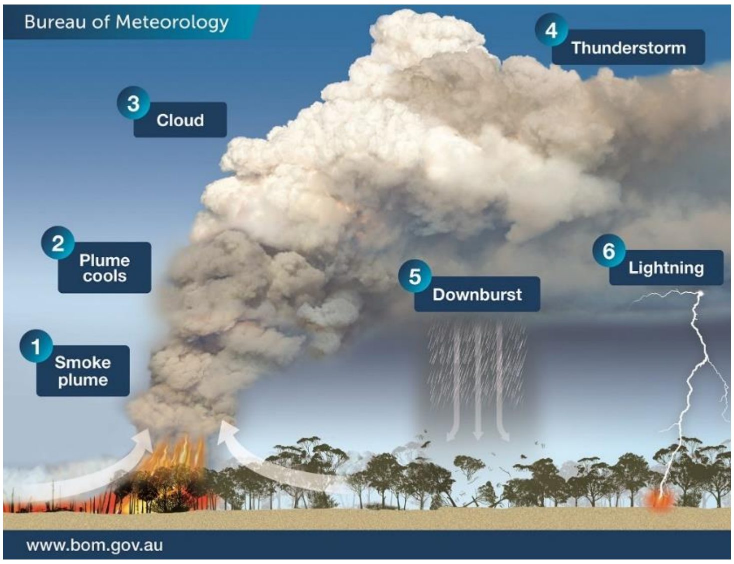
However, the total cost of bushfires should not just consider the damage to assets. When considered holistically the costs of bushfires incorporate all prevention, preparedness, response and recovery activities undertaken – not just the recovery activities undertaken in response to damage to infrastructure.

2.4 Environmental Impacts

Bushfires have extensive impacts on the surrounding natural environment. These impacts include:

- Biological, chemical and physical changes in the soil can occur, based on the temperature of the fire.
- Soils can be unintentionally removed from a site once a bushfire has been extinguished through the erosive processes of wind or rain. In some cases, severe bushfires induce water repellence within the soil, making it even more susceptible to erosion.
- Hydrology patterns across a landscape and the quality of waterways are significantly affected by bushfires. The removal of the vegetation encourages large-scale erosion that eventually flows into streams and rivers, causing sedimentation within these waterways leading to a deterioration in water quality. Smoke produced from bushfires contains a number of chemicals including plant nutrients which disperse throughout the environment.
- Greenhouse gases (e.g. carbon dioxide and nitrogen oxides) are emitted to the atmosphere via bushfire smoke, contributing to anthropogenic climate change.
- Fire can be a positive element for plant regeneration; however, if it is applied to the landscape outside its natural tolerances (e.g. too frequently or intensely, not frequently or intense enough), then some species are in danger of becoming locally extinct (Stephenson 2010).
- Bushfires can create their own weather, generating 'pyrocumulonimbus' clouds and storms (Bureau of Meteorology 2018). This is depicted in Figure 2.3. These types of clouds are particularly dangerous for the following reasons:
  - can cause intense updrafts and strong winds, leading to an increase in intensity of the fire
  - lightning can form in these storms which can spark additional bushfires
  - can involve intense downpours of rain, which can lead to localised flooding, erosion, landslip, etc.

Figure 2.3: Pyrocumulonimbus cloud development



Source: Bureau of Meteorology (2018).

2.5 Road Infrastructure Impacts

Roads and transportation related infrastructure (including structures) are one of the highest value infrastructure assets in a bushfire-prone area as they are critical to the mobility of the community for evacuation and for the continuing provision of goods in post-disaster recovery. Historical data demonstrates that the failure of roads and road structures can have catastrophic consequences on a community affected by disaster for these reasons *(*Setunge et al. 2021). Dependent on severity, bushfires can also cause road closures and even serious roadway damage (Fraser et al. 2020).

Roads can also be a source of ignition for bushfires. This includes the high use of these assets (i.e. regular interaction with the population), the presence of powerlines traversing the corridor and the proximity of the asset to vegetation or the nature of the surrounding landscape (VicRoads 2013).

Research undertaken by Morrison (2007) found that 88% of all bushfires (referred to as wildfires) in the USA were caused by humans. In addition, 95% of these fires occurred within a kilometre of a road and over 90% of all fires, of any cause, occurred within the same distance. This study found that there was a significant relationship between the occurrence of a bushfire and the distance to the nearest road and that only 3% of all bushfires start in the wilderness. This correlation between roads and bushfires is most probably caused by the population density around transportation routes rather than the population using the road being a common source of ignitions.

Within the literature, there are two common threads when discussing the impacts of bushfires on roads and transportation infrastructure. These are:

- the impacts and challenges associated with bushfire evacuation
- the impacts on the transportation system during an active bushfire.

The overall consequence of a bushfire starting on a road is determined by the amount, type and vulnerability of assets on the road reserve and beyond the road reserve in the potential path of the fire (VicRoads 2013). Bushfires can damage the road itself, in addition to the roadside assets including signs, guardrails, safety barriers, reflectors etc. The loss of this infrastructure has a direct impact on road user safety and emergency vehicle safety. Transport networks are disrupted by the closure of roads, with roads directly impacted by flames and heat often remaining closed until the associated infrastructure can be replaced and the trees assessed (Stephenson 2010).

Impacts to vegetation and pavements are elements worth critically evaluating; however, there are other factors surrounding road infrastructure that will also be impacted by bushfires. Such factors include immediate road use, the safety of the road post-fire and elements that will require replacement over time.

Immediately after a fire, a road pavement is likely to contain various physical barriers, such as fallen trees, branches, power lines and distorted pavement from prolonged intense heat exposure. Additionally, extreme fire damage can result in the structural integrity of bridges being compromised. Until addressed, these physical barriers can also cut off the only escape route in rural areas or access to essential services. The next topic to consider is the elements that will impact road use until rectified.

2.5.1 Road Pavement

Through an analysis of literature regarding the impact of fire on both asphalt and sprayed seal pavements, the following impacts were identified:

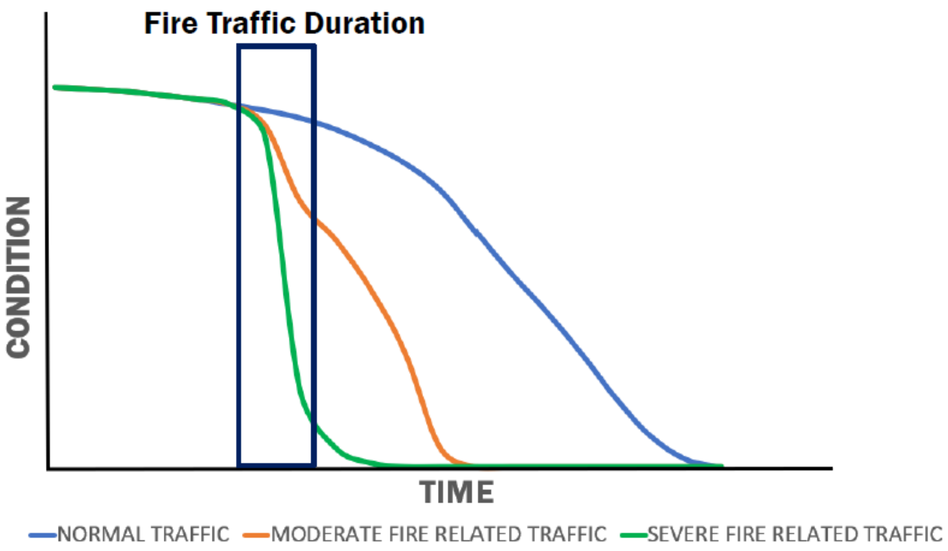
- Fire load, heat release rate and smoke can vary with different asphalt (Schartel et al. 2010).
- Burning pavement plays a negligible role overall in ignition or continuation of fire (i.e. the road does not contribute to the increasing of the fire front) (Schartel et al. 2010).
- Laboratory testing of pavements that have been exposed to 200 °C for 15 minutes, has shown a 72% decrease in the number of load repetitions which a fire-damaged pavement can experience before fatigue cracking of the asphalt. Further, there is a 51% decrease in loading cycles of the subgrade before rutting of the fire-damaged system, under dynamic heavy vehicle axle wheel loads (80 kN) (Van Staden & Fragomeni 2017).

Climate change projections predict that bushfire regimes will increase throughout the next few decades, leaving communities and road infrastructure vulnerable (Climate Council 2019). Therefore, it is critical to understand how bushfires behave and interact with society. Temperatures of bushfires reach as high as 1,600 °C in the reaction zone, where degraded vegetation releases gases and mixes with oxygen. The base of a flame reaches approximately 1,100 °C due to mixing with ambient air temperatures with the tips of the flames reaching, on average, 600 °C (Sullivan 2015). However, the temperature of the flame can vary depending on weather conditions, soil moisture content and access to fuel. Bituminous pavements are the least resilient to elevated temperatures as they are visco-elastic, and their properties are function-based around temperature. The lower the temperature, the more brittle and rigid the bitumen becomes. In contrast higher temperatures will soften the bitumen and allow it to expand, resulting in permanent structural damage. Standard unmodified bitumen typically softens at 50 °C. Assuming the temperature of the base flame was 1,100 °C, the flames can cause detrimental damage to roads and leave rural communities stranded.

There is limited research to understand the impacts of bushfires on long term pavement performance under Australian conditions. Internationally, pavement research often focuses on vehicle fires and tunnel fires as opposed to bushfires, noting the pavement response overall to bushfire events may not be well understood. Furthermore, the impacts of increased heavy vehicle and traffic volumes along local roads during evacuation and emergency response are anecdotally understood as a challenge but are not well documented or quantified.

Signore (2020) examined the impacts of wildfires on roadway pavements in California. Figure 2.4 provides an estimate of how traffic contributes to the deterioration of pavement condition, and how this is exacerbated by traffic in moderate and severe fire traffic related events. From Figure 2.4 it can be inferred that following these events pavements deteriorate in proportion to the severity of the fire.

Figure 2.4: Wildfires and pavement condition over time



Source: Signore (2020).

The most observed fire related damage on the Californian road network was crocodile (alligator) cracking and fatigue cracking. This was followed by edge cracking on non-improved rural roads, and increased rutting on lower volume rural roads (particularly where the surface layer was thin). Accelerated ageing of the pavement from the fire itself was less prevalent. Rather, the damage to the pavement and decrease in condition were caused by fire related traffic.

When bitumen binders are subjected to heat from a bushfire, anecdotal evidence has shown that the bitumen binder will oxidise and become hard and brittle. The bitumen will burn if the temperature it is exposed to is significantly high enough. The exact temperature at which damage will occur will depend on the type of bitumen used in the construction of the seal.

Anecdotal evidence from local government consultation (provided to this project via personal correspondence) detailed that, overall, there were minor, often isolated, impacts of bushfire on the road pavement. Where isolated impacts have occurred, this has been due to extreme heat in accompaniment of heavy vehicles. The most likely impacts of bushfires and extreme heat are flushing of the surface seal, however, this does not tend to create an unsafe roadway. For local government, the largest concern is a combination of smoke, low light, damage to road signage, roadblocks (i.e. fallen trees), damage to road furniture and an inability to see reflectors and road safety measures. These aspects create hazards for both the community and to fire emergency services who are trying to leave or access the areas (provided by personal communication White, Z & Phillips, N 2020, 'Pavement/seal damage: post bushfire assessment').

Evidence was provided from a local government in SA of an assessment of the immediate impacts of a bushfire on pavements following the 2019–20 Black Summer bushfire season. The majority of the roads assessed were unbound granular flexible pavements with a sprayed seal surfacing although some were also asphalt surfaced pavements. Examples of the damage are shown in Figure 2.5.

Further to the effects on the road pavement, vegetation, verges and trees surrounding roads are often burned or destroyed, and in the presence of heavy rain which can be caused by the presence of pyrocumulonimbus clouds or by the presence of a cold front, which commonly follows extreme fire weather. the roads in these areas are more prone to flooding, landslips and debris due to the loss of vegetation which stabilises the soil. This can also cause drainage issues causing further closures (Regional Roads Victoria 2020).

Figure 2.5: Example of damage to sprayed seal roads from bushfire

	
Typical condition Spray seal wearing course not damaged by fire.	**Fire damage – vitrified binder & loss of aggregate** Fire damaged area of spray seal close to the edge of the carriageway. Bitumen binder appears black and glassy (almost vitrified in appearance). Seal was noted to be more brittle than adjacent unburnt area. Localised loss of coarse aggregate from matrix of seal is apparent in burnt area.
	
Damage from falling debris Example of isolated burn to spray seal due to falling debris. Bitumen has same blackened appearance noted above. Base course is exposed where aggregate has been lost from seal. These locations provide a pathway for moisture ingress into the pavement which will accelerate deterioration of the pavement.	**Damage from falling debris** More serious damage to spray seal most likely due to falling tree branch. Bitumen appears friable. Coarse aggregate has been lost from seal and is apparent on the surface of the pavement.
	
Fire damage on asphalt Photograph showing damage to asphalt. Bitumen was noted to be friable and coarse aggregate was observed to have been lost from the asphalt matrix.	**Wheel path damage from radiant heat** Photograph showing close up of flushed/excess bitumen on surface of asphalt in vehicle wheel paths. The key serviceability issue for the road surface is reduced wet weather skid resistance.

Source: Provided by personal communication; White, Z & Phillips, N 2020, 'Pavement/seal damage: post bushfire assessment'.

2.5.2 Structures

The susceptibility of road structures to fire is dependent on the material from which they have been constructed and the surrounding environment. Bridges on the Australian road network are predominantly constructed from timber, steel or reinforced concrete.

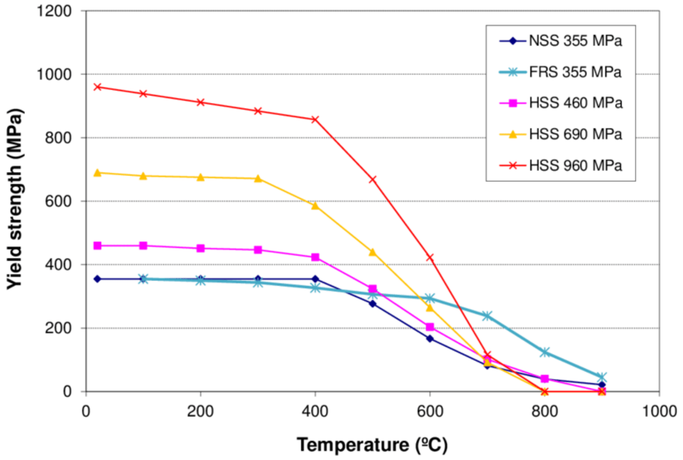
Timber structures are at an elevated risk of damage in a bushfire, with wood sustaining ignition at a temperature of approximately 250 °C to 300 °C. Bridges that feature timber decking or sheeting are of particular risk, as these members are typically thin enough to completely burn and induce sustained high temperatures across the structure. In larger sections typically used as longitudinal bridge girders a layer of char is formed on the surface and acts as an insulator, reducing the rate of burning to approximately 0.6 mm per minute. Therefore, for severe damage to timber bridges there needs to be sustained burning, such as insufficient vegetation clearance surrounding the structure (Roads and Maritime Services 2008). For example, in 2016, the intense heat of a bushfire in Western Australia caused the Samson Brook bridge to buckle and collapse, as shown in Figure 2.6.

Figure 2.6: Samson Brook bridge collapse due to bushfire

Source: Hampton et al. (2016).

The effects of bushfires on structures that are constructed from steel tend to vary greatly depending on properties of the bushfire. Whilst the temperature sustained in a bushfire event is unlikely to cause steel to melt, it can still reach temperatures which affect the yield strength and modulus of elasticity, as can be seen in Figure 2.7.

Figure 2.7: Temperature vs. yield strength of various steel types



Source: Espinos et al. (2015).

The surrounding environment is the largest contributing factor, with sustained high temperature and heat load in the area increasing the likelihood of steel yield strength falling to point of failure. Local areas that are surrounded by vegetation or directly in contact with combustible materials (such as timber deck planks) may create zones of weakness throughout the structure. The thickness of steel members also plays a notable part, with thicker steel requiring more heat energy to reach a given temperature.

Once yield strength has been reached steel members will become more susceptible to events such as buckling. Compromised steel bridges may fail during the fire event and remain at risk thereafter as a result of permanent deformation that may have occurred to members.

Reinforced concrete structures are the most common on the Australian road network. As has been the case with timber and steel, the largest factor contributing to concrete damage is the fuel load and capacity of the surrounding environment to provide sustained heat in direct proximity of the concrete.

Elevated temperatures in concrete can create significant modifications to the material microstructure, beginning to impact structural properties at a temperature of approximately 300 °C. This occurrence is evidenced by the colour of concrete shifting to a pink tinge, caused by dehydration of cementitious pastes and other siliceous aggregate present in the material.

At this temperature, spalling and cracking can occur as trapped moisture begins to escape the concrete. These may expose reinforcement and create further durability concerns. Around 300 °C is also the point at which concrete begins to incur significant strength loss, in the order of 30–40%, with a proportional loss in modulus of elasticity. This is a result of incompatibilities between the varying coefficients of thermal expansion within the cementitious materials and reinforcing steel (VicRoads 2011). This type of damage can be seen in Figure 2.8.

Reinforcing steel will gradually lose yield strength, however, it can regain this strength on cooling assuming significant deformation has not occurred. Pre-stress tendons are more susceptible, contributing to the loss of tension in cables at elevated temperatures.

Figure 2.8: Fire damage to reinforced concrete in excess of 300 °C

Source: VicRoads (2011).

2.5.3 Safety Infrastructure

Fires can impact road use until various safety elements are rectified. Such safety elements include lane markings, guideposts, road barriers, melted street signs and fallen streetlights to provide visibility during night. Melted materials from powerlines, signs and streetlights create obstacles that can be dangerous when traveling at typical rural road speeds between 70 and 110 km. An example of a damaged sign, warning drivers of a tight corner is shown in Figure 2.9.

Figure 2.9: Bushfire damage to safety infrastructure

Source: Mancini (2020).

2.5.4 Other Ancillary Infrastructure

In addition to roads and structural assets, bushfire can also damage roadside furniture, such as road signs. Examples of bushfire damage to road signs are shown in Figure 2.10.

Figure 2.10: Bushfire damage to road signs

Source: Dalton (2020).

Less critical elements can also be damaged and require rectification post-bushfire. While not critical these elements will still need to be considered. For example, fauna fencing which prevents wildlife and domesticated animals from crossing busy roads is highly susceptible to damage, as it typically has plastic elements. In addition, other examples include, slope stability is sediment can flow onto a road surface due to a lack of vegetation to keep it stable.

When planning for and managing the impacts of bushfires, the road agency will need to consider all the infrastructure in the road corridor which they manage, and which they may be reliant on. This includes examples such as:

- rest areas, without which, driver safety could be impact due to fatigue
- public transportation facilities such as bus stops and level crossings, meaning members of the community may not have access to the transportation services they need
- utilities, such as water and electricity, which means that the community cannot receive the services they need. In addition, loss of electricity could also impact road agency operations.

2.5.5 Vegetation

Aside from the damage to roads and road-side infrastructure, there is also the impact of damage to vegetation to consider. Vegetation that is present within the road reserve includes some type of plant cover including trees, shrubs or grasses. The loss of vegetation itself can cause issues directly as well as associated knock-on effects of the vegetation loss.

This includes issues such as:

- loss of vegetation increasing potential for erosion and damage to batters in subsequent rain. More details on the importance of revegetation are covered in Section 3.5.3.
- falling vegetation across roads and potential for further falling and impacts by vegetation after a fire event. More details on management of tree hazards is outlined in Section 3.4.6.
- potential loss and or disruption of fauna habitat connectivity which allow access to fire refuges for mobile species during and after bushfires (WWF 2020).

2.6 Why is Advice Needed on the Management of Bushfires in Road Corridors?

As described in Section 1.1, unprecedented bushfire events across Australia during the 2018 to 2020 period have highlighted the fact that roads and associated infrastructure are critical enablers of bushfire prevention, preparation, response and recovery activities. In addition, roads are also heavily impacted by the effects of bushfires.

As described, roads are critical in bushfire events for:

- emergency response – i.e. access for fire fighting vehicles, etc.
- evacuation – i.e. routes for the community to leave, or access evacuation centres.

However, during a bushfire event the level of service of a road may be impacted due to:

- direct damage – e.g. falling trees, damage to structures, etc.
- radiant heat – e.g. potential to melt soft materials such as bitumen and linemarkings.

Therefore, consideration needs to be given to:

- prevention of bushfire impacts – e.g. through fuel control
- preparedness for bushfire events – e.g. through planning for use of roads for emergency access
- response to bushfire events – e.g. planning for evacuations and managing traffic
- recovery from bushfire events – e.g. building back better through asset upgrades.

The role a road agency can play in improving these aspects, is focused on disaster management. A study undertaken by Withanaarachchi et al. (2010) identified issues with disaster management from case studies in Australia, New Orleans, Kobe and Japan. The identified areas of concern include:

- leadership failures
- misunderstanding the full scope of the pending catastrophe
- approval of developments in high-risk areas
- communication failures
- insufficient planning
- vulnerable critical infrastructure
- rate of evacuation not considered
- road blockages from light poles and debris not anticipated.

During the Victorian bushfires of 2009, several gaps in strategic transport planning were found, including road planning and layout. Further, 'previous disaster events have not really made an impact on the strategic planning processes' (Withanaarachchi et al. 2010). Following each disaster, a disaster report is prepared by the relevant authority. In the case of bushfires this is often the relevant fire and emergency services authority (e.g. Queensland Fire and Emergency Services or Western Australian Department of Fire and Emergency Services (DFES)) or the Attorney General's Office. This report shows issues to be addressed, including actions before the next bushfire season to avoid loss of life. Table 2.2, from Withanaarachchi et al. (2010) shows how issues identified can be seen to continue to be an issue year after year.

Table 2.2: Recurring issues in disaster prevention, preparedness, response and recovery

Main Issues identified for improvement	1999 CFA Report	2004 Auditor General, WA Report	2005 / 06 CFA Report	2006 /07 CFA Report	2009 Victorian Bushfire Royal
	Identified as a major issue in the above reports				
Fire Fighter	Yes	Yes	-	-	Yes
Policies	Yes	Yes	Yes	Yes	Yes
Planning	Yes	Yes	Yes	Yes	Yes
Command	Yes	Yes	Yes	-	Yes
Communication	Yes	Yes	Yes	Yes	Yes
Information	Yes	Yes	Yes	Yes	Yes
Coordination	-	Yes	Yes	Yes	Yes
Evaluation	-	Yes	-	-	Yes
Emergency	-	-	Yes	-	Yes
Logistics	-	-	-	Yes	Yes

Note: 2009 Bushfire Royal Commission.

Source: Withanaarachchi et al. (2010).

Consideration should be given to the issues outlined in Table 2.2 when planning for how to improve the management of bushfire disaster events in Queensland and Western Australia.

3 Prevention, Preparedness, Response and Recovery of Road Networks

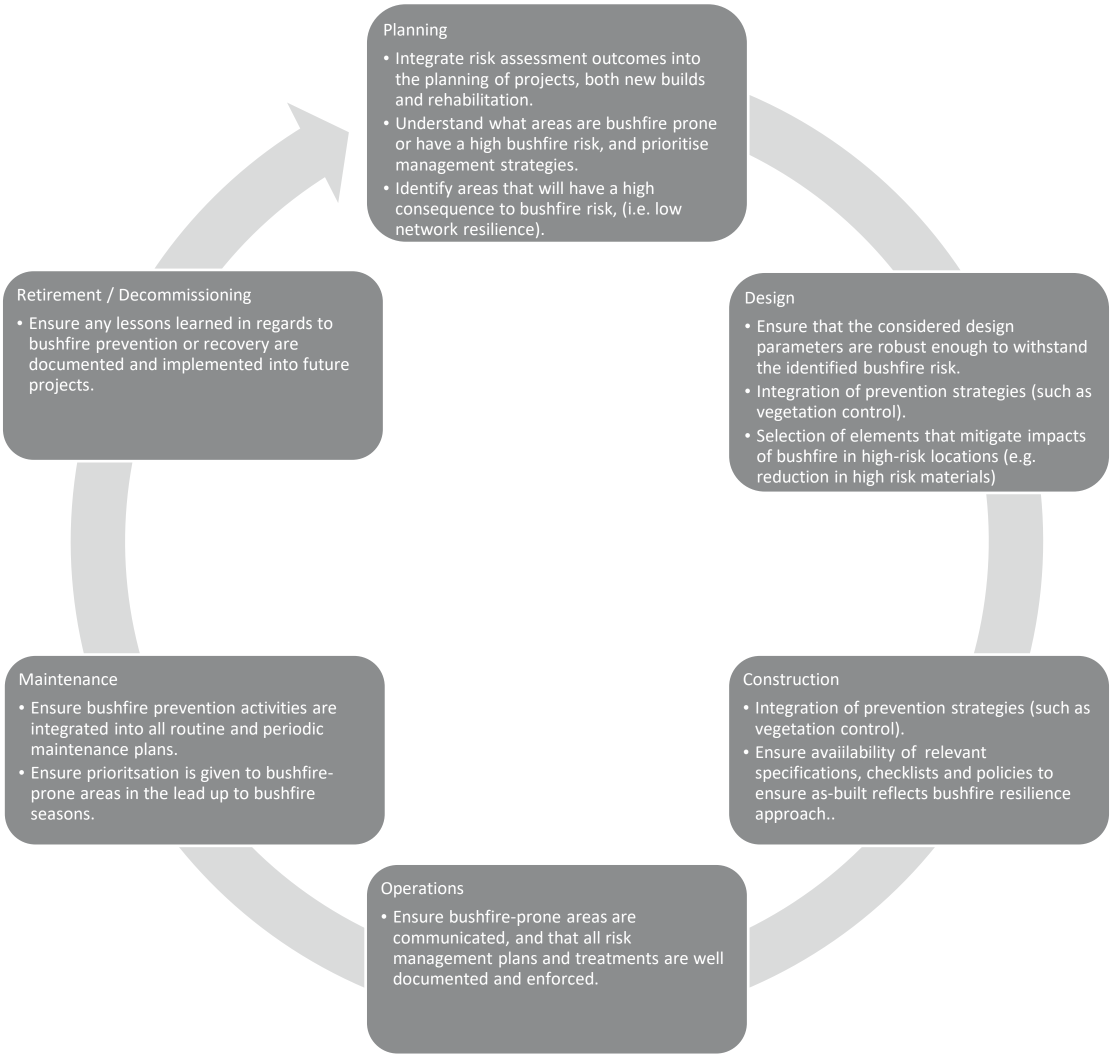
This section summarises the literature, frameworks and guidance material related to increasing the resilience and recovery of road networks prior to, during and after bushfire events. The incorporation of bushfire protection measures into road network management is cited in literature as the most efficient way of addressing bushfire risk. Critical recommendations and considerations are highlighted in call out boxes throughout the following sections of the report and are summarised in Section 4.

There are three key strategies for protecting life and assets from bushfires, these are:

1. the incorporation of bushfire protection measures, in addition to firefighting and evacuation planning, into road design and construction considerations
2. the planning and implementation of bushfire hazard reduction and prevention activities (e.g. roadside vegetation management), including the ongoing maintenance of these bushfire protection measures by land-owners and asset-owners, into road maintenance and operations
3. building of communication networks (using intelligent transport systems, ITS) and emergency response planning across the network to provide real-time information to drivers of fire hazards, as a mitigation measure for harm to public on the road.

These elements are summarised in the infrastructure life-cycle decision-making process, as shown in Figure 3.1.

Figure 3.1: Incorporating bushfire risk into the life cycle of a road project



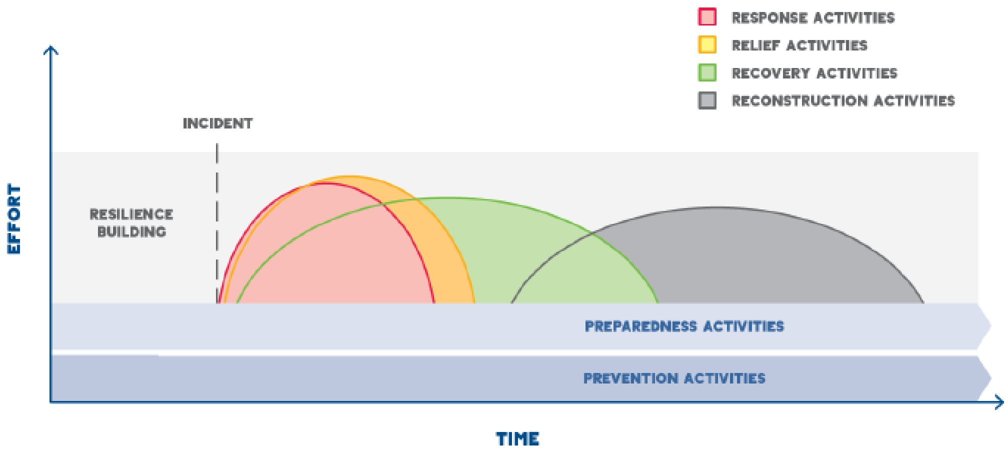
Source: Adapted from Gibson (2017).

Notably, during the review, it was found that the SA Government developed the *South Australia State Bushfire Management Plan* (Government of SA 2021) in response to an independent review of SA's 2019–20 bushfire season. This management plan included the use of the Prevention, Preparedness, Response and Recovery (PPRR) spectrum or risk management model, Figure 3.2. The PPRR spectrum includes the following areas for consideration:

- importance of undertaking a risk assessment (references are provided to assist with the risk assessment process)
- **prevention** through risk avoidance and risk reduction strategies
- **preparedness** through overall policy strategic objective solutions
- **response** strategies for disaster management
- **recovery** strategies for improvement in post-disaster recovery.

It is important to note that the SA management plan does not set specific action points, rather suggesting bushfire response is a joint effort requiring cooperation from communities, individuals, and agencies.

Figure 3.2: The PPRR spectrum



Source: Government of SA (2021).

This PPRR framework is used similarly by the Western Australian government as part of their State Hazard Plans (State Emergency Management Committee 2021). Each defined and prescribed hazard has a dedicated State Hazard Plan (Westplan) that outlines the arrangements on how to manage that hazard across the PPRR spectrum. There is a Westplan specific to fire. The Westplan document contains information relating to the arrangements for managing fire emergencies (State Emergency Management Committee 2020).

The PPRR spectrum represents a logical and robust process for bushfire management. Therefore, the review of published literature was based around the PPRR areas of consideration. Each of these areas are covered in the subsequent sections, as follows:

- **Prevention** (Section 3.2) – all activities concerned with minimising the occurrence of incidents, particularly those of human origin.
- **Preparedness** (Section 3.3) – all activities undertaken in advance of the occurrence of an incident to decrease the impact, extent, and severity of the incident and to ensure more effective response activities.
- **Response** (Section 3.4) – all activities undertaken immediately before, during and after an incident to ensure that its effects are minimised and that those immediately affected are given relief and support.
- **Recovery** (Section 3.5) – all activities undertaken after the occurrence of an incident to provide ongoing support to affected communities in reconstruction of the physical infrastructure and restoration of emotional, social, economic, and physical wellbeing.

Recommendation 1: The PPRR risk framework should be implemented into road agency practice.

3.1 Strategic Planning Objectives

Prior to commencing any works in relation to the prevention of, preparedness for, response to or recovery from bushfires, the strategic objectives of the task need to be identified. This allows for the minimisation of the impact of major bushfires on human life, communities, essential and community infrastructure, industries, the economy and the environment (Forest Fire Management 2015). This includes articulating:

- what functions the road agency want the road network to perform before/during/after a bushfire and how these functions contribute to public safety
- what conditions need to be in place for the road network to effectively perform each of these functions and what can be practically done to increase effectiveness
- what is the cost-benefit relationship and management practicalities of implementing solutions.

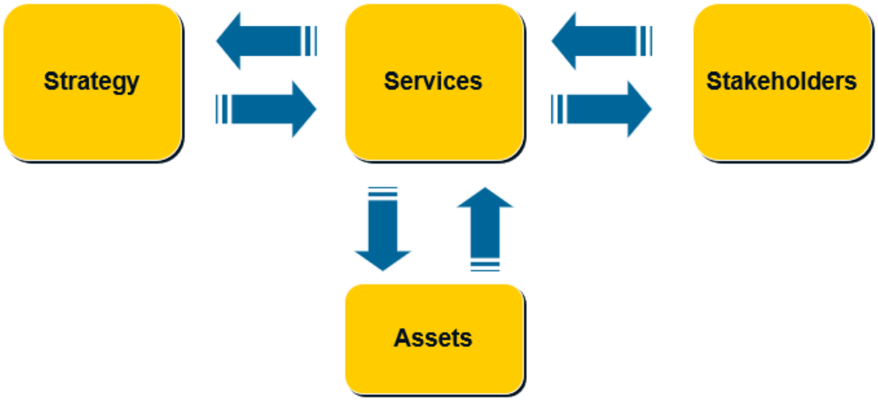
Therefore, identification of strategic objectives is a key first step in roadside fire management, similar to other natural disaster types (e.g. flood) and hazard events. An example of the strategic objectives in roadside fire management, used by the Gippsland Regional Strategic Fire Management Planning Committee (GRSFMPC) includes:

1. Prevent fires on roadsides – cause may be natural, accidental or deliberate.
2. Contain roadside fires i.e. manage the factors that affect fire spread.
3. Manage the safety of road users i.e. reduce the likelihood of people being on roads during the passage of a fire front, reduce the likelihood of the fire being close to the road.
4. Provide control lines:
   - Roads, combined with fuel modification, may provide an opportunity to limit the spread of large fires. They provide good access for suppression activities and through existing fuel-modification, can provide a continuous break.
5. Minimise the potential impact of bushfires on the community and significant community assets:
   - Road networks, individual roads, and sections of a road can be identified as being of strategic value to the protection of individual assets from a municipal and national perspective.
   - Appropriate and ongoing treatments of these roads may significantly contribute to the community's ability to sustain bushfire suppression operations and increase the community's bushfire recovery capacity.
6. Provide safe vehicle access and egress for the community and fire management and suppression operations:
   - Roads play a critical role in the protection of the community and its ability to safely 'leave early' in the event of encroaching bushfires.
   - Roads play an equally critical role in the prevention and suppression of bushfires.
   - Access for a variety of fire management vehicles must be considered and catered for.
7. Recovery from roadside fires:
   - The road infrastructure is an important asset to the community and its service ability following a major bushfire and will be critical to the community's recovery (GRSFMPC n.d.).

However, as can be seen from this methodology, this is specific to emergency management and does not provide strategies on how to manage risks within the road corridor. At Step 1 of the methodology outlined by the GRSFMPC (n.d.), road infrastructure asset management practices should be implemented in order to reduce the risk of infrastructure damage.

The asset management strategy which is implemented will drive the level of service that is provided by the asset, and the demand for these assets in accordance with economic, social and environmental considerations of stakeholders. This is described in Figure 3.3.

Figure 3.3: Strategy drives services – services demand assets



The key elements of this asset management strategy which will be significant in bushfire risk management include:

1. Ensure the asset management policy framework in place supports decisions when it comes to bushfire management and a bushfire risk assessment is effectively incorporated.

2. Ensure that the assets controlled by the road agency in a bushfire-prone area are identified and their condition including remaining service life is documented.
3. Ensure there is a documented understanding of how funding is spent on maintenance, renewal/refurbishment and ongoing operations and how bushfire risk prevention activities can be incorporated.
4. Know what levels of service the community needs from the road network.
5. Establish a long-term process and understand the requirements for maintenance and prevention funding and priorities.
6. Have well-documented and agreed upon asset management Plans, developed through consultation with relevant stakeholders (Department of Sustainability and the Environment n.d.).

These aspects can be considered using a program logic model. This methodology can be used to determine fire and road management objectives, and context the risk controls/treatments, as discussed in the following sections. A program logic model sets out the resources and activities that comprise the program, and the changes that are expected to result from them. It visually represents the relationships between the program inputs, goals and activities, its operational and organisational resources, the techniques and practices and the expected outputs and effects (Australian Institute of Family Studies 2021).

Recommendation 2: Develop a program logic model to determine road agency objectives in strategic asset management when considering bushfire risk.

3.1.1 Importance of Risk Assessment

A common theme across reviewed literature, frameworks and guidance was the importance of the first step of assessing what the vulnerability of the road network is to bushfire hazards. How to undertake a risk assessment itself is out of scope for this project. Nonetheless, it is a critical first step in this process.

TMR undertakes risk assessment for bushfires using the *Roadside Bushfire Risk Assessment Model* (RBRAM) (TMR 2021a). TMR's Maintenance, Preservation and Operations Fire Risk Management Program (Element 6) is responsible for bushfire mitigation activities within the state-controlled road reserve. The purpose of Element 6 is to minimise the chance of bushfire ignition and spread through, or from, the state-controlled road reserve through the removal/modification of bushfire fuel hazard. Element 6 requires a consistent bushfire risk assessment process to report asset liabilities related to bushfire risk, assist TMR districts with planning bushfire fuel hazard treatments and to ensure available funding is prioritised to manage the highest bushfire risks across the TMR network. Therefore, the RBRAM was developed to achieve these process requirements (TMR 2021a). The aim of the RBRAM is to assess the potential for bushfire within the road reserve and aid in the prioritisation of management. The RBRAM is used to assess bushfire risk across the state-controlled road corridor network but does not include estate outside of the road corridor (e.g. offsets, office buildings and so on). Moreover, while TMR has RBRAM for corridor management, there is currently no specified method to assess bushfire risk for a road section/project during planning and pre-construction activities. Whether the RBRAM could be suitable for this, has yet to be considered. Currently the RBRAM is only utilised by the environment management area of TMR and has not been adopted or adapted for use on infrastructure projects.

In order to assess the relative access value of the state-controlled road network, the Network Incident Bypass Assessment (NIBA) was developed. NIBA is a spatially enabled network analysis methodology developed to assess the relative importance of discrete road sections between any two nodes on the state-controlled road network. The methodology is applied separately for light and heavy vehicles (Aurecon 2020).

TMR's *Climate Change Risk and Adaptation Assessment (CCRAA) Framework for Infrastructure Projects* (TMR 2020b) provides a strategic framework for considering and responding to climate change risks on infrastructure projects. The risk management framework for assessing the climate risks was developed in accordance with AS 5334:2013 *Climate Change Adaptation for Settlements and Infrastructure – A Risk-based Approach* and TMR's *EP170 Climate Change Risk Assessment Methodology* (TMR 2020a).

The CCRAA Framework and the engineering policy *EP170* support each other. The framework provides guidance on typical adaptation and resilience risk treatments to address potential climate change risks while the engineering policy *EP170* provides advice on the minimum climate change information and assessments to be undertaken to incorporate climate change considerations into TMR's standard Risk Management Framework. The CCRAA uses a risk matrix methodology where likelihood/exposure is assessed with consequence/severity to identify the risk of climate change impacts.

In order to assess the risk of impacts of climate change, Main Roads WA has a *Guidelines: Climate Change Risk Assessment* (Main Roads WA 2019a). Bushfires are noted as one of the impacts detailed within this risk assessment guideline. In addition, Main Roads WA's Asset Management Committee endorsed the limited adoption of the Office of Bushfire Risk Management's (OBRM) Bushfire Risk Management System (BRMS) in July 2018. The BRMS system is a cloud based, geospatially enabled, risk assessment and management system specifically for bushfire risk. Main Roads WA has uploaded and undertaken a preliminary risk assessment within 400 m of a bushfire-prone area for timber/timber hybrid structures and 24-hour rest areas.

Further, Main Roads WA is developing a road closure dashboard and a pilot mapping tool for network management asset resilience. The road closure dashboard is a dashboard-style information portal developed in Microsoft Power BI that generates graphical representation of past road closure data. The main purpose of this tool is to assist asset managers to appreciate the historical level of disruptive impacts that environmental events including bushfire have had on state-owned roads. The mapping tool for network management asset resilience is a Geographic Information System (GIS) based tool that overlays various types of climate information and estimated climate risks onto a map of Main Road's road network. These tools could be used to assist with the identification of bushfire-prone areas, or bushfire risks to assets and network vulnerability.

More generally, examples of how others have undertaken risk assessments in bushfire-prone area include:

- *Bushfire Risk Assessment Guideline and Risk Mapping Methodology* developed by VicRoads (2013)
- AS 3959:2018 – *Construction of Buildings in Bushfire-prone Areas* developed by Standards Australia (2018)
- *Roadside Fire Management Guidelines* developed by Country Fire Authority (2001)
- *South Australia State Bushfire Management Plan* developed by the Government of SA (2021)
- *California's Wildfire and Forest Resilience Action Plan* developed by Blumenfeld and Porter (2021).

Bushfire-prone areas are often identified by other agencies. For example, in Victoria bushfire-prone areas are identified under the Building Regulations. In addition, in Victoria, there is a bushfire management overlay area under the Planning Scheme that is informed by state-wide bushfire hazard level mapping. Further, information is available on hazardous areas in relation to management of vegetation around powerlines, fire spread and behaviour simulations to inform fuel reduction burning etc.

Rather than undertaking a standalone risk assessment, coordinating this effort between government agencies will allow processes to be streamlined, with the outcome being a broadscale hazard map. From there, each road agency can focus on the criticality of their assets and the resultant risk to these assets[1].

If the bushfire risk profiles specific to a region are known, an understanding of the functional characteristics of the bushfire hazard, exposure to that potential bushfire and the level and type of vulnerability in a given location can be developed. These three aspects can be combined to develop what is known in literature as a

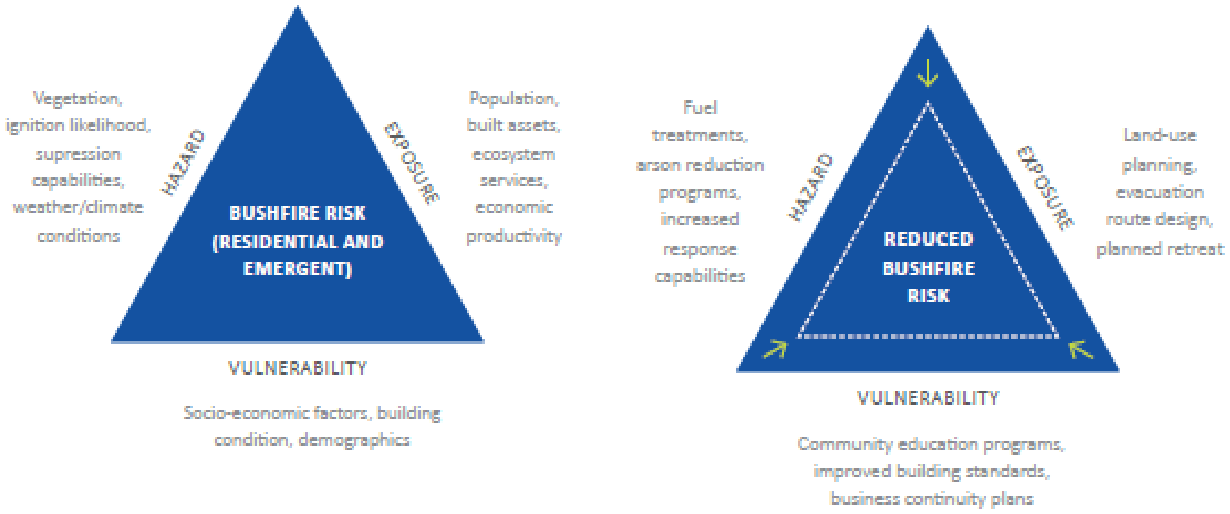
---

[1] The Queensland Government has the Queensland bushfire hazard mapping methodology, which can be accessed here: data.qld.gov.au.

The Department of Fire and Emergency Services in Western Australia has a Western Australian bushfire-prone area mapping tool here: dfes.wa.gov.au.

‘risk triangle’, with an example shown in Figure 3.4. Image A details the main elements of bushfire risk, whereas Image B details the indicative actions which can be taken to reduce those risks (March et al. 2020).

Figure 3.4: The risk triangle is a combination of exposure, vulnerability and hazard for bushfire risk



Note: This figure is based on the general concepts of risk reduction for assets (i.e. buildings, structures, etc.). Prior to implementation of concepts, this figure should be adapted to the specific context in which it will be implemented (i.e. road design, maintenance, etc.).

Source: March et al. (2020).

Recommendation 3: Ensure a risk assessment is undertaken to identify bushfire-prone areas, including likelihood and consequence of the risk in order to provide a representative risk score.

Once a risk assessment has been undertaken, this information can be used to identify if an area is bushfire-prone and what level of risk is present for that area of the road network. A key outcome of a risk assessment is to ensure that the road networks/links that will be critical in disaster recovery have been identified (Sustainable Built Environment National Research Centre 2016).

Recommendation 4: Ensure that the road networks/links that will be critical in disaster recovery have been identified.

Another key outcome of the risk assessment process is to identify what assets are present in bushfire-prone areas and what the criticality of those assets is, to ensure that any management strategies implemented are appropriate to those asset types. This includes roads (sealed or unsealed), bridges, culverts, roadside furniture, etc. It is also essential to document an asset inventory to ensure all assets within the bushfire-prone area have been identified.

Recommendation 5: Ensure all assets within the bushfire-prone area have been identified.

3.2 Prevention

While bushfires cannot be fully prevented, mitigation activities can be undertaken to reduce the likelihood, vulnerability and consequences. ‘Prevention’ is defined by the Australian Institute for Disaster Resilience as (AIDR 2021; cited in Government of SA 2021):

- all activities concerned with minimising the occurrence of incidents, particularly those of human origin
- regulatory and physical measures to ensure that emergencies are prevented or their effects mitigated
- measures to eliminate or reduce the incidence or severity of emergencies.

Prevention strategies include mitigation activities undertaken in order to ensure that an asset will be more resilient (i.e. less susceptible to the impact of bushfires). This includes material selection, geometric design, landscaping, etc.

Since 2007 there have been a number of reports into significant bushfires in Western Australia. The Special Inquiry into the Waroona Bushfire in 2016 noted that, 'There is a compelling argument that the State [Government] needs to readjust expenditure away from fire response and recovery towards a greater investment in prevention and fuel hazard management.' (Government of Western Australia 2016).

This report is focused on infrastructure managed by road authorities. It is important when implementing preventative strategies to improve bushfire resilience that ancillary infrastructure potentially managed by other authorities is considered. This can be through consulting with these authorities when selecting prevention strategies. This may include utility providers, local councils, fire and emergency services, etc.

3.2.1 Responsibilities

The typical responsibilities of Prevention in bushfire management are:

- responsibility of police to monitor arson and high-risk activities
- responsibility of local government to have a thorough system in place for processing burn permits
- responsibility of local government to provide clear information on native vegetation clearance specific to the area
- responsibility of state government to set appropriate chains of responsibility
- responsibility of the fire and emergency services authority to support local government by providing expert knowledge and advice in relation to bushfire risk, prevention and treatment
- responsibility of public and private landholders to undertaken hazard reduction practices
- responsibility of state government to prioritise asset protection and plan infrastructure strategically to support local emergency authorities (Government of SA 2021).

The road agency will sit within several of these categories. The road agency will have a responsibility to undertake and maintain hazard reduction practices, similar to private and public landholders. In addition, the road agency will need to prioritise the protection of their assets and work strategically with emergency response agencies when it comes to prioritise critical access routes. The focus is collaboration and stakeholder consultation, this is a common theme throughout this review.

Recommendation 6: Understand the roles and responsibility of each party and ensure that road agency bushfire-related practices are coordinated with the relevant parties.

3.2.2 General Considerations

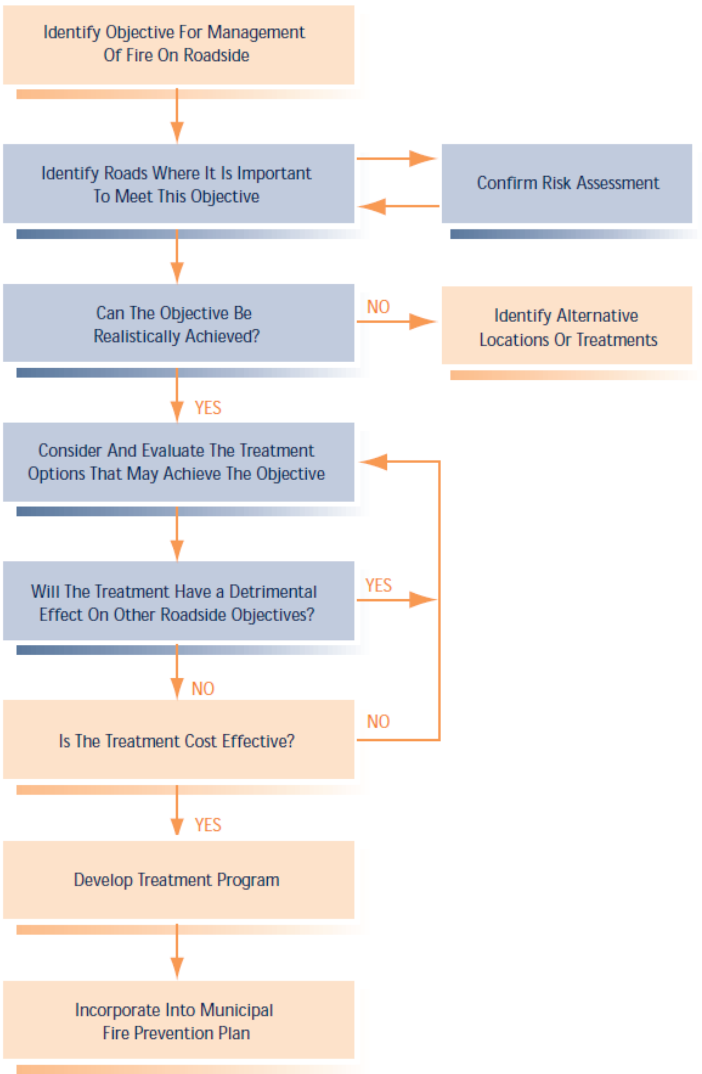
Thorne et al. (2021) noted that it is critically important to include and liaise with local fire agencies in the planning stages of a project, particularly for vegetation control plans. As cited in Thorne et al. (2021), Caltrans assessed the priority locations for vegetation treatment within the lands it owns. A 2019 analysis was undertaken of both the risk of wildfire and the risk to disadvantaged communities that may need to use the transportation network as a means of evacuation. Recommendations which emerged from this work, included that all adaptive management strategies needed to incorporate learnings from past experiences. In addition, these strategies need to be focused on resources that are potentially limited (e.g. maintenance funding), so that these resources can be funnelled into targeted management strategies. It is pivotal that these strategies are then tracked and monitored for their effectiveness, in order to inform future decision making.

The CFA's *Roadside Fire Management Guidelines* (Country Fire Authority 2001) provides state and local road agencies with a framework for the prevention and management of roadside fires, to reasonably comply with the CFA Act 1953 Section 43(1). The guidelines (Country Fire Authority 2001) identifies the core priorities as:

- prevent fires from starting on roadsides
- contain roadside fires in the event they occur
- manage safety of road users
- provide control lines (to limit the spread of a fire)
- ensure the infrastructure is preserved in a condition that allows a swift restoration and recovery post-fire.

Figure 3.5 provides a summary of the steps of the CFA's Municipal Fire Prevention Planning Process. The framework highlights the importance of restoring or treating roads of strategic importance as priority and taking into consideration other factors such as current roadside objectives and cost effectiveness.

Figure 3.5: Steps of the Municipal Fire Prevention Planning Process



Source: CFA (n.d.a).

Recommendation 7: Ensure learnings in bushfire recovery are implemented back into planning practices. Understand that strategies need to be focused on the limited resources and funding that are available, so that these resources can be incorporated into targeted management strategies.

3.2.3 Roadside Design Strategies

The Austroads *Guide to Road Design Part 6: Roadside Design, Safety and Barriers* (Austroads 2020), and *Part 6B: Roadside Environment* (Austroads 2021) provide information on the typical road design for a clear zone from the edge of the trafficked way. This zone varies with width dependent on speed. Typically, clear zones are grassed areas free from trees and are mown infrequently. Where crash barriers are located on the side of the road (typically steeper batter locations) the set back of trees is dictated by the deflection zone of the crash barrier system. This can result in trees being closer to the trafficked way compared to a situation without crash barriers. The roadside design strategies presented in this section should be considered relative to current roadside design strategies, such as those described by Austroads Guides.

VicRoads developed a *Bushfire Risk Assessment Guideline and Risk Mapping Methodology* (2013) which notes that potential roadside mitigation strategies for bushfire risk include:

- horizontal separation between fuel and vehicles through fuel-free road shoulders (maintained during the fire danger period)
- vertical separation between fuel and vehicles using fire breaks
- bare earth fuel breaks to contain small ignitions
- fuel reduction burning
- fuel management around assets adjacent to the road to reduce flame distance, flame height and radiant heat around the road.

VicRoads (2013) notes that the type of treatment used needs to be prioritised based on the identified level of risk, as well as the location and the level of practicality of the treatment for that location. Treatment options should be determined on a case-by-case basis, given consideration of both financial and physical factors. An example of treatment standards, as used by Vic DoT is shown in Table 3.1

Table 3.1: Proposed roadside vegetation management criteria

Priority rating/risk	Treatment type	Treatment standard
High/Extreme	Permanent	Permanently treated roads are managed to the current VicRoads maintenance standards specified in maintenance contracts (Standard Section 750 & 752) plus identified annual fire mitigation treatments which may include removal of hazardous trees or limbs that are likely to fall on a road in high wind events plus any other treatment as agreed to by all agencies involved in integrated fire management planning.
Moderate	Periodic	Periodically treated roads are managed to the current VicRoads maintenance standards specified in maintenance contracts (Standard Section 750 & 752) plus identified annual fire mitigation treatments which may include removal of hazardous trees or limbs that are likely to fall on a road in high wind events.
Low	Routine	Routinely treated roads are managed to the current VicRoads maintenance standards specified in maintenance contracts (Standard Section 750 & 752).

Source: Adapted from VicRoads (2013).

Recommendation 8: Implement bushfire prevention techniques based on the outcome category of the risk assessment i.e. for extreme risk, implement permanent treatments; for moderate risk implement treatments as part of periodic maintenance; for low risk implement treatments as part of routine maintenance.

The Department of Sustainability and Environment (2012) developed a Guideline for *Roadside Vegetation Management for Bushfire Risk Mitigation Purposes*. This document outlines the following process when considering vegetation removal:

- Conduct a risk assessment to identify priority roads for fire mitigation treatments.
- Undertake a roadside treatment selection process through collaboration with relevant agencies. The recommended treatment selection process is outlined in Section 3.2.5.
- Vegetation removal activities to be undertaken are to be documented in a plan. Vegetation removal that may have significant environmental impacts should require a planning permit.
- Develop a works plan to document the works to be undertaken and the objective of the works.

In 2013, Deloitte Access Economics was commissioned to prepare the report, *Building our Nation's Resilience to Natural Disasters* by the Australian Business Roundtable for Disaster Resilience & Safer Communities. The report found that investing in better vegetation management has a positive benefit-cost ratio of 1.3:1 (Deloitte 2013).

Several of these strategies, particularly relating to vegetation management, have been implemented in the USA. The Caltrans Division of Research, Innovation and System Information (CDRISI 2020) undertook research into roadside design strategies for fire presuppression which had been implemented by Departments of Transportation across the USA. The strategies noted included:

- implementing vegetation free zones
- the use of inert materials on roadsides
- specifying plant materials to be used
- the use of vertical firebreaks
- other effective fire suppression design strategies such as prescribed burns.

CDRISI (2020) also consulted with other Departments of Transportation regarding the effectiveness of each of these strategies, using a rating scale of 1, being not at all effective to 5, being extremely effective. The implementation of vegetation free zones, the use of inert material and the use of fire resilient culverts were the most frequently cited as being effective. A summary of these key fire presuppression strategies to be considered in roadside design is provided in the following sections.

Main Roads WA, as outlined in *Operational Procedure 108 – Bushfire Risk Management and Mitigation* (Main Roads WA 2020), has defined road maintenance levels of service in terms of Road Maintenance Intervention Parameters (RMIPs). RMIPs that contribute to bushfire risk management include: 6.03 Overhanging Trees and Limbs, 6.04 Excessive Roadside Vegetation and 6.05 Fire Hazards. These RMIPs are assessed in advance of the bushfire season each year. For 6.05 Fire Hazards, the following risk inspection activities are to be undertaken:

- 6.05.01 Any fire hazard near timber structures, roadside stopping areas, etc.
- 6.05.02 Any vegetation within < 10 m beyond the kerb line for both sides of a timber structure
- 6.05.03 Any vegetation within 500 mm of guideposts, guardrails, signs, etc.
- 6.05.04 Any vegetation on an existing firebreak.

It should be noted that where utilities are located in the road corridor there are typically offset requirements. For example, for above ground services such as utilities, a grassed verge below will typically be used in order to provide access. Similarly, below ground services are not planted on. These areas are typically treated with a grass finish relative to their offset requirements. Consideration needs to be given to the offset requirements of utilities, prior to implementing any roadside management strategies for bushfire prevention.

Recommendation 9: Consideration needs to be given to the offset requirements of utilities, prior to implementing any roadside management strategies for bushfire prevention. It is recommended to consult with the relevant utility providers or authorities.

Implementing a protection zone

The Fire and Emergency Services Authority (Fontaine & Enright 2011) Western Australia note that the impact from fire on assets can be greatly reduced when there is little or nothing to burn. In this instance, the vulnerable road infrastructure will be protected if there is nothing to burn on the roadsides. This can be implemented by introducing a protection zone.

The aim of the protection zone is to reduce the fuel that can burn, within a minimum 20 m radius of critical structures identified on critical links, to ensure that there will be no direct flame contact from a bushfire, and to reduce the risk of ember attacks. This can be achieved by:

- maintaining a minimum 2 m gap between trees and the critical structures and have no trees overhanging the critical structure

- keeping the grass short and pruning the scrub so that it is not dense and does not have fine, dead aerated material in the crown of the scrub
- raking up leaf litter and twigs under trees and removing trailing bark
- pruning lower branches up to 2 m off the ground to stop a surface fire spreading to the canopy of the trees
- creating a mineral earth firebreak to interrupt the continuity of vegetation and litter (see the use of an inert firebreak in Section 3.2.3)
- making sure there is a gap between shrubs and trees and that they are not clumped together
- ensuring fences and roadside furniture that are combustible will not burn down and break the integrity of the zone around the critical structure
- keeping structure drainage and expansion joints free of leaves and other material that can burn and spread the fire.

Recommendation 10: Implement a protection zone around structures that have been identified as critical, for example, timber bridges which have been defined as part of a critical route for disaster evacuation.

Vegetation free zones along the pavement edge/fuel-free road shoulders/horizontal firebreaks

A firebreak is defined as a strip of land that has been cleared of all trees, shrubs, grass and other combustible material, providing a 'fuel free' area. Firebreaks are intended to allow access for firefighting vehicles and can provide a fuel free area from which prescribed burning can be undertaken. They may slow or stop the spread of a low-intensity bushfire however they should not be relied upon to prevent the spread of a fire (DFES 2018).

Firebreaks are often constructed with a machine such as a dozer, front end loader, grader, tractor or skid-steer loader. In some situations, they may be created by other methods such as hand tools, ploughing, herbicide treatment, grazing stock and controlled fire (DFES 2018).

Firebreaks are more effective when they are able to cause a break in both the vertical and horizontal continuity of the fuel and this reduces the flame length, making the fire easier to suppress. In addition, the effectiveness of a firebreak will be impacted by the proximity and height of nearby trees and shrubs which may create embers.

Across the USA, the concept of vegetation free roadsides to reduce the spread of possible roadside ignition events is commonly used. Examples from State Departments of Transportation are as follows:

- Caltrans, California Department of Transportation has district landscape specialists from their maintenance divisions who regularly liaise with local fire officials to develop vegetation control plans. In addition, the maintenance division within Caltrans has implemented roadside fire strip widths from 8 feet (~2.4 m) to up to 10 feet (~3 m). Currently, the development of a defensible space is being investigated. This space will focus on establishing firebreaks through both horizontal and vertical spacing of plant materials (discussed further in subsequent sections).
- The Arizona Department of Transportation (ADOT) specifies the requirements for vegetation free zones along roadsides on a project-by-project basis. This decision is made based on the region and a thorough review undertaken by the landscape architecture division. The minimum distance for dense vegetation commencement tends to be either 30 feet (~9 m) or 60 feet (~18 m) depending on the region.
- The Nevada Department of Transportation defines minimums for vegetation free zones of 10 feet (~3 m) from the pavement edge for new roadway designs, and 7 feet (~2 m) in road maintenance.
- The Oklahoma Department of Transportation defines minimums for vegetation free zones of 30 feet clear from the road.
- The Colorado Department of Transportation specifies both a minimum and considerations of requirements on a project-to-project basis. If guardrail exists adjacent to the road edge, weeds are eradicated under and around the structure to reduce the spread of fire. In addition, a mow zone of typically 15 feet (~4.5 m) is maintained adjacent to highways.

- The Utah Department of Transportation specifies that there is to be no vegetation on the untreated base course layer of a road (CDRISI 2020).
- Both the Florida and Utah Departments of Transportation recommend frequent mowing to reduce the impact of bushfires in fire-prone areas (CDRISI 2020).

The Vic DoT notes the importance of maintaining vegetation free zones throughout bushfire seasons. In Victoria, the predominant treatment chosen for managing potential roadside ignitions is slashing a 3-m break on the road verge, thus providing a fuel free area suitable for vehicles to pull over if required (Terramatrix 2013).

The CFA (2001) notes that a slashed verge will be sufficient if the current road shoulder is of sufficient width. The slashed verge should be maintained at 10 cm height during the fire danger period. However, the CFA (2001) notes that there are limiting factors when it comes to the success of implementing vegetation free zones. These include erosion occurring on the roadsides, ground disturbance encouraging weed growth, visual amenity reduction and Occupational Health and Safety (OH&S) concerns with herbicide use. Although research has shown that the rate of spread of a fire in slashed grass is about the same as that in standing grass (Cheney & Sullivan 1997; cited in CFA (2001)), the flame height will be approximately halved. Where there is an insufficient road shoulder, the CFA (2001) recommends an inert material firebreak.

However, it should be noted that the impact of roadside vegetation and landscape on a bushfire's ability to spread significantly is influenced by the downwind condition. Therefore, consideration needs to be given to the potential prevailing conditions (VicRoads 2013).

The Western Australian Department of Fire and Emergency Services Rural Fire Division has developed *A Guide to Constructing and Maintaining Firebreaks* (DFES 2018). This document provides land managers with advice on constructing and maintaining firebreaks on the rural-urban interface, farms, pastoral leases and reserves. This document recommends that firebreaks be at least 3 m wide, with an additional horizontal clearance of half-a-metre on both sides and a vertical clearance of 4 m to allow the passage of firefighting vehicles.

Main Roads WA also have guidelines for vegetation placement (Main Roads WA 2013). In agricultural areas, vegetation is to be controlled as described in Figure 3.6. The maintenance zone is where fire control prevention measures are to be implemented.

Lastly the Main Roads WA *Operational Procedure 108 – Bushfire Risk Management and Mitigation* (Main Roads WA 2020) identifies that vegetation management in each region is guided by a regionally specific vegetation maintenance plan. Vegetation management treatments include but are not necessarily limited to mowing/slashing of road verges, herbicide treatment in areas such as road shoulders and verges and lateral and overhead pruning/clearance of roadside vegetation.

Recommendation 11: Implement vegetation free zones along roadsides and ensure these zones are maintained prior to bushfire seasons. Consideration should be given to the environmental context on a case-by-case basis.

There is some contention around the effectiveness of vegetation removal or 'slashing'. The CSIRO National Bushfire Research (1988; cited in Country Fire Authority n.d.b) are quoted as stating:

> Road maintenance slashing is considered in many areas as fire prevention slashing for the purpose of firebreaks.
>
> It is arguable that this type of slashing, done under the name of fire prevention, may raise false expectations, as the breaks created will be of limited value during high fire danger periods.
>
> Slashing of treed roadsides, which are often categorised as the areas of greatest conservation value, usually does not assist fire prevention, as these areas are easily compromised by leaf and bark litter.

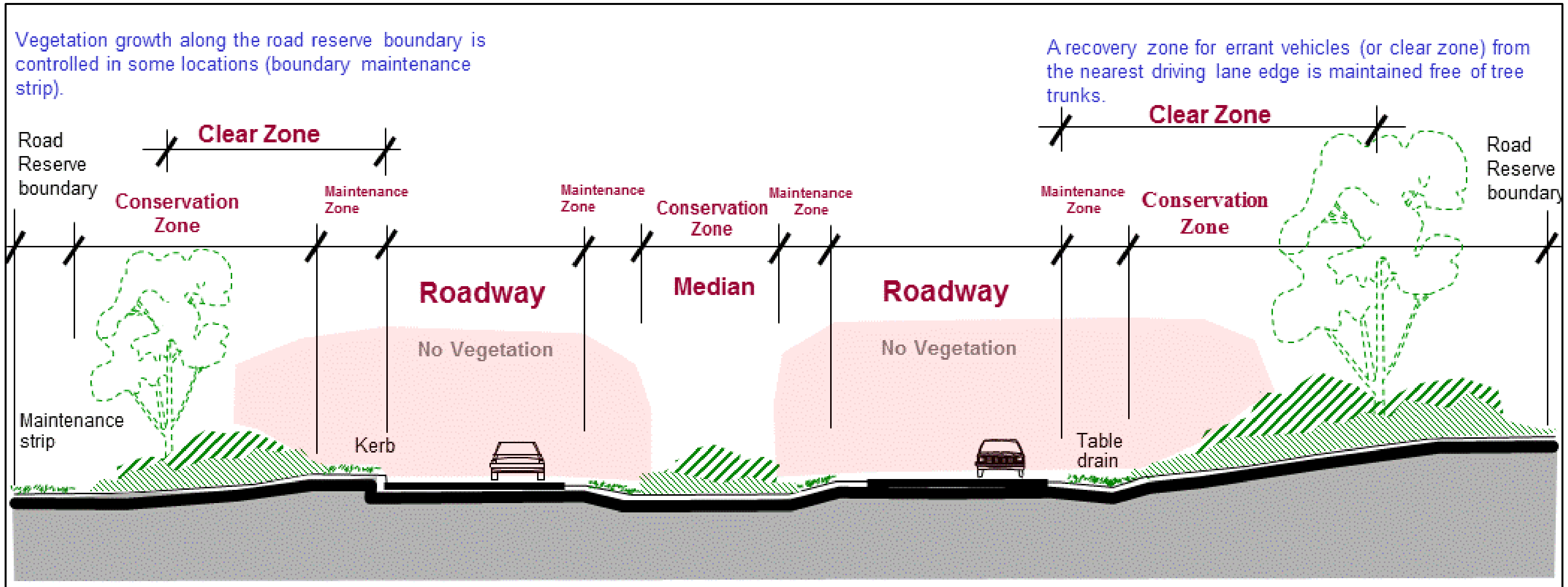
However, as stated previously, research has shown that even though the rate of spread of a fire in slashed grass is about the same as that in standing grass (Cheney & Sullivan 1997; cited in Country Fire

Authority n.d.b), the flame height will be approximately halved. This means that suppression is more likely to succeed. The difference of a reduced flame height in suppression may mean the difference in being able to extinguish a fire, after a wind change (Country Fire Authority n.d.b).

It should be noted that, prior to the implementation of vegetation clearance strategies, consideration needs to be given to the environmental context on a case-by-case basis. Consideration needs to be made towards to the environment value trade-off, and habitat destruction that may occur through these practices. In addition, recognition needs to be given to the potential paradox between the environmental outcomes that can be achieved by maintaining vegetation connectivity, particularly around waterways, for fauna movement and for weed prevention and erosion protection and balancing this with the risk of bushfires within this vegetation.

Further, it should be noted that vegetation free zones may be impractical to apply in some sections of the network, given other environmental considerations and potential soil stability or erosion issues for example, where soils are dispersive, of where high rainfall is often experienced. In addition, consideration would need to be given to the potential use of herbicides for vegetation clearance, and if regular use could be harmful to the surrounding environment (e.g. run-off into waterways).

Figure 3.6: Typical cross-section of a road reserve in rural or bushfire-prone regions



ROAD RESERVE - VEGETATION MANAGEMENT OBJECTIVES

ROADWAY
No Vegetation

Width as necessary to meet operational needs.

- **Pavement stability**.
- Off road surface drainage.
- Driver visibility.
- Placement of road hardware.
- Maintained free of debris.
- Maintain and enhance visual quality.

MAINTENANCE ZONE
Vegetation controlled

Zone width varies by location and height of vegetation is controlled to meet operational needs.

- **Vehicle recovery area**.
- Maintain clear sight distances at curves intersections and driveways.
- Ensure effective surface drainage.
- Prevent erosion.
- Control weeds.
- Control fires.
- Maintain clearances to utilities.
- Maintain and enhance visual quality.

CONSERVATION ZONE
Vegetation conserved

Width to road reserve boundary varies by location
Vegetation type and condition varies by location.
Vegetation is managed as necessary to:

- **Maintain safety clear zone** (or recovery zone).
- Remove hazards (overhanging branches).
- Maintain clearances to utilities.
- Control fires.
- Control weeds.
- Prevent erosion.
- Maintain and enhance visual quality.
- Conserve and enhance biodiversity.
- Preserve heritage values.

Source: Main Roads WA (2013).

The use of inert materials as a firebreak

A firebreak is a strip of land that is cleared of all flammable material. The use of inert materials is also a concept implemented by various Departments of Transportation in the USA. This refers to the use of road shouldering materials, or rocks/mulch, to develop a barrier between the road and the landscape. This is undertaken by the Arizona and Nevada Departments of Transportation, for fire-prone areas (CDRISI 2020). In addition, the paving or sealing of road shoulders can provide an effective inert firebreak and a safe surface for additional traffic during evacuation or for emergency services access.

The CFA (n.d.a) notes that graded firebreaks, made from inert materials or bare earth breaks should be as close to the road as possible. The effectiveness of bare earth firebreaks depends on the width of the break, the fire intensity and the presence or absence of trees and shrubs within 20 m. For road reserves with heavy grass fuel loads, if there are trees present on the road reserve, the success of a 3 m bare earth firebreak is limited to about 20% on fire danger days above a moderate category. If there are no trees, this break would be effective on about 50% of occasions. For a 6 m bare earth break, the success rates are about 40% and 95% with and without trees respectively.

The CFA in Victoria recommends the use of at least a 3 m graded strip, which can double as both a vegetation free-zone and as a pull-over area for road safety.

Recommendation 12: Inert materials should be used in conjunction with vegetation free zones to create a firebreak between the road and the landscape in high-risk areas.

It should be noted that firebreaks are not currently considered as part of road design by TMR and Main Roads WA. Therefore, this could be incorporated into planning and design stages of projects.

Recommendation 13: Incorporation fire breaks should be considered in the planning and design stages of road projects (i.e. implemented as part of the road shoulder).

Specifying plant material in roadside and verge design

Some US Departments of Transportation also specify the types of plant materials that can be used outside of the vegetation free zones in order to ensure that the material does not contribute to the growth of a fire in fire-prone areas. Examples of this include:

- The Colorado Department of Transportation specifies native grass and forb seed mixes for roadside revegetation following construction rather than specifying the setback of plant material in fire-prone areas. In addition, the Department clears setbacks of woody trees and shrubs as part of routine maintenance, generally for traffic safety and sight lines rather than due to fire risk clearance.
- The Nevada Roadway Design Division undertakes landscaping, such as the addition of trees, shrubs and large boulders, outside of the roadway or vegetation free zone. The majority of these ‘beautification’ efforts occur around interchanges.
- The New Mexico Department of Transportation specifies a mowing height for grass on roadsides to deter fires which may be caused by catalytic converters on vehicles.

The City of Rockingham’s (Western Australia) *Verge Development Guideline* (2019) notes that in areas identified as bushfire-prone or where bushfire risk is a concern, appropriate plant selection and maintenance can significantly reduce the risk of bushfires spreading. This is important in both densely populated rural areas and more remote areas as fires can spread many kilometres from a fire front. Research has identified a number of plants that are fire retardant and/or reduce the intensity of fire. Information on this can be found in the documents such as the *Plant Guide within the Building Protection Zone for the Swan Coastal Plain of Western Australi*a (Fontaine & Enright 2011).

Recommendation 14: Ensure appropriate plant types are selected for roadside verges if the area is known to be bushfire prone.

Consideration of requirements based on vegetation type

Australia's diverse landscapes create a challenge for vegetation classification as particular vegetation types can lead to greater fire intensity, flame length and resultant radiant heat flux. Whilst this issue has yet to be tackled within the roadside environment, it is well documented in the Australian Standard for *Construction of Buildings in Bushfire-prone Areas*, AS 3959:2018.

AS 3959 involves the determination of what is known as a Bushfire Attack Level, an assessment undertaken to determine the level of bushfire resistant construction required. The site assessment process of this calculation takes into consideration the type of vegetation, the slope of the landscape, the proximity of the vegetation to the building, and the fire weather (expressed as a Fire Danger Index) of regions within states and territories.

AS 3959 breaks Australian vegetation into 8 major categories for evaluation, listed below and summarised in Figure 3.7:

- Forest
- Woodland
- Shrubland
- Scrub
- Mallee/Mulga
- Rainforest
- Grassland
- Tussock moorland.

Once the vegetation has been categorised, AS 3959 provides data tables that allow the designer to determine Bushfire Attack Level (BAL), based on proximity to the site and the slope of the landscape.

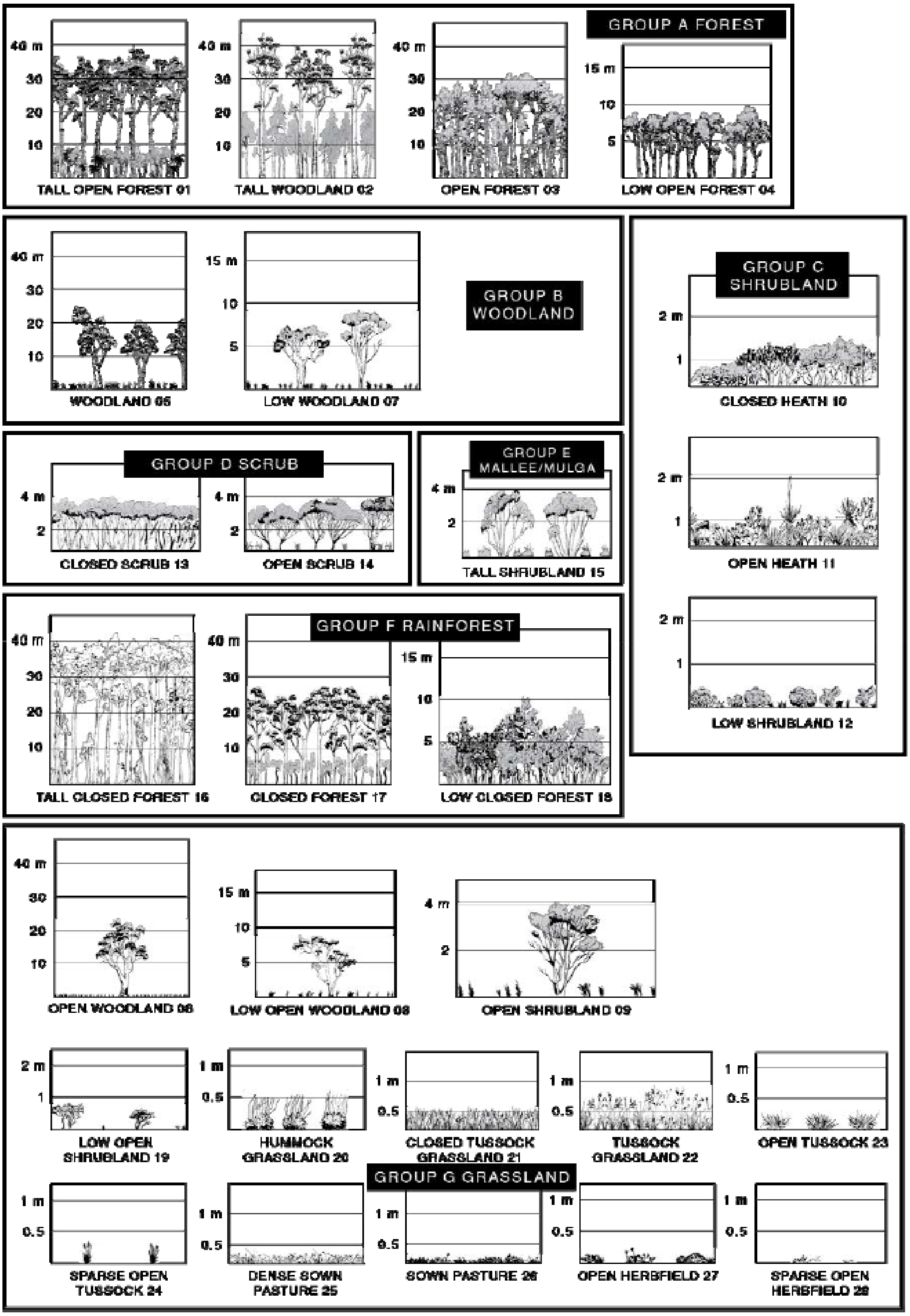
As an example, forest vegetation situated on a flat slope within NSW would result in a larger design radiant heat value if it were within 19 m of the building in question, gradually reducing to lower design radiant heat values at 48 m from the building.

In contrast, grasslands (which have a much lower fuel load than forest) on a 0-degree slope in Queensland need only be within 4 m to receive the highest level of design radiant heat categorisation. The radiant heat-distance relationship of grasslands tapers more aggressively than forests and can be classified as low when 12 m from the building.

Had the same grassland been present on a 15-to-20-degree down slope from the building, the highest radiant heat category would apply at an increased distance of 7 m.

The vegetation vs. radiant heat vs. distance relationships evaluated in AS 3959 are based on incremental research innovations and are applicable exclusively to building elements. Substantial research would be required to develop an equivalent specification and relationships for the road environment. However, AS 3959 does provide a valuable skeleton structure for what factors should be considered, such as vegetation and sloping characteristics of the terrain. This specification is discussed to provide insight into bushfire management standards present in other industries and AS 3959 cannot be applied to the road infrastructure space.

Figure 3.7: Australian vegetation categories for evaluation



NOTE: See Figures 2.4(B) to 2.4(H) for greater vegetation detail.

Source: AS 3959:2018.

The use of vertical firebreaks

Vertical firebreaks refer to strategies which are implemented to stop a fire spreading vertically through fuel types. This includes reducing the vegetation height directly adjacent to a firebreak or vegetation free zone by a roadside. The Departments of Transportation in Michigan and New Mexico employ this technique. In Michigan, vegetation removal is the primary practice, and in New Mexico lower mowing heights are required from right of way fence to right of way fence (CDRISI 2020).

For vertical firebreaks, the Western Australian Department of Fire and Emergency Services Rural Fire Division recommends a vertical clearance of 4 m.

However, as mentioned, consideration needs to be given to the environmental context of the region on a case-by-case basis, prior to implementation of specific strategies. For example, in the case of vertical fire breaks, consideration needs to be given to the fauna residing in the region that may be affected (e.g. gliders).

Recommendation 15: Where possible vegetation heights should be reduced close to the road as a vertical firebreak. This includes large trees and flammable materials used for roadside furniture.

3.2.4 Roadside Maintenance Strategies

This section details strategies which can be used in order to reduce bushfire risk, and prevent bushfire impacts, during the maintenance phase of the road life cycle. This includes fuel reduction activities, which can be undertaken in conjunction with road maintenance. In addition, as part of road maintenance, all strategies implemented as part of roadside design need to be maintained (i.e. vegetation free-zones).

It is of key importance where road maintenance strategies have been implemented, that these are adequately reported and communicated. This will ensure that resources can be effectively prioritised in terms of areas that have had their bushfire risk managed and areas that have not.

Recommendation 16: Develop a data set/mapping tool to identify when areas have been managed with fire prevention activities or when these areas are due to be managed, relative to their vegetation type/category.

Fuel reduction/prescribed/planned to burn

Another effective fire presuppression strategy is the implementation of fuel reduction burning, prescribed burning, or planned burning, which is defined as the process of planning and applying fire to a predetermined area, under specific environmental conditions, to achieve a desired outcome (Department of Environment and Water (DEW) 2018). Prescribed burns are used to reduce fuel loads across strategic areas of public and private land to help limit the spread and intensity of bushfires and protect communities (DEW 2018).

When undertaken on the road reserve, prescribed burning may temporarily reduce surface fuels to a minimum and deprive an ignition source of fuel. In areas where there is a history of successful fuel reduction burning and where there is no dispute over the application of this treatment, it is the suggested practice by the CFA Victoria (n.d.a).

Hazard reduction burning is undertaken in Queensland. TMR in collaboration with the Queensland Fire and Emergency Services have developed guidelines for *Hazard Reduction Burns within the State-controlled Road Corridor* (TMR 2021b). The document provides clarity on the process for obtaining approval from TMR to conduct a hazard reduction burn within the state-controlled road corridor and from Queensland Fire and Emergency Services (QFES) to light the fire for various scenarios, depending on who has requested and is responsible for the burn.

The SA Department of Environment and Water, in collaboration with National Parks SA, developed a *Guide to Prescribed Burning*. Plants regrow and re-establish surface and elevated fuel layers over time. Depending on the type of vegetation it can take as little as 5 years or as long as 30 years for the fuel level to return to how it was before the fire. The 'fuel hazard' (amount of available fuel for a bushfire) will typically be lower than it was pre-fire for at least 10 years (DEW 2018). This highlights the importance of maintenance of these areas on the roadside.

In Kansas, the Department of Transportation implements these prescribed burns across the grass on the right of way side of the road (CDRISI 2020).

For Main Roads WA, a Memorandum of Understanding (MOU) was established in October 2016 between the Department of Biodiversity, Conservation and Attractions (DBCA) to encourage both parties to work together to facilitate periodic prescribed burning along and adjacent to the road reserve.

Recommendation 17: Prescribed burning should be undertaken in collaboration with the relevant rural fire service to reduce fuel loads along roadsides particularly along roads which are critical access and evacuation points.

Cultural burning

Cultural burning describes burning practices developed by Aboriginal people to enhance the health of Country and culture. Cultural burning is an important part of how Aboriginal people have practiced cultural land management for thousands of years, supporting the regeneration and management of flora and fauna and helping to prevent large, out of control bushfires. This is similar to the concept of contemporary prescribed burning (DFES 2021).

Prescribed burning undertaken by land management agencies across Western Australia broadly follows principles of cultural fire management. Burning is conducted during cooler months at a size and scale that aims to promote and maintain a range and mosaic of fuel ages across the landscape. Increasing engagement between Traditional Owners and other land managers in building an understanding of the nuances and the opportunities to improve fire management practices through a partnership approach (DFES 2021).

Recommendation 18: Collaboration with local Indigenous Australian communities should take place to understand the landscape and cultural burning practices.

Management of tree hazards

Australasian Fire and Emergency Service Authorities Council developed a guideline for *Managing Tree Hazards* (2018). Tree hazards are events such as falling trees and falling limbs/branches. These pose a safety risk for not only road users but also emergency service responders or personnel undertaking prescribed burning activities. In addition, a potential also exists for tree hazards to interact with other hazard types such as those associated with gas supplies, water supplies, powerlines (above and below ground), adjacent buildings and trees and terrain features (e.g. steep slopes).

As a prevention activity, trees should be assessed for the level of risk they pose. Tree hazards should be continually assessed in emergency management and prescribed burning contexts due to the potential for rapid changes to occur in relation to the hazard posed by falling trees, limbs and branches, resulting from fire, wind, flooding or operational activities.

Characteristics that indicate a potential tree hazard are as follows:

- trees with hangers or damaged limbs that could fall and impact personnel in planned work areas or access routes
- trees affected by one or more of the following: excessive rot content including dry sides, scars or hollows; exposed root systems; root, trunk or stem damage; storm, snow or fire damage; impact by machinery, snigged logs or insect attack
- trees with shallow root systems in unstable, eroded or steep ground
- dead trees
- trees that have been cut, wind thrown or pushed up and which have become caught in or lodged against another tree, stopping it from falling to the ground (e.g. a hung-up tree)

- trees with excessive lean or an obvious lean towards the work area or trees with potential to fall on to other trees and impact the work area (Australasian Fire and Emergency Service Authorities Council 2018).

When undertaking hazard reduction activities, consideration needs to be given to:

- the structural characteristics of trees
- the tree's contribution to slope stability (i.e. will the removal of a tree result in other environmental or operational risks such as erosion or an unstable slope?)
- the tree's exposure to the causal factors and external influences of tree hazard
- the cultural, social or economic values associated with a tree or its immediate surroundings
- the operational context (e.g. does a given road need to be accessed?).

Methods of tree hazard reduction in prevention include:

- elimination/removal of trees
- clear fuel around trees (using hand tools or machinery)
- candle (burn) tree to remove flammable bark during suitable conditions
- application of ground-based retardants or suppressants
- wetting down of trees with water (Australasian Fire and Emergency Service Authorities Council 2018).

Recommendation 19: As part of permanent, periodic and routine maintenance activities, (based on bushfire risk) tree hazards should be managed.

3.2.5 Roadside Vegetation Treatment Selection Process

The Department of Sustainability and Environment's (2012) Guideline for *Roadside Vegetation Management for Bushfire Risk Mitigation Purposes* provides a treatment selection process to assist road managers with determining which fire risk mitigation treatments will provide the most benefit to the community, with consideration for other potential impacts such as amenity and the environment.

The guideline states that the treatment selection process should include multi-agency consultation (see Section 3.3.5 on Stakeholder Consultation) to assist with selecting and assessing high priority roads; and to determine the appropriate fire mitigation treatments, including any required vegetation treatments.

Recommendation 20: A multi-agency stakeholder group for risk identification and treatment selection should be implemented. Stakeholders should be selected on a case-by-case basis, based on the issue to be discussed.

- **a road design engineer from the relevant road agency**
  - **Queensland Department of Transport and Main Roads**
  - **Main Roads Western Australia**
- **a landscape architect or horticultural specialist from the relevant road agency**
  - **Queensland Department of Transport and Main Roads**
  - **Main Roads Western Australia**
- **a municipal fire prevention officer**
- **a council environmental officer**
- **a biodiversity officer from the state environment department**
  - **Department of Water and Environmental Regulation, Western Australia**
  - **Department of Environment and Science, Queensland**
- **an emergency management representative from the relevant fire services authority**
  - **Queensland Fire and Emergency Services**
  - **Department of Fire and Emergency Services, Western Australia**
- **a state environment department fire prevention planner and/or an operational officer from the relevant fire services**
  - **Queensland Fire and Emergency Services**
  - **Department of Fire and Emergency Services, Western Australia.**

Prior to the commencement of the treatment selection, the multi-agency group needs to ensure that all environmental and cultural issues associated with vegetation removal have been resolved. Relevant legislation should be consulted (e.g. *Environmental Protection and Biodiversity Conservation Act*, *Aboriginal Torres Strait Islander Heritage Protection Act*, *Australian Heritage Council Act*, etc.).

The treatment selection process, as adapted from the Department of Sustainability and Environment's (2012) Guideline for *Roadside Vegetation Management for Bushfire Risk Mitigation Purposes,* may include, but is not limited to, the following steps:

1. Selecting roadside vegetation treatments (including fuel reduction burning)
2. Consulting land use, settlement and landscape scale planning provisions under regional and municipal fire planning processes
3. Educating the community about fire preparedness, vegetation management and 'leave early' options
4. Consideration of additional or other strategies and responses contained in fire services operations plans
5. Consideration of environmental implications of treatment options, this may limit some options
6. Consideration of environmental law
7. Developing a works plan for selected roadside treatment practices and seeking endorsement
8. Implementing the works plan.

Once the treatments have been established for each high bushfire risk road, they need to be prioritised and works budgeted for. A workplan should then be developed, identifying the location of works to be completed, the roadside management objective being managed for, and the type of treatment being carried out.

Recommendation 21: Develop a work plan, identifying the location of works to be completed, the roadside management objective being managed for, and the type of treatment being carried out – for all selected and prioritised treatments.

When selecting a roadside bushfire prevention strategy, such as vegetation clearance to be implemented as part of road maintenance, consideration should be given to the current maintenance requirements present in contracts and the current layout of the roadsides. For example, it is likely that road maintenance contracts (e.g. within TMR) do not include levels of service relating to fire risks. Therefore, any such any works related to fire hazard reduction are funded and managed outside yearly maintenance contracts. However, there may be some parallels with other maintenance activities that could be built upon. For example, there is similarity between the establishment of 'clear zones' for the purpose of creating a fire break and a 'clear zone' as a buffer for errant vehicles. This is one aspect which is generally considered within maintenance contracts. Although, it should be noted that the errant vehicle 'clear zone' is limited to non-frangible vegetation so it would be reasonable to expect shrubs and small trees within the 'clear zone'. Furthermore, where there are safety barriers the need for 'clear zones' is eliminated leading to an increase in large vegetation and potential fuel loads in these areas.

3.2.6 Consideration of Environmental Law

As described by the Australian Government's Department of Agriculture, Water and the Environment (2021), Australia's key national environment law is the *Environment Protection and Biodiversity Conservation Act* 1999, also known as the EPBC Act. This legislation regulates activities that are likely to have a significant impact on nationally protected assets.

The state and territory governments have primary responsibility for care and management of the environment. National environment law does not generally regulate fire prevention measures taken by state and territory governments, and only applies in limited circumstances. Fire prevention activities only need federal environmental approval if: they are likely to have a significant impact on a nationally protected assets, and they are not specifically exempted by the national environment law.

National environment law is not about regulating day-to-day land management. Fire prevention activities that are unlikely to require approval by the federal government may include:

- routine fuel reduction burns, including roadside burns, done in accordance with state or territory law requirements
- routine maintenance of fence lines, access roads or tracks

- routine maintenance of existing firebreaks, fire infrastructure, services and utilities
- replacing sheds or other infrastructure at the same site
- localised weed control by hand or machinery
- minor sediment and erosion prevention works and repairs
- temporary repairs and track closures
- clearing of a defendable space around a home or rural asset in accordance with state/territory and local government requirements.

These examples are a general guide only. Whether a particular activity will have a significant impact on a nationally protected asset is influenced by a variety of factors and must be considered on a case-by-case basis. For example, there may be compliance issues for the removal of vegetation, including the need to maintain wildlife habitat in the form of tree hollows. This could impact on a program of vegetation removal for the purpose of establishing fire breaks etc.

In addition, consideration needs to be given to relevant legislation in states and territories as well as any local planning schemes that may be in place. This needs to be reviewed on a case-by-case basis.

Recommendation 22: Ensure all relevant environmental legislation has been consulted, prior to implementing any bushfire prevention programs.

3.2.7 Roadside Furniture Design Strategies

As well as vegetation control, Departments of Transportation in the USA implement strategies around their roadside furniture. Some of these strategies include:

- In addition to preventing weed growth under guardrail and around signs, Caltrans uses metal posts for guardrails and signs in fire-prone areas.
- Arizona, Oklahoma, Pennsylvania and Utah use standard hardware. Similarly, Idaho uses hardware that is compliant with American Association of State Highway and Transportation Officials (AASHTO)'s *Manual for Assessing Safety Hardware* (MASH) (AASHTO 2016).
- The Kansas Department of transportation specifies the use of both wood and steel posts.
- The Colorado Department of Transportation does not use herbicide sprays under and immediately adjacent to guardrails to suppress weed growth (CDRISI 2020).

Based on this, it is recommended that roadside furniture, such as road signs, are constructed from fire resistant materials (e.g. metal posts). In addition, roadside vegetation management strategies (Section 3.2.3) should be implemented to ensure there is no fuel surrounding key road signs. Maintenance of this vegetation can be undertaken in collaboration with road maintenance activities.

Recommendation 23: Bushfire risk should be integrated in the design and maintenance strategies for roadside furniture. This includes removing vegetation growth and using metal posts (rather than timber).

Further, consideration should be given to how roadside furniture can assist with disaster prevention, preparedness, response and recovery. For example, Intelligent Transport Systems (ITS) can be used for the communication of hazards, road closures and alternative routes. The location of ITS at key decision points along the network is essential, so that road users can be notified and diverted if there is a danger or road closures.

Recommendation 24: Intelligent transport Systems (ITS) should be incorporated in roadside furniture design, to assist with the communication of information in a disaster event.

Consideration should also be given to truck stops and rest areas that may have infrastructure. This includes signage, picnic tables, toilet blocks etc. When planning, designing and constructing roadside stopping bays in bushfire-prone areas preventative strategies should be considered. This is because, where evacuation facilities are not available, any part of the road reserve, such as a roadside stopping bay, may be used as an evacuation facility.

3.2.8 Road Design Strategies

When selecting road design strategies, consideration should be given to the risk assessment that has been undertaken for the bushfire-prone area. In addition, the type of road that is likely to be designed should be taken into account. For example, there will be difference in the risk associated with a flatter road corridor with grassed clear zones, compared with a narrower road corridor with steep batters, crash barriers and nearby trees.

In order to plan for bushfire protection, the New South Wales Rural Fire Service & Planning (2001) has guidelines for both public roads and property access roads**.** The design criteria for public roads are as follows:

- Roads should be two-wheel drive, all weather roads.
- Sealed roads should be two-way, that is, at least one traffic lane in either direction (ideally 3.5–4 m wide per lane) with shoulders on each side.
- Perimeter roads in a housing estate should have a minimum total road reserve width of 20 m. These roads would, therefore, not be dead-end or cul-de-sac style roads.
- The perimeter road should be linked to the internal road system at an interval of no greater than 500 m.
- Internal roads should be through roads. Dead-end roads are not recommended, but if unavoidable dead-end roads should be not more than 200 m in length, incorporate a minimum 12 m radius turning circle and should be clearly sign posted as No Through Roads.
- Road curves should have a minimum inner radius of 6 m and be minimal in number to allow for rapid access and escape.
- The minimum distance between inner and outer curves should be 6 m, allowing for both the inner and outer turning circles of emergency services vehicles.
- Roads should provide sufficient width to allow firefighting vehicle crews to work with firefighting equipment around the vehicle.
- The use of local area traffic management devices to control speeds should be limited to those devices that will have a minimal effect on fire and emergency vehicles, such as ‘speed cushions’, which allow larger vehicles to straddle the device without impacting speed or comfort.
- The capacity of road surfaces and bridges should be sufficient to carry fully loaded firefighting vehicles (approximately 28 tonnes or 9 tonnes per axle).
- Roads should be clearly sign-posted (with easily distinguished names) and buildings/properties should be clearly numbered. Bridges should clearly indicate load rating.
  - Note: ideally each road would have an asset management number so that it can be easily reported and identified.
- Roads should not traverse through a wetland or other land potentially subject to periodic inundation.
- Different structural design requirements may be set in accordance with the structure’s risk level and their importance.
- Where possible, road shoulders should be sealed. This provides an inert firebreak, as well as additional access for both emergency vehicles and evacuation. Inert fire breaks are discussed in Section 3.2.3.

Road design should incorporate the roadside design strategies, as outlined in Section 3.2.3.

MFB Fire Safety Advisory Group (2014) developed *Planning Guidelines for Emergency Vehicle Access and Minimum Water Supplies within the Metropolitan Fire District.* This guideline notes that the road network is a key component in providing access to a site of an emergency for fire and ambulance vehicles. It details recommendations for maximising the efficient travel of emergency vehicles via arterial road networks. The recommendations relevant to road design are:

- Where a centre median is not provided along an arterial road, emergency vehicles need to have the ability to divide the traffic lanes to make their way through the traffic (note: this ability is significantly reduced when traffic lanes are bounded by solid kerbing or barriers preventing the traffic from moving out of the way of emergency vehicles, therefore, the use of this should be minimised).
- The centre median of an arterial road should not obstruct the ability of emergency vehicles to cross and travel along the opposite side of the road (note: bollards or trees should be sufficiently spaced, or not used, to allow easy access for emergency vehicles to cross the centre median to travel along the opposing carriageway).
- The centre median should be sufficiently wide for emergency vehicles to straddle the median and carriageway to enable travel along a congested road (note: the centre median is required to be sufficiently low, if raised, and unobstructed).
- In the instance of a centre median being provided along an arterial road where no provision is made for emergency vehicles to cross to the opposite side or it is not considered to be appropriate, then an emergency vehicle lane or sufficient paved shoulder (see Section 3.2.3) should be provided along the left-hand edge of the carriageway.
- Arterial roads should provide a minimum height clearance of 4.2 m to allow for the passage of emergency vehicles.

Consideration needs to be given to assessing if these requirements align with current TMR and Main Roads WA road design practices. Amendments may need to be made. In addition, best practice documents for road design such as the Austroads *Guide to Road Design,* should be reviewed. Although these documents may not be specific to bushfires or emergency vehicle access, they will provide the minimum requirements for road safety and other considerations.

Further, when undertaking road design, Intelligent Transport Systems (ITS) should be integrated into the design, where relevant. This is because ITS can be used to communicate locations of hazards, road closures and alternative routes.

Recommendation 25: Available guidelines for public and property access roads should be followed to ensure that emergency vehicles have adequate access and emergency egress for all road users.

3.2.9 Structures Infrastructure Design Strategies

The most effective preventative strategy for bushfire impacts on structures is ensuring that the fire passes by structures quickly. In doing so the structure does not have time to generate significant heat energy that may damage critical members. This requires the removal of flammable elements wherever possible throughout the structure and the surrounding environment. Ensuring fire design requirements are considered in bushfire-prone areas guarantees all components have been thoroughly reviewed for a design fire event and mitigated where possible. The surrounding environment is also a key consideration, and removal of flammable elements can be conducted using vegetation management strategies as outlined in Section 3.2.3.

The fire design requirements for bridges are documented in AS 5100.1 (Standards Australia 2017) which requires consideration of an applicable design time-temperature curve. Notably, fire design of structures is only considered in the event where it is stipulated by the relevant authority. New structures in areas of known bushfire risk should incorporate this design requirement. Where it is known, a hydrocarbon fire curve that aligns with suspected bushfire behaviour could be provided to the structural designer and asset manager to offer an enhanced level of resilience.

For existing structures, targeted maintenance of components that have been previously identified as contributory to poor fire performance such as timber deck planks and splitting timber piles, may decrease the likelihood of serious damage to the overall structure in a bushfire event. Together with identified geographical risk areas, this approach could assist in prioritisation of repairs as part of the overall asset management process.

Although bridges are often identified in critical route analysis as being key assets for emergency access (see Section 3.3.3), it may not always be possible (or practical) for bridges to be designed for or upgraded to have capacity to support a fully loaded firefighting vehicle, depending on asset owner, bridge condition etc. This is of particular importance when assets are not owned by the road agency as they may be within a state forest or national park.

3.2.10 Materials Selection

Pavement materials

As discussed in Section 2.5.1 fire can have varying impacts on pavement materials most notably on bituminous wearing courses. Bitumen binder will oxidise and become hard and brittle when heated to high temperatures and can even burn if the temperature it is exposed to is significantly high. While these bituminous materials cannot be substituted, it should be noted that a change in ongoing maintenance treatment periods and treatment types may be required preceding a bushfire event depending on the damage to the pavement.

Slope stabilisation

Slope stabilisation refers to any implemented technique that aims to stabilise an unstable or inadequately stable slope. One slope stabilisation technique is to use geosynthetic fibres or plastic netting. These materials need to be considered in fire-risk areas as they may be at risk in fires.

Timber on structures

As described in Section 2.5.2, the susceptibility of road structures to fire is dependent on the material from which they have been constructed and the surrounding environment. Bridges on the Australian road network are predominantly constructed from timber, steel or reinforced concrete.

Timber structures are at an elevated risk of damage in a bushfire, with wood sustaining ignition at a temperature of approximately 250 °C to 300 °C. Bridges that feature timber decking or sheeting are of particular risk, as these members are typically thin enough to completely burn and induce sustained high temperatures across the structure.

Therefore, when constructing bridges or upgrading structures, use of flammable materials should be minimised – most critically, timber, rubber, and plastic products. In bushfire-prone areas concrete and steel products should be prioritised to ensure design life of the structure/road corridor is maintained.

Recommendation 26: Fire-resistant materials should be used for structures in high-risk areas.

Fire resilient culvert materials

Damage to culverts in bushfires is a key concern. For example, anecdotal evidence from TMR has shown that culverts made from high-density-polyethylene (HDPE) have burned due to bushfire exposure and then subsequently collapsed under the road, leaving a severe road safety impact.

Therefore, Departments of Transportation in the USA have implemented practices pertaining to the use of fire resilient materials for culverts. Examples include:

- For the construction of new culverts in fire-prone areas, the Idaho Transportation Department primarily uses corrugated metal pipe or concrete. When undertaking maintenance and rehabilitation of culverts, some of the Idaho Transportation Department maintenance division uses metal or concrete culverts, instead of plastic liners, because these liners are difficult to extinguish when ignited.
- Similarly, the Nevada Department of Transportation Roadway Design Division uses reinforced concrete pipe, corrugated metal pipe and concrete culvert pipe or boxes, where applicable.

- Nevada Department of Transportation also uses high-density-polyethylene (HDPE) pipe if it is buried underground and has metal end sections beyond the 10-foot buffer. The North Dakota Department of Transportation uses non-flammable material for culvert end treatments.
- Caltrans has eliminated the use of plastic culverts in fire-prone areas, specifically HDPE (CDRISI 2020).

Recommendation 27: Consider the use of fire-resistant materials for culverts and associated pipes should be used in high-risk areas.

3.3 Preparedness

This section details the strategic solutions, which can be made at the policy and management level to assist with developing the resilience of road networks to bushfire risk. Preparedness is defined as all activities undertaken in advance of the occurrence of an incident to decrease the impact, extent and severity of the incident and to ensure more effective response activities (Government of SA 2021).

All emergency preparedness strategies presented in this section need to be considered along with all other current jurisdictional practices and requirements. In addition, where effective processes are in place for other natural disaster types (e.g. cyclones) these strategies should be adapted to bushfire preparedness. As an example, TMR's Northern District currently has a joint emergency management committee with local governments and other relevant stakeholders for how to prepare for cyclone season. Similar communication and coordination processes could be developed, for preparation for the fire season.

3.3.1 Roles and Responsibilities

The key agencies relevant to this work, from a road management perspective, define their roles as follows:

- QFES: is to provide leadership, mitigation planning and a responsive service to ensure the safety of the Queensland community.
- TMR: is responsible for planning, managing and delivering an integrated transport network across road, rail, air and sea for the state.
- Main Roads WA: is to plan, build, maintain and operate Western Australia's state road network.
- DFES: works in collaboration with Western Australian communities and other government agencies to help prevent, prepare for, respond to and recover from diverse hazards.

The responsibilities of preparedness are detailed in Table 3.2.

Table 3.2: Roles and responsibilities in preparedness

Authority/Organisation	Roles/Responsibilities
Emergency authorities	To have prepared and planned suitable routes for movement to areas of reduced risk.
Households and businesses	To have appropriate individual plans for bushfire response, business to have continuity plans in place.
Bureau of Meteorology (BoM)/ weather associations	To have accurate predictive services outlining seasonal outlook and expected risks in advance.
State government	To ensure firefighting infrastructure is available and capable to manage and forecast a bushfire event. The allocated budget to fire authorities including equipment is deemed satisfactory year on year.
Road agency	To coordinate with emergency services when it comes to road closures and road condition. The road agency will need to provide information to emergency response authorities on what roads have been designed for and/or maintained for emergency vehicle access. In addition, the road agency will be responsible for assessing what roads need to remain open during an emergency response and will need to prioritise these roads. This includes roads identified in the critical route analysis, roads to evacuation centres and roads that are key water access routes for firefighting.
Maintenance contractors	Will be responsible for implementing and actioning all prevention activities to be undertaken as part of road maintenance activities.

Source: Adapted from the SA State Bushfire Management Plan (Government of SA 2021).

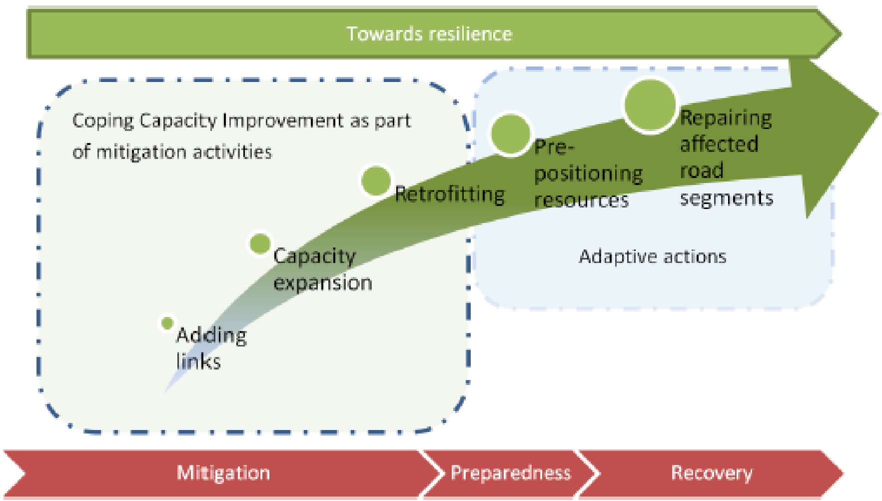
In Queensland, under the TORUM (*Transport Operations (Road Use Management Act* 1995), authorised Transport and Main Roads officers, Queensland Police Service (QPS), and local government officers have the power to close roads.

3.3.2 How to Consider Network Resilience

Damage to transport infrastructure creates a cascading effect on other critical infrastructure systems such as telecommunications, energy, material supply, emergency services and health and utilities. Thus, transport networks are one of the main systems that need to be protected during a disaster event (Withanaarachchi et al. 2010). Road network resilience refers to system performance under disruptive conditions and gives a quantitative measure for network resilience as performance of the network in terms of traffic flow in an unusual circumstance (Murray-Tuite 2006; cited in Kaviani et al. 2015).

There are two main aspects to this inherent quality of a network through its topological and operational attributes to cope with a disruptive condition, that is called 'coping capacity' (Faturechi & Miller-Hooks 2014; cited in Kaviani et al. 2015); and the set of adaptive actions that could be taken into account to make the road network more resilient. These actions may be either pre-incident or post-incident. Put simply, not only should a road network be designed in a way to be more resilient, but the activities also that are performed during the aftermath of a disaster play an important role in its resilience. The concept of road network resilience is presented in Figure 3.8.

Figure 3.8: Inherent and adaptive aspects of road network resilience



Source: Kaviani et al. (2015).

The Australian Government's Department of Industry Science, Energy and Resources, through the Bushfire and Natural Hazards Cooperative Research Centre (CRC), produced a report on *Enhancing Resilience of Critical Road Structures: Bridges, Culverts and Floodways under Natural Hazards* (Setunge et al. 2021). The main objective of the project was to understand the vulnerability of critical road structures, including bridges, culverts and floodways under natural hazards of flood, bushfire and earthquakes. This project was undertaken as it was hypothesised that once the level of vulnerability of a road asset is established, the evaluation of importance of the structures for prioritisation for resilience enhancement can be made by road agencies. This project concluded that optimised asset management of road structures would enhance the resilience of the structures under the threats of natural hazards, such as bushfires.

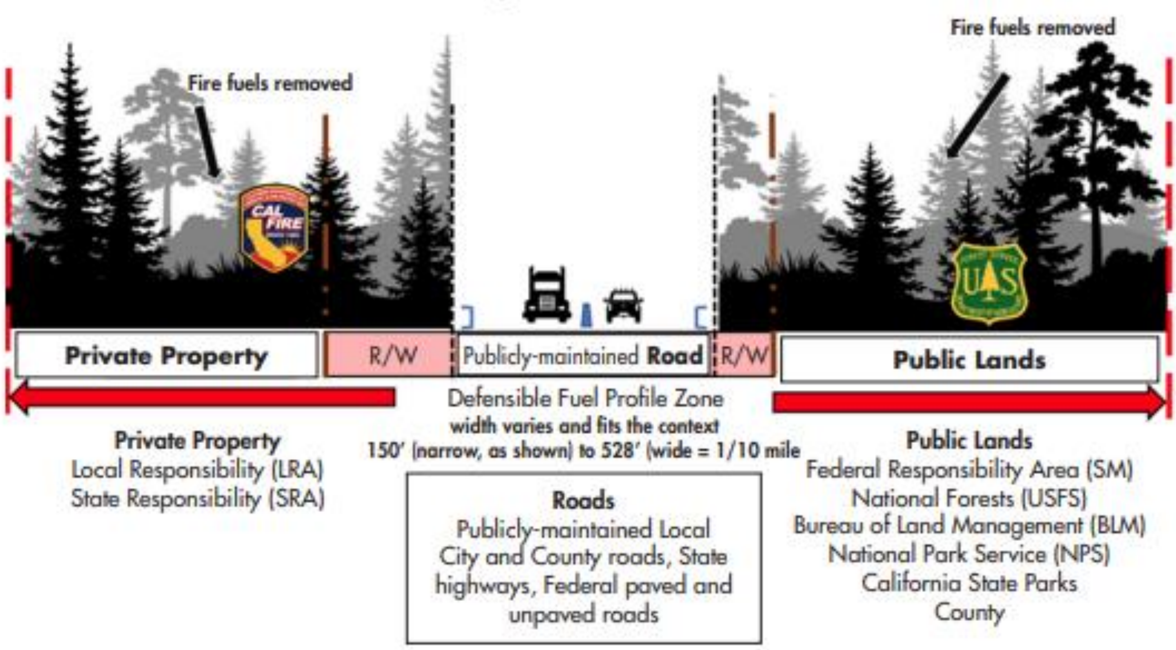
The *California's Wildfire and Forest Resilience Action Plan* (Blumenfeld & Porter 2021) was produced in response to the catastrophic fires that occurred throughout California in 2020. During this time, 5 of the 6 largest fires in the state's modern history burned concurrently. The plan sets out to achieve 4 primary goals:

1. Increase the pace and scale of forest health projects.
2. Strengthen the protection of communities.
3. Manage forests to achieve the state's economic and environmental goals.

4. Drive innovation and measure progress.

An action item within Goal 2 is the creation of fire-safe roadways, as shown in Figure 3.9.

Figure 3.9: Fire-safe roadways – public roads with defensible fuel profile zone



Source: Blumenfeld and Porter (2021).

As shown in Figure 3.9, Caltrans acknowledges the limitations in creating a defensible fuel profile zone, when adjacent areas of land are the responsibility of other authorities/stakeholders and may not be at the same standard. To combat this issue Caltrans has identified the following key actions:

- Identify subdivision secondary emergency access – state government to collaborate with local government in identifying subdivisions at risk and work with them to improve design and accessibility.
- Develop a framework for safe road corridors – hold workshops and educate key agencies and stakeholders on how to improve the fuel reduction processes. State government to provide identified critical road infrastructure to relevant stakeholders to ensure their awareness of priority burn reduction locations.
- Assist with management plans – Caltrans to assist local government and other stakeholders with improving their general action plans for bushfires, identifying key evacuation routes etc.
- Develop a good neighbour agreement – state government to work with the relevant local authorities and landowners in identifying risk areas and establish an agreement to allow the state government to manage land adjacent to highways.

3.3.3 Importance of Critical Route Analysis

In order to plan for bushfire readiness, critical routes along the road network need to be identified. Important locations and bushfire-prone areas can be identified through the use of a risk assessment process. This is described in Section 3.2.

Key aspects which may lead to a route being identified as critical are:

- designed for emergency vehicle access
- designed as a firebreak
- provides an access route to water supplies for firefighting purposes
- provides a route to an evacuation shelter
- is the only link between a community and the goods and services that they require.

Recommendations developed by the Gippsland Regional Strategic Fire Management Planning Committee (GRSFMPC), for the establishment of a standardised road identification and classification process for fire management purposes include:

- Nationally significant roads: Roads that in the event of bushfire would have a significant detrimental effect on the nation. These include roads which provide access to the following:
  - interstate transport/commerce routes
  - defence force facilities
  - national and interstate air, rail, road and seaports
  - power industries and infrastructure
  - critical infrastructure and essential services.
- State significant roads: Roads that are identified as providing strategic value to the protection of assets significant to the state. These include access to major supply routes, power, gas and water industry infrastructure, water catchments and telecommunications.
- Regionally significant roads: Roads that are identified as being of strategic fire prevention and suppression value to regional assets. These include access to:
  - townships
  - community escape routes
  - communications infrastructure
  - fire suppression infrastructure
  - industries
  - emergency service access
  - neighbourhood safer places.
- Municipally significant roads: Roads identified as having a strategic value to part or all of the municipal area. This includes municipal emergency response and recovery centres and roads that link strategic fire suppression access routes (GRSFMPC n.d.).

This is an example of a standardised road identification and classification system which may be of use when defining critical routes. Consideration needs to be given to current road agency practices, and how their current road inventory is classified.

Recommendation 28: A prioritisation system, specific to the road agency's network, should be developed for the classification of roads.

Factors influencing the failure of critical infrastructure links

Critical infrastructure refers to links within the road network that are interdependent, where if disrupted or destroyed, normal operating capacity can be impacted. Critical transport infrastructure consists of motorways, trunk roads and local roads, bridges and tunnels. Critical Infrastructure is pivotal because it provides fundamental functions to sustain society with a breakdown likely leading to significant economic losses and high number of deaths (Kiel et al. 2016).

Withanaarachchi et al. (2010) undertook a case study assessment considering the failure of transport infrastructure to identify existing gaps in strategic planning which led to failure of transport systems. The case studies assessed included:

- Black Saturday bushfires, Victoria – 7 February 2009
- Hurricane Katrina, New Orleans, USA – August 2005
- Kobe earthquake, Japan – January 1995.

The transportation-related issues which were identified through this assessment included:

- effective leadership failures
- failure to understand the full scope of the pending catastrophe
- insufficient planning to respond to catastrophic events

- deployment of personnel
- approval of developments in high-risk areas
- communication failures
- timing of evacuations
- inadequate disaster management policies
- emergency management action plans failed
- critical infrastructure systems were vulnerable, structures such as bridges, rail, highways and buildings were damaged
- rate of evacuation was not considered
- no directions for advance preparations
- road blockages from light poles and debris were not anticipated.

The VicRoads *Bushfire Risk Assessment Guideline and Risk Mapping Methodology* (VicRoads 2013) notes that potential mitigation strategies for bushfire risk include:

- regulation
- enforcement
- education
- bushfire scenario operational planning and preparedness.

Main Roads WA (2020), identified critical assets as those which fall within 400 m of bushfire-prone areas, including 24-hour rest bays, traffic and pedestrian bridges, regional offices and operationally important facility depots.

Recommendation 29: Ensure that critical routes and risk of bushfire impact have been considered when prioritising periodic and routine maintenance activities to ensure that these roads are available to provide sufficient access for both evacuation and emergency services.

Note: The identification of whether or not a road or structure is part of a critical route should be undertaken in the planning stages of a project, where possible, to ensure that it is designed adequately. The identification of risk of bushfire impacts should be undertaken as part of the risk assessment process.

3.3.4 Importance of Community Readiness

In order to determine methods for improving and enhancing transport network resilience, during and in the aftermath of natural disasters, the Sustainable Built Environment National Research Centre undertook a stakeholder engagement project (Sustainable Built Environment National Research Centre 2016). The aim was to reduce the impacts of natural disaster events on communities and businesses. A key outcome was that a well informed and prepared community will be more resilient. This will reduce the pressure on the road and transport networks during and in the aftermath of a disaster. Community readiness can be undertaken through hosting information sessions on key issues (e.g. ‘Cyclone Sunday’ organised by the Townsville City Council which takes place at the start of cyclone season each year).

Consultation with the community not only increases their disaster preparedness but can also provide valuable information about the region. Certain communities that are at risk of bushfires know their roads and may be able to provide valuable information in assisting with reducing bushfire risk.

A study by the Victorian Office of the Emergency Services Commissioner on community movements aimed to identify the context surrounding people’s intended decision and behaviour before and during a bushfire (Betts 2009). The research demonstrated that an average of 10% of a location’s population will remain to defend their properties. The majority of the population will be motivated to leave and seek alternative shelter because of their sense of danger and threat combined with their personal circumstances, their perception of risk and the information that they have accessed and understood (Betts 2009).

A summary of the findings is as follows:

- There is a decreasing number of people who intend to defend their properties from bushfire.
- The community has strong expectations of neighbourhood safe places and public fire refuges.
- Triggers for leaving properties and travelling around and through a bushfire zone varied greatly. There is a relationship of gender, age, family and geographic location characteristics to the public's intended bushfire preparedness and response behaviours.
- Intended responses to fire risk indicators, in particular Code Red weather forecasts showed that the public continues to rely on information from the emergency services about when to leave and where to go.
- Bushfire safety decisions are mostly prominently influenced by 'senses of danger' and threat, highlighting the importance of messaging (Betts 2009).

Recommendation 30: There is a need to work with the relevant rural fire service authorities to ensure that communities in bushfire-prone areas are aware of what they need to do in the event of a bushfire. This includes identifying and communicating the evacuation routes along the road network.

3.3.5 Importance of Stakeholder Consultation

Stakeholder consultation was a common theme across literature, frameworks and guidance reviewed.

In addition, in the Sustainable Built Environment National Research Centre's (2016) stakeholder consultation project, it was identified that multi-agency coordination was necessary, for both community readiness and for coordination between disaster response agencies.

Similarly, as described in Section 3.2.5, the Department of Sustainability and Environment's (2012) guideline for *Roadside Vegetation Management for Bushfire Risk Mitigation Purposes* outlines the importance of stakeholder consultation in the roadside treatment selection process.

Recommendation 31: Appropriate stakeholders must be engaged in all preparedness activities.

3.3.6 Considerations when Undertaking Road Maintenance

When undertaking road maintenance, in preparation for a bushfire season, consideration needs to be given to whether there are regulations in place or rules that need to be followed for projects working in high bushfire-risk areas. This includes projects using power tools or other equipment during high fire risk periods, such as on total fire ban days. The Western Australian Department of Fire and Emergency Services (2019) notes that during a total fire ban, road work may only be carried out in the course of trade or commerce or by (or on behalf of) a public authority. In addition, it can only be undertaken when the fire danger rating is not catastrophic. The Department of Fire and Emergency Services provides a simple set of steps to follow in the instance of road maintenance in a high-risk location (Department of Fire and Emergency Services 2019). This is summarised in Figure 3.10.

Figure 3.10: Steps to follow for road work in high-risk settings

Check	• Confirm if it's a TFB • DFES Total Fire Ban + **www.dfes.wa.gov.au/totalfirebans** • Phone: TFB hotline 1800 709 355
Notify	• Notify DFES and the relevant local government by completing the DFES online notification form between 24 hours and 30 minutes prior to the activity commencing. • Notify Parks and Wildlife Service (P&W) between 24 hours and 30 minutes prior to the activity commencing where the activity is occuring within 3 kms of land managed by P&W.
Proceed	• Subject to prescribed activity conditions, proceed with the activity as required.

Note: This process should be adapted by the relevant authority in the jurisdiction where it is being implemented.

Source: Department of Fire and Emergency Services (2019).

3.4 Response

Restoring the normal function of a roadway or transportation asset to the community following a major bushfire event will help to mitigate the impacts on the community (Country Fire Authority 2001). The road infrastructure is an important asset to the community and its serviceability following a major fire will be critical to the community's recovery. Management of the road network during and in the immediate aftermath of a bushfire event needs to be coordinated with the locations of fire evacuation centres in order to ensure that safe passage can be provided for the community. Where evacuation facilities are not available, consideration will need to be given to if any part of the road reserve, such as a roadside stopping bay, may be used as an evacuation facility.

The SA State Bushfire Management Plan (Government of SA 2021) details the responsibilities of Response as follows:

- state government responsibility to provide timely and accurate warnings
- state government responsibility to provide swift activation of relief centres
- weather authority to provide advice on suggested days of total fire ban, fire weather forecasts and smoke management and updates
- emergency authorities to provide reactive damage assessment and communicate applicable information to the broader public minimising the utilisation of hazardous routes and infrastructure.

3.4.1 Defining Key Access/Egress Roads and Fire Control Lines

Key access/egress roads are roads which are critical for both the evacuation of a community and use by emergency service vehicles. Understanding which roads on the network belong in this category is critical in disaster response, as priority should be given to ensuring these routes remain open (Country Fire Authority n.d.a). Key access/egress roads can be broken down into three major categories, as an example:

- Priority 1 roads: Key access/egress roads for communities and the travelling public via major link roads. Major link roads primarily provide a direct linkage between significant population centres, or major traffic generators, or residential, industrial and commercial nodes, or the arterial road network to connect the highest risk locations with areas of relative safety. For these roads, implementation of techniques for ignition control, dangerous trees treatment, critical infrastructure protection, emergency services access and emergency services turning areas are critical.

- Priority 2: Critical access/egress for high bushfire risk communities. These are key roads that provide access for sections of high-risk communities to travel to Priority 1 Roads. These roads are generally referred to as the local road network. When defining Priority 2 roads consideration needs to be given to where access to and from communities is one way, or where vegetation may prohibit the function of a road during a fire. Where practicable the roadsides for these roads should be managed to reduce hazards from vegetation, as detailed in Section 3.2.
- Priority 3: Emergency service roads. These roads are designed to aid in the transition of emergency vehicles to and from an incident/fire. These roads can be accessible for portions of the year or all year round.
- Fire trail/fire access track: A trail used for access with local knowledge and suitable fire agency vehicles. These trails can be locked/unlocked for the exclusive use of emergency and management vehicles only. These trails are only accessible or used during the fire danger period. They require annual pre-summer inspection, followed by identified remedial works to maintain access over this period.

Recommendation 32: A prioritisation system, specific to the road agency's network, should be developed for key access/egress roads.

A fire control line is an inclusive term for all constructed or natural barriers and retardant-treated fire edges used to control a fire. Roads defined as strategic fire control lines allow for a dual use in the protection of townships and population centres. These roads can also be key access roads. When designated roads are strategic fire control lines, consideration should be given to the direction any significant fire would come from so that risk controls can be established. These roads should be a defined section of road length, rather than an entire road which will allow for concentration of treatments and greater utilisation of resources in a specific focal area (Country Fire Authority n.d.a).

There are two main types of strategic fire control lines. These are:

- Active lines: where vegetation is modified to offer safety to emergency services and allow for fire-fighting activities.
- Passive lines: where graded or ploughed back techniques are used during the progress of a fire. These areas may have pre-planned works done to aid the access of plant and machinery (removal of impediments, rocks etc.) (Country Fire Authority n.d.a).

Recommendation 33: Understanding which roads on the network are key access/egress roads (critical for both the evacuation of a community and use by emergency service vehicles) is critical in disaster response. Priority should be given and controls should be in place to ensure that these roads can remain open.

3.4.2 Emergency Vehicle Access

As described in Section 3.2.8, Road Design Strategies, the MFB Fire Safety Advisory Group (2014) developed *Planning Guidelines for Emergency Vehicle Access and Minimum Water Supplies within the Metropolitan Fire District.* This guideline notes that the road network is a key component in providing access to a site of an emergency for fire and ambulance vehicles. The method of access for emergency vehicles to a site is based on first travelling as far as possible using the highest order roads and gradually using lower order roads as the emergency vehicle gets closer to the site.

The order of roads typically used for access, as detailed by the MFB Fire Safety Advisory Group (2014) is summarised as follows:

- primary arterial roads
- secondary arterial roads
- collector roads
- access streets
- laneways.

This Guideline details recommendations for maximising the efficient travel of emergency vehicles via arterial road networks. These recommendations are:

- It is recognised that where a centre median is not provided along an arterial road, emergency vehicles have the ability even when congested to divide the traffic lanes to make their way through the traffic.
- Emergency vehicles can straddle the centre median and carriageway to enable travel along a congested road.
- Where only a single lane is provided along a road or car parking occupies the left-hand lane, emergency vehicles should have permission to travel along the opposite side of the road.
- In the instance of a centre median being provided along an arterial road where no provision is made for emergency vehicles to cross to the opposite side or it is not considered to be appropriate, then an emergency vehicle lane or paved shoulder will be provided along the left-hand edge of the carriageway.

Recommendation 34: Ensure all key access/egress roads are effectively designed for or upgraded to a standard for emergency vehicle access.

3.4.3 Access to Water

Fire response access to water can be confusing at times, especially as to what can and cannot be used as a resource to combat fires. According to the Western Australian Department of Fire and Emergency Services (WADFES), the requirement for access to water depends on the source and/or whether that source is on private or public land. Additionally, conditions for an allotment or building are also dependent on this access. For example, if the source of water is a dedicated fire water tank supply erected on private property as a mandated requirement of the building approvals process, then as part of that, access provisions may also be included. If it is part of a fire safety system required as a condition of the occupancy permit, then there will be some clear requirements with respect to access. It is less likely that there will be any stipulations with regard to water tanks on a rural allotment used to gather rainwater and not stipulated as fire water or something like a pond or swimming pool. The WADFES recommends that if unclear, residents contact their local government as it has jurisdiction over these matters relating to bushfires.

3.4.4 Evacuation Planning

Evacuation planning is a critical component of bushfire response, with a shared responsibility between individuals and authorities to ensure both private and public infrastructure are suitably prepared should a bushfire occur.

Evacuation routes should be implemented as identified through critical route analysis (Section 3.3.3). This allows for the identification of the most adequate infrastructure links for the evacuation of the community that will not impact on emergency access to the disaster zone. Evacuation routes should be planned in collaboration with evacuation facilities to ensure that the community has access to the goods and services they may require.

The appropriate guidance and education must be provided to communities in high-risk areas. California Department of Forestry and Fire Protection’s (CALFIRE) ‘ready, set, go!’ bushfire campaign is a comprehensive example that provides guidance and outlines the framework for an evacuation plan (California Department of Forestry and Fire Protection 2019). The document provides information for personnel in high-risk areas with encouragement to plan and identify an evacuation method, route and location as well as providing information on essential survival equipment.

Wong et al. (2020) studied the behavioural methods of evacuees throughout the 2017 Southern California wildfires and 2018 Carr wildfire. From the observed behaviour, they were able to make the following recommendations/observations to road agencies:

- Agencies should be proactive in ensuring additional traffic control measures are in place, specifically ‘low-tech’ communication mechanisms in areas where loss of power and traffic signalling is likely.

- Agencies should brace for additional network congestion during evenings from multi-vehicle evacuations, with evidence indicating households that own multiple vehicles are more likely to utilise them in the event of a mandatory evacuation order.
- Highways are more likely to be utilised in voluntary evacuation zones whereas local roads are more likely to be utilised in mandatory evacuation orders.
- In the event of a bushfire, individuals are more likely to travel short distances i.e. shifting to nearest non-evacuation area rather than travelling substantial distances and will not utilise highways in travel.

The results of the study highlight the importance of proactive and effective traffic modelling in the event of a bushfire. Furthermore, effective communication and broadcasting of traffic conditions on highways may benefit evacuation planning especially if highways are in the path of lowest risk out of a bushfire, as road users may preference local roads on the assumption there is greater congestion which may not be the case.

Encouraging or requiring the use of singular vehicle evacuation in areas where congestion is of concern may also be beneficial as multi-vehicle evacuations (where families may use multiple vehicles to bring possessions) are forecast to apply unnecessary stress on a critical evacuation route.

A study by Leon and March (2013) was undertaken in order to:

- evaluate the total required evacuation time for a given urban fringe community during a bushfire
- the way urban structure characteristics affect that time
- the emergency management policy implications related to those findings.

The results showed that a complete evacuation takes considerable time (between 30 minutes and 1 hour), despite spatially different sizes and urban patterns and that it is possible for bushfires to overrun or surround settlements before people leave following a warning.

The results confirmed the ‘leave early’ policy, if adequately supported by timely warning systems with a high degree of penetration across the population. Certain urban structure characteristics, such as urban density, may also have an impact on the total evacuation time, and should be considered due to the traffic which may be caused.

Recommendation 35: Ensure effective emergency management plans have been developed through consultation with relevant stakeholders, particularly the relevant rural fire service. Ensure these plans are effectively communicated to the community.

3.4.5 Traffic Management

Roadblocks

Following the bushfires of February 2009 in Victoria, now known as Black Saturday, the 2009 Victorian Bushfires Royal Commission was set up to conduct an extensive investigation into the causes of, the preparation for, the response to and the impact of the fires (Victorian Bushfires Royal Commission 2010). This report noted that roadblocks play an important part in maintaining public safety during a bushfire and after a bushfire and can protect health and safety or facilitate fire investigations.

The report notes:

> On and after Black Saturday, more than 4,500 roadblocks were established to regulate traffic on roads leading into and around fire-affected areas. The evidence revealed a number of systemic problems with the way the roadblocks operated, among them inflexibility, poor communication and denying access to firefighters. Since Black Saturday, new guidelines have been released that improve the operation of full and partial roadblocks, allow an Incident Controller to delegate responsibility for the establishment and operation of roadblocks with the support of Victoria Police, and formalise a system of wristbands to identify people who can pass through a roadblock. Guidance is also provided on how Police should exercise discretion at a roadblock (Victorian Bushfires Royal Commission 2010).

Queensland and Western Australia can take learnings from the experiences of Victoria and implement the findings of the Inquiry.

Recommendation 36: Ensure guidance for roadblocks is well-disseminated and understood. Ensure that roadblocks are implemented effectively during disaster response.

Traffic management points

During and following a bushfire, failure to effectively manage a road network system can lead to major disruptions and potential safety risks for the community. Traffic management points (TMP), which are a series of roadblocks implemented to manage traffic during a bushfire event are often employed as a standard process for emergency services. However, these roadblocks can often become significant traffic hazards. Research has shown that the general warning provided to communities and motorists are often not very effective particularly to motorists who are unfamiliar with the area and what alternative routes may be available. In addition, the onset of disasters can be rapid, meaning information may not be effectively disseminated in time and the community may be in shock.

Therefore, decision support systems (DSS) are used in order to mitigate some of these complex issues. DSS involves representation of disaster scenarios to assess vulnerability, damage cost and emergency response policies in disaster mitigation, preparedness, response and recovery phases. These models can predict potential losses from natural disasters, utilising Geographic Information Systems (GIS) to visualise high-risk locations and infrastructure. However, there are not many systems available which support emergency managers and motorists in responding to hazardous conditions during or immediately following a disaster. Therefore, Kaviani et al. (2015) identified a need for an improved decision support to reduce the disruption costs for drivers as well as enhance their level of security in emergency situations. Recent developments in sensor networks, spatial data analysis procedures and traffic models provide an opportunity for improving the management of traffic during disaster events.

The Centre for Disaster Management and Public Safety and the University of Melbourne developed the Intelligent Disaster Decision Support System (IDDSS) as a platform for integrating various information and data such as meteorological information, road networks and traffic, geography and economic data. Combining these with dynamic disaster and transport modules provides a spatial platform for decision makers. As well as bushfires and floods, the IDDSS provides a platform to aid in decision making for a wide variety of natural disasters. It also accesses a range of data and dynamic feeds from social media channels and sensor networks such as those managed by Vic DoT and the Australian Bureau of Meteorology to provide real-time updates (Kaviani et al. 2015).

By utilising widely accepted libraries such as GRASS (Geographic Resource Analysis Support System) and GeoTools, the IDDSS is able to provide advanced and sophisticated bushfire and flood models. By combining this up-to-date and accurate spatial data with models, both disaster and traffic, the IDDSS is an important tool in disaster management (Kaviani et al. 2015).

The importance of traffic management during a bushfire event is illustrated in Figure 3.11.

Figure 3.11: Traffic during bushfire event on the Warrego Highway, Queensland

Source: https://www.abc.net.au/news/2019-10-09/bushfire-closes-warrego-highway-as-dozens-of-blazes-burn/11583980, viewed 01/09/2021.

3.4.6 Management of Tree Hazards

As outlined in Section 3.2.4, the Australasian Fire and Emergency Service Authorities Council developed a guideline for *Managing Tree Hazards* (2018). The guideline covers prevention activities and emergency management activities when responding to a bushfire.

An example of tree hazards on the road during a bushfire event is shown in Figure 3.12.

Figure 3.12: Tree hazards

Source: Australian Institute for Disaster Resilience Knowledge Hub, https://knowledge.aidr.org.au/resources/black-summer-bushfires-qld-2019/, viewed 01/09/2021.

Readiness and response activities should be undertaken in the immediate lead-up to and during an emergency. A key activity is ensuring that organisations, the community and individuals are informed and ready to respond (e.g. readiness activities). This phase extends to response, relief and initial recovery activities which include:

- If there are routes that have been assessed and noted with tree hazards, these areas should be prioritised for crew deployment in the event of an emergency. This will ensure that these roads do not become blocked or if blockages occur, these can be promptly removed.
- Ensuring incoming emergency responses or community members evacuating are notified about any tree hazard identified on or around the incident ground.
- Prior to commencement of emergency response operations, the person in charge should ensure a tree hazard assessment is undertaken for the operational area (the operational area includes escape routes and safety zones, and these should be identified and assessed as soon as is practical).

- Withdrawing from and establishing an exclusion zone where tree hazard has been identified especially in high-risk conditions (such as periods of high wind).
- Instituting traffic management procedures to minimise the risk from tree hazards.
- Moving or abandoning control lines in areas of high tree hazard.
- Where possible, movement of trees to create a path for evacuation and emergency access (for example, a dozer could be used to push trees aside to reinstate access, then following the event, these trees will be removed).
- Treatment by removal of tree or limb as appropriate.

Recommendation 37: Ensure tree hazards along the roadside are effectively managed during disaster response to ensure that critical routes remain open to the community for evacuations and for emergency response. This will need to be managed and coordinated on a case-by-case basis between the relevant authorities (i.e. emergency management authority, road agency, etc.)

3.4.7 Consideration of Smoke Hazards

Bushfire smoke contains a mixture of water vapour, airborne particles and gases (such as carbon monoxide, carbon dioxide and nitrogen oxides). Risk treatments for bushfire smoke hazards are difficult to identify for road design, as smoke is considered in amongst other hazards such as fog, dust, heavy rain, snow, etc. All of these aspects are considered in road design when it comes to gradient, curvature, speed setting etc. Therefore, if these items have been adequately considered, smoke does not need to be considered as a standalone risk when designing roads. More often than not, the risks of driving in a bushfire area or through bushfire smoke comes down to human nature and driving knowledge. For example, when there is heavy rain present, road users know not to drive at high speeds, similarly, when it is foggy road users will leave more space on the road. An example of smoke on the road from a bushfire is shown in Figure 3.13.

Figure 3.13: Smoke haze over the road during a bushfire

Source: Australian Institute for Disaster Resilience Knowledge Hub, https://knowledge.aidr.org.au/resources/black-summer-bushfires-qld-2019/, viewed 01/09/2021.

There are several ways in which smoke can impact on a roadway, and many factors which can contribute to this including:

- Landscape features and proximity – Smoke-related consequences can be minimised by being aware of conditions that reduce roadway visibility and by knowing when to implement timely mitigation measures.
- Burn area – The size of the area with active fire and/or smouldering fire is important to evaluate. A large area of hundreds of hectares has a higher likelihood to influence visibility impairment on roadways.
- Fuel – The presence of heavy and surface fuels and fuel conditions can lead to greater smoke emissions.

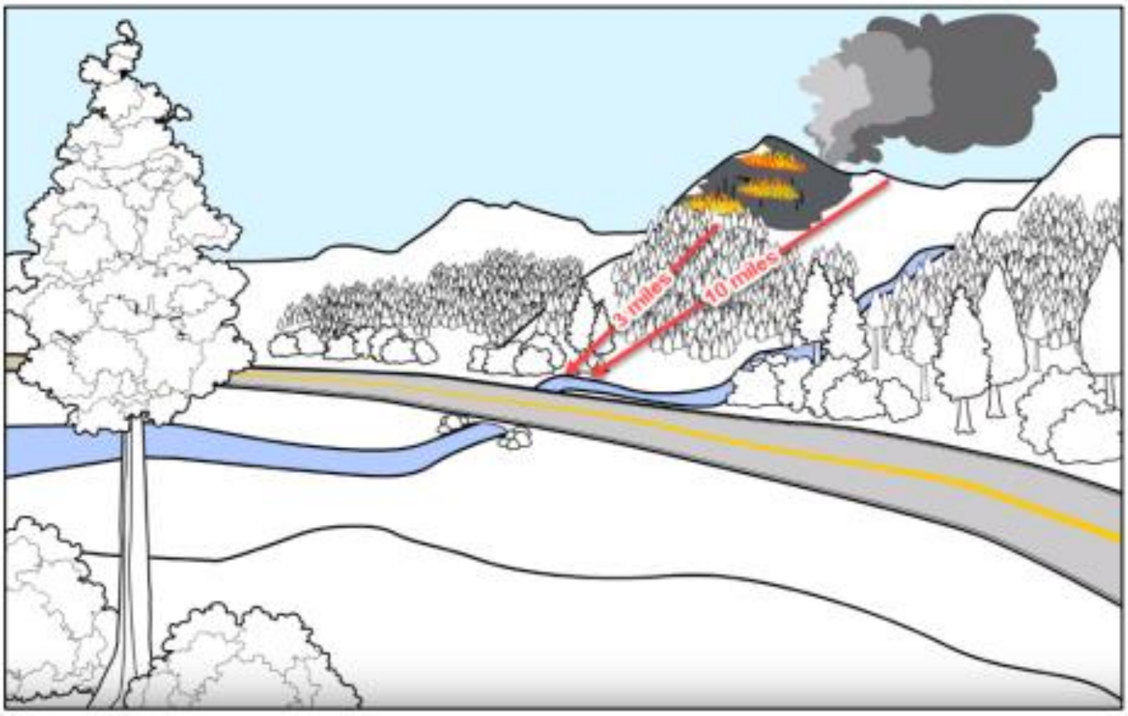
- Air quality – It is important to understand local sources of air pollution near the burn and the outlook for local air quality conditions.
- Weather – Knowing basic weather elements, including cloud cover, surface air temperature, relative humidity and wind speed is vital to assess the risk of reduced roadway visibility and minimise smoke impacts.

In relation to proximity, the *Smoke and Roadway Safety Guide* developed by the National Wildfire Coordinating Group (Curcio et al. 2020) notes that:

- Roadways within 3 miles (~4.8 km) of the fire can be easily impacted and should be considered high risk.
- Roadways as far as 10 miles (~16.1 km) from the fire can be impacted, especially if those fires are large or if visibility issues have occurred in those locations in the past. This larger radius should be considered for potential smoke impacts during larger incidents and can be caused by the presence of drainage routes or vegetation breaks that can funnel smoke.

Distance from roadways as well as position on the landscape when considering potential smoke impacts is shown in Figure 3.14.

Figure 3.14: Distance from roadways and position on the landscape can affect smoke impacts



Source: Curcio et al. (2020).

Recommendation 38: Ensure smoke hazards are adequately considered as part of response efforts.

3.5 Recovery

This section details strategies which can be implemented as part of the recovery effort following a bushfire event. This includes reconstruction activities such as how to maintain and rehabilitate the road, and how to upgrade or improve assets to build resilience for future events.

The *South Australia State Bushfire Management Plan* (Government of SA 2021) details the responsibilities of Recovery which includes ensuring the community is involved in emergency and recovery planning and in debriefs to record their experience and help prepare for future disasters.

3.5.1 Developing a Works Plan

Based on the assessment of bushfire risk, using strategies such as the TMR *Roadside Bushfire Risk Assessment Model* (TMR 2021a), prioritisation should be undertaken of key risk areas and critical routes (VicRoads 2013). Once identified and prioritised, prevention and maintenance programs can be implemented. There are 5 major categories of works to be considered in a bushfire recovery works plan, these are:

5. Maintenance: Regular ongoing day-to-day work necessary to keep assets operational, e.g. road patching
6. Operations: Regular activities to provide public health, safety and amenity, e.g. street sweeping, grass mowing, street lighting
7. Renewal/refurbishment: Restores, rehabilitates, replaces existing asset to its original capacity, e.g. gravel resheeting of road infrastructure – same level of service
8. Upgrade/Improvements: Enhances existing asset to provide higher levels of service, e.g. widen seal
9. New/expansion: Creation of a new asset to meet additional service level requirements, e.g. new building or new service (Department of Sustainability and Environment 2012).

Recommendation 39: Prioritisation should be undertaken of key risk areas and critical infrastructure and prevention and maintenance techniques implemented.

Recommendation 40: Develop a list of critical infrastructure to check prior to opening a road. This should include key safety infrastructure to be inspected and repaired/replaced.
Identify potential controls for areas where key infrastructure elements are impacted. These controls may include detouring, changes in operational speed, installation of temporary signage, etc.

3.5.2 Road Maintenance

In order to identify the impacts that a bushfire has had on roads and therefore, what maintenance activities should be undertaken Signore (2020) recommended both a condition assessment and structural assessment.

For a condition assessment, a pavement condition index (PCI) analysis can be undertaken. This can be through the automated collection of network data to identify changes, or through visual surveys in priority locations. The outcomes of this assessment will be able to assist the road agency with identifying their maintenance needs (Signore 2020). This maintenance can be on an as needs basis or the scheduled routine maintenance schedule could be brought forward.

It is recommended that road agencies have a clear understanding of the condition of their road network periodically. This will mean that if a condition survey is undertaken post a fire event, there will be a baseline of data for comparison allowing the agency to understand exactly what damage has occurred (Signore 2020). This damage and the pattern of impacts can then be incorporated back into the planning process for the prevention activities being undertaken.

A structural assessment will provide information on pavement distress which may not be visible. Structural assessments are useful as they can provide information on the remaining useful life of a pavement. This can be compared with data from before the fire event and used to determine how much the life of the pavement has decreased due to the fire and associated traffic. This can then be costed as a percentage of the value of the pavement (Signore 2020).

As described in Section 2.5, when bitumen binders are subjected to heat from a bushfire, anecdotal evidence has shown that the bitumen binder will oxidise and become hard and brittle. The bitumen will burn if the temperature it is exposed to is significantly high. The exact temperature at which damage will occur will depend on the type of bitumen used in the construction of the seal. When this oxidisation has occurred and a seal has become very brittle, remedial treatments need to be undertaken in order to preserve the pavement and ensure additional deterioration does not occur. Signs that this binder oxidisation has occurred include the stripping of aggregate from the seal or cracking in the seal.

All areas where sections of seal have been lost due to fire should be removed or replaced with either an asphalt patch repair or localised spray seal application. All cracks should be sealed with a hot rubberised bitumen overlay. Although the damage from bushfire may not pose an immediate serviceability issue for the road it is likely that without maintenance, accelerated deterioration of the surface (and hence overall pavement) will occur. All roads known to have been damaged by the fire should be monitored for further deterioration on a six-monthly basis and repairs prioritised as a part of a broader pavement maintenance program.

Recommendation 41: Undertake road maintenance activities as required, based on the assessed bushfire damage. Where opportunity arises to make improvement or undertake preventative maintenance, this should be implemented in conjunction with recovery maintenance activities. This approach is known as 'build-back-better'.

3.5.3 Revegetation

Revegetation refers to the re-establishment of a cover of vegetation suited to the location. This usually means a cover of local native plants and involves regeneration, direct seeding and/or planting methods. Revegetation is necessary as the establishment of vegetation cover helps to prevent soil erosion by rainfall impact and surface water flows. In addition, the establishment of vegetation can help maintain the stability of the roadside and road formation (Main Roads WA 2004).

Revegetation involves:

- preparation of finished soil surfaces, e.g. By ripping or tilling the soil surface and respreading site topsoil and chipped vegetation, to assist regeneration to occur naturally
- regeneration of vegetation through the seed existing within the site topsoil if this is stripped and respread during the earthworks or from the seed that is carried in the cleared site vegetation that is chipped and respread over the soil
- seeding by direct broadcast by hand or machine onto the prepared soil surface
- planting of nursery grown plants in pots or small tubes by hand or machine
- landscaping includes grassing and irrigated planting beds, feature paving etc. Undertaken for functional and amenity objectives, for example at key locations along urban roads and town entries (Main Roads Wa 2004).

Recommendation 42: Ensure revegetation is undertaken within an effective period of time to prevent soil erosion from rainfall impact and surface water flows where the land is now bare due to bushfire destruction.

It is recommended that immediate cover is prioritised in high-risk areas such as steep slopes and where water movement is likely to occur (e.g. sheet flow off road batters, drainage lines etc.). An example of such an approach is hydraulically applying a wetting agent, followed by hydromulch with a bonded fibre matrix. In this example, the seed mix composition should focus on cover crop species and other appropriate grass species to ensure quick stabilisation of slopes and to minimise the risk of broadscale erosion and landslips. Post-immediate surface stabilisation, additional planting or supplementary seeding should be implemented as required. However, there is no single best approach to post-fire slope stabilisation.

Selection of revegetation techniques should be based on the value of the asset seeking to be protected and the risk of bushfire in the area where the asset is located. In order to designate a treatment, the cost of that treatment should be weighed against the value of the asset and the potential success that the treatment will have in that area. For example, in some burned areas, a no treatment response will be appropriate, such as areas burned at low or moderate severity where adequate ground cover is provided by remaining forest floor material and natural mulch such as scorched conifer needles and in areas where rapid natural recovery is expected. The no treatment option may also be appropriate in areas burned at high severity that do not pose a high risk to identified values (Robichaud et al. 2010).

Recommendation 43: Ensure immediate cover is prioritised in high-risk areas such as steep slopes and areas where water movement is likely to occur.

Vegetation planning needs to have regard to future fire hazards created by these plantings, based on the risk to the road and its function/criticality during bushfire. This is where consideration needs to be given to the appropriate prevention strategies for roadsides, as described in Section 3.2.4.

3.5.4 Inspections and Maintenance of Structures

The likelihood of damage to structures in bushfire events is difficult to predict and is influenced by multiple factors such as behaviour of the fire, surrounding environment, material and existing condition of the structure.

Throughout Australia, it is a requirement within the structures inspection manual of multiple road authorities to conduct at minimum a visual (Level 1) inspection after a fire event has occurred. The inspection should include review of existing documentation to ensure comprehensive understanding of condition pre- and post-bushfire, such that damage caused by a fire event can be differentiated from historic wear. For timber bridges, a co-ordinated response directly after fire may be beneficial for early intervention as the bridge may have caught fire in a small section but not progressed to full engulfment of the structure.

A visual inspection undertaken after a bushfire should not only capture routine defects, but also make note of the likely level of exposure the structure has experienced to fire and look for traits more specific to fire related damage i.e. pink tinged concrete indicating the structure has been exposed to heat greater than 300 °C.

Defects or evidence of significant fire exposure should prompt further inspections (Level 2) and investigations (Level 3) as required. Given the known effects of heat exposure on timber, steel and concrete previously discussed, destructive and non-destructive testing may be required to assess the remaining strength properties of materials.

The outcome of these assessments may conclude the structure is no longer safe in its current state. In the short term this may be handled administratively through speed or load limits imposed or overall closure of the route. In the long term, maintenance may be required to rehabilitate the structure or an ‘options analysis’ of replacement and strengthening solutions assessed.

3.5.5 Asset Upgrades

In order to ensure the future resilience of infrastructure following a bushfire event, asset upgrades should be made, where possible. This includes the implementation of the prevention strategies defined for road design, roadside design and structural design in Section 3.2, Prevention. In addition, in a national context, upgrading assets and ‘building back better’ improves network resilience in the face of climate change.

In addition, an assessment should be undertaken of asset redundancies. For example, in areas where guardrails were built to protect drivers from trees, these may not need to be rebuilt if the protection of the hazard (e.g. trees) have been lost in a bushfire.

Gibson (2017) assessed the *Challenges and Opportunities for Climate-smart Infrastructure in California*. This study identified a need to shift towards pooling resources and upgrading systems to consider a wider range of events other than specific impacts i.e. if upgrading a sewer network below a road to improve flood resilience can be used as an opportunity to resurface the road with materials that have higher heat tolerance/permeability to withstand bushfires as well. Consideration needs to be given to what other opportunities present themselves when upgrading assets following a bushfire event.

Recommendation 44: Consider what other assets could be upgraded or improved to be more resilient to climate threats when undertaking infrastructure works. Consultation with stakeholders is recommended. ***Where replacement or upgrades can occur to these areas of the network during maintenance, this should be investigated and considered.***

In 2013, Deloitte Access Economics was commissioned to prepare *Building our Nation's Resilience to Natural Disasters* by the Australian Business Roundtable for Disaster Resilience & Safer Communities. The report found that loss of the electricity service was a major consideration in bushfires, with the power outage caused by the 2007 Victorian bushfires estimated to have cost the national economy $234 million. In the example provided, an economic benefit was found in relocating transmission lines underground, as the cost of doing so would outweigh the cost of damage plus the cost of bushfire management in the area around the above ground transmission lines. The report concluded that investing in resilient housing in bushfire-prone areas had a benefit-cost ratio of 1.4:1, investing in better vegetation management had a benefit-cost ratio of 1.3:1, and moving electricity lines underground had a benefit cost ratio of 3.1:1 (Deloitte 2013).

Learnings from the Australian Standard for Building Construction in Bushfire-prone Areas

AS 3959:2018 *Construction of Buildings in Bushfire-prone Areas*, is the Australian Standard that provides guidance on the construction of buildings in bushfire-prone areas. The Standard takes into consideration several factors such as:

- relevant fire danger index (based on location in Australia) – as shown in Table 3.3
- surrounding classified vegetation
- distance of vegetation to site location
- effective slope of the vegetation relative to the building.

Table 3.3: Jurisdictional and regional values for fire danger index

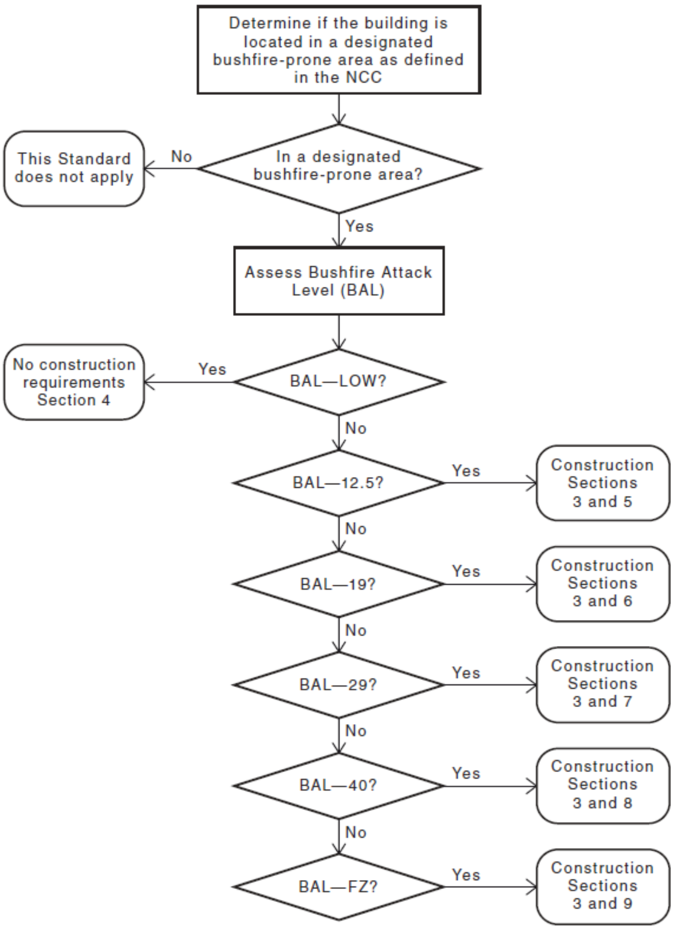
State/region	FDI
Australian Capital Territory	100
New South Wales	
(a) Greater Hunter, Greater Sydney, Illawarra/Shoalhaven, Far South Coast and Southern Ranges fire weather districts[(2)]	100
(b) NSW alpine areas[(3)]	50
(c) NSW general (excluding alpine areas, Greater Hunter, Greater Sydney, Illawarra/Shoalhaven, Far South Coast and Southern Ranges fire weather districts	80
Northern Territory	40
Queensland	40
South Australia	80
Tasmania	50
Victoria	
(a) Victoria alpine areas[(3)]	50
(b) Victoria general (excluding alpine areas)	100
Western Australia	80

Source: AS 3959:2018.

Based on the criteria in Table 3.3, and the other factors listed, a bushfire attack level is produced, which then directs users to relevant design requirements. All structures where fire is indicated as a risk greater than 'low' share escalating construction requirements to withstand increasing levels of radiant heat and increasing ember attack. The process for determining construction requirements is detailed in Figure 3.15.

Road infrastructure may benefit from application of the principles outlined in AS 3959. However, thorough consideration would need to be given to determine equivalent parameters applicable to the roadside environment.

Figure 3.15: Flow diagram showing the process for determining construction requirements



Source: AS 3959:2018.

4 Outcomes

Based on the literature review to identify practices to consider bushfire prevention, preparedness, response and recovery in the planning, design, construction and maintenance of transport infrastructure many recommendations have been made which are listed below.

Monitoring of the implementation of these is essential in identifying the most effective strategies for particular use cases and locations. Monitoring will be a key step implemented in the development of the framework.

In addition, it should be noted that there are limitations on some of the elements of the network which mean that these cannot be improved to be more bushfire resilient. Understanding these limitations is important for planning and risk assessment and needs to be considered on a case-by-case basis.

The major recommendations include:

- Recommendation 1: The PPRR risk framework should be implemented into road agency practice.
- Strategic Planning Objectives
  - Recommendation 2: Develop a program logic model to determine road agency objectives in strategic asset management when considering bushfire risk.
- Importance of Risk Assessment
  - Recommendation 3: Ensure a risk assessment is undertaken to identify bushfire-prone areas, including likelihood and consequence of the risk in order to provide a representative risk score.
  - Recommendation 4: Ensure that the road networks/links that will be critical in disaster recovery have been identified.
  - Recommendation 5: Ensure all assets within the bushfire-prone area have been identified.
- Prevention
  - Recommendation 6: Understand the roles and responsibility of each party and ensure that road agency bushfire-related practices are coordinated
  - Recommendation 7: Ensure learnings in bushfire recovery are implemented back into planning practices. Understand that strategies need to be focused on the limited resources and funding that are available, so that these resources can be incorporated into targeted management strategies.
  - Recommendation 8: Implement bushfire prevention techniques based on the outcome category of the risk assessment i.e. for extreme risk, implement permanent treatments; for moderate risk implement treatments as part of periodic maintenance; for low risk implement treatments as part of routine maintenance.
  - Recommendation 9: Consideration needs to be given to the offset requirements of utilities, prior to implementing any roadside management strategies for bushfire prevention. It is recommended to consult with the relevant utility providers or authorities.
  - Recommendation 10: Implement a protection zone around structures that have been identified as critical, for example, timber bridges which have been defined as part of a critical route for disaster evacuation.
  - Recommendation 11: Implement vegetation free zones along roadsides and ensure these zones are maintained prior to bushfire seasons.
  - Recommendation 12: Inert materials should be used in conjunction with vegetation free zones to create a firebreak between the road and the landscape in high-risk areas.
  - Recommendation 13: Incorporation fire breaks should be considered in the planning and design stages of road projects (i.e. implemented as part of the road shoulder).
  - Recommendation 14: Ensure appropriate plant types are selected for roadside verges if the area is known to be bushfire prone.
  - Recommendation 15: Where possible vegetation heights should be reduced close to the road as a vertical firebreak. This includes large trees and flammable materials used for roadside furniture.

- Recommendation 16: Develop a data set/mapping tool to identify when areas have been managed with fire prevention activities or when these areas are due to be managed, relative to their vegetation type/category.
- Recommendation 17: Prescribed burning should be undertaken in collaboration with the relevant rural fire service to reduce fuel loads along roadsides particularly along roads which are critical access and evacuation points.
- Recommendation 18: Collaboration with local Indigenous Australian communities should take place to understand the landscape and cultural burning practices.
- Recommendation 19: As part of permanent, periodic and routine maintenance activities, (based on bushfire risk) tree hazards should be managed.
- Recommendation 20: A multi-agency stakeholder group for risk identification and treatment selection should be implemented.
- Recommendation 21: Develop a work plan, identifying the location of works to be completed, the roadside management objective being managed for, and the type of treatment being carried out – for all selected and prioritised treatments.
- Recommendation 22: Ensure all relevant environmental legislation has been consulted, prior to implementing any bushfire prevention programs.
- Recommendation 23: Bushfire risk should be integrated in the design and maintenance strategies for roadside furniture. This includes removing vegetation growth and using metal posts (rather than timber).
- Recommendation 24: Intelligent transport Systems (ITS) should be incorporated in roadside furniture design, to assist with the communication of information in a disaster event.
- Recommendation 25: Available guidelines for public and property access roads should be followed to ensure that emergency vehicles have adequate access and emergency egress for all road users.
- Recommendation 26: Fire-resistant materials should be used for structures in high-risk areas.
- Recommendation 27: Consider the use of fire-resistant materials for culverts and associated pipes should be used in high-risk areas.

- Preparedness
  - Recommendation 28: A prioritisation system, specific to the road agency's network, should be developed for the classification of roads.
  - Recommendation 29: Ensure that critical routes and risk of bushfire impact have been considered when prioritising periodic and routine maintenance activities to ensure that these roads are available to provide sufficient access for both evacuation and emergency services.
  - Recommendation 30: There is a need to work with the relevant rural fire service authorities to ensure that communities in bushfire-prone areas are aware of what they need to do in the event of a bushfire. This includes identifying and communicating the evacuation routes along the road network.
  - Recommendation 31: Appropriate stakeholders must be engaged in all preparedness activities.
- Response
  - Recommendation 32: A prioritisation system, specific to the road agency's network, should be developed for key access/egress roads.
  - Recommendation 33: Understanding which roads on the network are key access/egress roads (critical for both the evacuation of a community and use by emergency service vehicles) is critical in disaster response. Priority should be given and controls should be in place to ensure that these roads can remain open.
  - Recommendation 34: Ensure all key access/egress roads are effectively designed for or upgraded to a standard for emergency vehicle access.
  - Recommendation 35: Ensure effective emergency management plans have been developed through consultation with relevant stakeholders, particularly the relevant rural fire service. Ensure these plans are effectively communicated to the community.
  - Recommendation 36: Ensure guidance for roadblocks is well-disseminated and understood. Ensure that roadblocks are implemented effectively during disaster response.

- Recommendation 37: Ensure tree hazards along the roadside are effectively managed during disaster response to ensure that critical routes remain open to the community for evacuations and for emergency response.
- Recommendation 38: Ensure smoke hazards are adequately considered as part of response efforts.

- Recovery
  - Recommendation 39: Prioritisation should be undertaken of key risk areas and critical infrastructure and prevention and maintenance techniques implemented.
  - Recommendation 40: Develop a list of critical infrastructure to check prior to opening a road. This should include key safety infrastructure to be inspected and repaired/replaced.
    Identify potential controls for areas where key infrastructure elements are impacted. These controls may include detouring, changes in operational speed, installation of temporary signage, etc.
  - Recommendation 41: Undertake road maintenance activities as required, based on the assessed bushfire damage. Where opportunity arises to make improvement or undertake preventative maintenance, this should be implemented in conjunction with recovery maintenance activities. This approach is known as 'build-back-better'.
  - Recommendation 42: Ensure revegetation is undertaken within an effective period of time to prevent soil erosion from rainfall impact and surface water flows where the land is now bare.
  - Recommendation 43: Ensure immediate cover is prioritised in high-risk areas such as steep slopes and areas where water movement is likely to occur.
  - Recommendation 44: Consider what other assets could be upgraded or improved to be more resilient to climate threats when undertaking infrastructure works. Consultation with stakeholders is recommended.

As part of this literature review, an assessment was undertaken of guidelines and frameworks which are available on one or multiple aspects of this topic. These frameworks and guidelines are summarised in Table 4.1.

Table 4.1: Framework and guideline assessment

Document	Organisation/reference	Risk assessment	Prevention	Preparedness	Response	Recovery
A Guide to Constructing and Maintaining Firebreaks	Western Australian Department of Fire & Emergency Services Rural Fire Division (2018)		Construction of firebreaks		Construction of firebreaks	
Bushfire Risk Assessment Guideline and Risk Mapping Methodology	VicRoads (2013)	Processes for assessing risk relating to each objective. • Assesses the likelihood of an ignition in the road corridor, and the likelihood of fire spread beyond • Factors assessed and weighted on relative importance • Breaks down into low-risk, moderate risk and high-risk roads	Guidance for determining what treatment is to be employed based on the risk of bushfire. Work sheets to assist with risk assessment and treatment selection	An outline of the key objectives with respect to road bushfire management. • Roadside fire management works program Fuel management and establishment of control lines	An outline of the bushfire management planning process. • Local response plan	Not included in guidelines – listed as an objective – however stated out of scope.
Planning for Bushfire Protection: A guide for Councils, Planners, Fire Authorities, Developers and Homeowners	New South Wales Rural Fire Service & Planning (2001)	Risk assessment discussed in form of bushfire risk management program with objectives • Reduce human-induced bushfires • Manage fuel • Reduce community vulnerability • Effective fire containment	Bushfire emergency management and operations plan	Bushfire emergency management plan with objectives of • Providing an appropriate defendable space • Providing a better bushfire protection outcome Ensures respective authorities are not increasing responsibility of adjoining landowners without prior consent.	Response handled through design criteria for roads, buildings, subdivisions etc. • Minimum radius requirements to accommodate fire trucks • Hydrant locations • Minimum carriageway widths • Allowable grades, passing lane requirements	Document does not focus on post bushfire recovery – appears out of scope.

Document	Organisation/reference	Risk assessment	Prevention	Preparedness	Response	Recovery
California's Wildfire and Forest Resilience Action Plan	Blumenfeld and Porter (2021)	Risk assessment process not mentioned in document, however key action item to improve and refine existing risk assessment documentation noted.	Key action items detailed throughout document: • Improve utility-related wildfire risk • Utilise best available science and accelerate applied research • Improve regulatory efficiency (permit approval, forest management)	Key action items detailed throughout document. • Support community risk reduction and adaption planning • Establish a national prescribed fire training centre • Launch smoke ready campaign Develop framework for safer road corridors.	Key action items detailed throughout document: • Create fire-safe roadways • Increase fuel breaks • Extend defendable space • Expand highway treatment	Key action items detailed throughout document: • Accelerate restoration across all lands • Reforest burned areas • Help landowners conserve endangered species as a result of bushfires.
South Australia State Bushfire Management Plan	Government of SA (2021)	An explanation of the risk assessment process and strategic priorities: • Preserve life • Protect critical infrastructure	A detailed authority matrix outlining action items and the stakeholder responsible: • Arson prevention and management • Issuing of permits to burn • Fuel reduction	A detailed authority matrix outlining action items and the stakeholder responsible: • Evacuation planning • Operational response planning • Seasonal outlooks • Training and development	A detailed authority matrix outlining action items and the stakeholder responsible: • Public information and warnings • Total fire bans • Fire weather forecasts and fire danger ratings • Industry brigade co-ordination	A detailed authority matrix outlining action items and the stakeholder responsible: • Recovery management • Recovery planning – community involvement
Roadside Fire Management Guidelines	Country Fire Authority (2001)	Emphasises the importance of clear objectives in effective risk management: • Prevent fires on roadsides • Contain roadside fires • Manage safety of road users	Prevention addressed in treatment options table: • Adequate identification of causes • Regulation • Education • Fuel-free shoulder maintenance	Preparation not explicitly listed as heading. Pre-season burning mentioned several times as a preparation method of choice.	Emphasis on fire containment: • Bare earth firebreak limitations • Fuel-reduction burning	Recovery addressed in treatment options table: • Planning • Education

Document	Organisation/reference	Risk assessment	Prevention	Preparedness	Response	Recovery
Managing Tree Hazards	Australasian Fire and Emergency Service Authorities Council (2018)	Addresses the risk of trees collapsing and/or limbs and branches falling, in whole or in part, due to tree characteristics (e.g. defects) and external influences (e.g. impact of fire, wind or flood).	This guideline provides agencies with a risk-based framework for developing doctrine to manage tree hazards during the different phases of emergency management and prescribed burning.	Prevention, mitigation and preparedness activities undertaken before an emergency. These activities aim to prevent and mitigate the impacts of an emergency and increase the preparedness of organisations, the community and individuals to appropriately respond to an emergency.	Readiness and response activities undertaken in the immediate lead-up to and during an emergency. Such activities include ensuring that organisations, the community and individuals are informed and ready to respond (e.g. readiness activities). This phase extends to response, relief and initial recovery activities.	Ongoing recovery activities following an emergency. These assist and support organisations, the community and individuals to return to a new normality as quickly as possible.
Plant Guide within the Building Protection Zone for the Swan Coastal Plain of Western Australia	Fontaine and Enright (2011)	This booklet is designed as a planting guide for landscape designers and land managers to choose plants and position them at the appropriate distances from buildings to reduce the risk of bushfire damage.	Assists with appropriate vegetation selection for roadsides and around critical structures.			

4.1 Limitations of this Literature Review

This report has presented the findings from a review of national and international literature on the topic of bushfire prevention, preparedness, response and recovery, focused on the road network and the aspects which a road agency can influence.

There was limited information available on a variety of sub-topics even though they were noted to be of potential interest to road agencies for consideration of bushfire impacts.

As an example, there is limited research to understand the impacts of bushfires on long term pavement performance under Australian conditions. Internationally, pavement research often focuses on vehicle fires and tunnel fires as opposed to bushfires, noting the pavement response overall to bushfire events may not be well understood. Furthermore, the impacts of increased heavy vehicle and traffic volumes along local roads during evacuation and emergency response is anecdotally understood as a challenge but not well documented or quantified.

Another topic with limited information available was the impact of bushfires on different types of line markings. Linemarkings can be paint, thermoplastic or epoxy materials. Some types of line marking are removed by using high temperatures so there is a potential for issues depending on the material.

The majority of the literature which was able to be sourced was agency relevant documents, grey literature, unpublished reports and local initiatives. It is apparent that although many jurisdictions have similar issues when managing bushfire impacts, there is no widely accepted or mature process for comprehensive planning and management response.

Moreover, when it comes to the management of bushfires, there can be conflicting issues for the authorities involved. For example, vegetation clearance can reduce bushfire impact. However, this needs to be balanced with habitat conservation, environmental value, shade in parks, etc. These issues need to be managed on a case-by-case basis, as there is no framework for this type of decision making available in literature.

5 Conclusion

This report has presented a literature review undertaken in as part of the joint NACOE and WARRIP project *Incorporating Bushfire Impacts into Road Design*.

Currently, TMR and Main Roads WA planning, design and construction practices for infrastructure projects do not actively consider bushfire risk in the same way that flooding risk is considered. Bushfires are characterised as a natural disaster or natural hazard due to the way in which they can progress through landscapes and at what intensity/severity. Climate change has had an impact on both bushfire frequency and severity. Research has shown that climate change has the potential to influence more severe and longer fire seasons around the globe (Dowdy 2008, cited in March et al. 2020; Setunge et al. 2021). Severe bushfires have the potential to produce numerous economic, social and environmental impacts, which can range from short-term inconveniences to long-term life-changing impacts (Stephenson 2010).

Queensland and WA have experienced a growing number of bushfire impacts over the recent decade. Roads and transportation infrastructures are often regarded as the highest value assets in a bushfire-prone area as they are critical to the mobility of the community for evacuation and for the receipt of goods in post-disaster recovery. Historical data demonstrates that the failure of roads and road structures can have catastrophic consequences on a community affected by disaster for the reasons stated *(*Setunge et al. 2021). Depending on severity, bushfires can also cause road closures, and even serious roadway damage (Fraser et al. 2020). Therefore, this project aimed to identify ways of incorporating best practice bushfire management into TMR and Main Roads WA infrastructure planning, design, construction, and maintenance practices.

As unprecedented bushfire events across Australia have highlighted, roads and associated infrastructure are critical enablers of bushfire prevention, preparation, response and recovery activities. Roads are critical in bushfire events for:

- emergency response – i.e. access for fighting vehicles, etc.
- evacuation – i.e. routes for the community to leave or access evacuation centres.

However, during a bushfire event the level of service of a road may be impacted due to:

- direct damage – e.g. falling trees, damage to structures, etc.
- radiant heat – e.g. potential to melt soft materials such as bitumen and linemarkings.

Therefore, consideration needs to be given to:

- prevention of bushfire impacts – e.g. through fuel control
- preparedness for bushfire events – e.g. through planning for use of the roads for emergency access
- response to bushfire events – e.g. planning for evacuations and managing traffic
- recovery from bushfire events – e.g. building back better through asset upgrades.

The literature review was broken down into four categories in accordance with the PPRR framework. The PPRR framework includes the following areas for consideration:

- importance of undertaking a risk assessment (references are provided to assist with the risk assessment process)
- prevention through risk avoidance and risk reduction strategies
- preparedness through overall policy strategic objective solutions
- response strategies for disaster management
- recovery strategies for improvement in post-disaster recovery.

The major recommendations which emerged from this literature review are detailed in Section 4.

References

American Association of State Highway and Transportation Officials (AASHTO) 2016, Manual for Assessing Safety Hardware (MASH), ISBN 978-1-56051-665-1, AASHTO, Washington, DC

Aurecon 2020, 'Roadside bushfire risk assessment model 2020: network incident bypass assessment methodology', Queensland Department of Transport and Main Roads, Brisbane, Qld.

Australasian Fire and Emergency Service Authorities Council 2018, *Managing tree hazards*, AFAC, Melbourne, Vic.

Australian Institute of Disaster Resilience 2020, *Bushfires: black summer*, webpage, AIDR, Melbourne, Vic, viewed 14 December 2021, <https://knowledge.aidr.org.au/resources/black-summer-bushfires-nsw-2019-20/>.

Australian Institute of Family Studies 2021, *How to develop a program logic for planning and evaluation*, webpage, AIFS, Southbank, Vic, viewed 14 December 2021, <https://aifs.gov.au/cfca/expert-panel-project/program-planning-evaluation-guide/plan-your-program-or-service/how-develop-program-logic-planning-and-evaluation>.

Austroads 2020, *Guide to road design part 6: roadside design, safety and barriers*, AGRD06-20, Austroads, Sydney, NSW.

Austroads 2021, *Guide to road design part 6B: roadside environment*, edn 1.1 2021, AGRD06B-15, Austroads, Sydney, NSW.

Betts, R 2009, *"Where are they going?": people movement during bushfires*, Office of the Emergency Services Commissioner, Melbourne, Vic.

Blumenfeld, J & Porter, T 2021, *California's wildfire and forest resilience action plan*, California Department of Water Resources, Sacramento, CA, USA.

Bureau of Meteorology 2018, *When bushfires make their own weather*, webpage, BOM, Canberra, ACT, viewed 14 December 2021, <https://media.bom.gov.au/social/blog/1618/when-bushfires-make-their-own-weather/>.

Bushfire ABC n.d., *Black Saturday bushfires*, webpage, Weebly, San Francisco, CA, USA, viewed 14 December 2021, <https://blacksaturdaybushfiresabc.weebly.com/environmentalsocialeconomic-impacts.html>.

California Department of Forestry and Fire Protection 2019, *Prepare for wildfire*, Cal Fire, Sacramento, CA, USA, viewed 14 December 2021, <https://www.readyforwildfire.org/prepare-for-wildfire/ready-set-go/>.

Caltrans Division of Research, Innovation and System Information 2020, *Roadside design strategies for fire presuppression: survey of practice*, PI-0235, CDRISI, Sacramento, CA, USA, viewed 14 December 2021, <https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/pi-0235a-a11y.pdf>.

City of Rockingham 2019, *Verge development guidelines*, City of Rockingham, Rockingham, WA.

Climate Council 2015, *The heat is on: climate change, extreme heat and bushfires in Western Australia*, Climate Council, Sydney, NSW.

Climate Council 2019, *The facts about bushfires and climate change*, webpage, Climate Council, Sydney, NSW, viewed 14 December 2021, <https://www.climatecouncil.org.au/not-normal-climate-change-bushfire-web/>.

Country Fire Authority 2001, *Roadside fire management guidelines*, CFA, Burwood East, Vic.

Country Fire Authority n.d.a, 'Guidelines for defining key access/egress roads and strategic fire control lines', CFA, Burwood East, Vic.

Country Fire Authority n.d.b, 'Separation distances required for vehicle passengers to survive a bushfire', CFA, Burwood East, Vic.

Curcio, G, Mueller, D, Lahm, P, Fitch, M & Hyde, J 2020, *Smoke and roadway safety guide*, PMS 477, National Wildfire Coordinating Group.

Dalton, T 2020, 'Back from the black', *The Australian*, 28 February 2020, viewed 14 December 2021, <https://www.theaustralian.com.au/weekend-australian-magazine/tracking-the-impact-of-australias-horror-bushfires/news-story/ab3f5032a6d5e9bbcab41c88c7358c34>.

Deloitte 2013, *Building our nation's resilience to natural disasters*, Deloitte, London, UK.

Department of Agriculture, Water and the Environment 2021*, Bushfire management and national environment law*, webpage, DAWE, Canberra, ACT, viewed 14 December 2021, <https://www.awe.gov.au/environment/epbc/publications/factsheet-bushfire-management-and-national-environment-law>.

Department of Environment and Water 2018, *A guide to prescribed burning*, DEW, Adelaide, SA.

Department of Fire and Emergency Services 2018, *A guide to constructing and maintaining firebreaks*, DFES, Perth, WA.

Department of Fire and Emergency Services 2019, *Total fire ban exemption: road work*, DFES, Perth, WA, viewed 14 December 2021, <https://www.dfes.wa.gov.au/totalfirebans/Documents/TFBRoadWorkFactSheets.pdf>.

Department of Fire and Emergency Services 2021, *Cultural and contemporary fire management practices in Western Australia*, DFES, Perth, WA.

Department of Sustainability and Environment 2012, *Roadside vegetation management for bushfire risk mitigation purposes: a guideline for road managers*, DSE, Melbourne, Vic.

Department of Sustainability and Environment n.d., 'Strategic fire access network', DSE, Melbourne, Vic.

Espinos, A, Romero, ML & Hospitaler, A 2015, 'Fire design method for bar-reinforced circular and elliptical concrete filled tubular columns', *Engineering Structures*, vol. 56, pp. 384–95.

Filkov, A, Ngo, T, Matthews, S, Telfer, S & Penman, T 2020, 'Impact of Australia's catastrophic 2019/20 bushfire season on communities and environment: retrospective analysis and current trends', *Journal of Safety Science and Resilience*, vol. 1, no. 1, pp. 44–56.

Fontaine, JB & Enright, NJ 2011, *Plant guide within the building protection zone for the Swan Coastal Plain of Western Australia*, Fire and Emergency Services Authority (FESA) Western Australia, Perth, WA.

Forest Fire Management 2015, *Appendix 1: program logic*, FFM, Melbourne, Vic, viewed 15 December 2021, <https://www.ffm.vic.gov.au/__data/assets/pdf_file/0019/25732/BushfireMER_Framework_Appendix1.pdf>.

Fraser, A, Chester, M & Underwood, B 2020, 'Wildfire risk, post-fire debris flows, and transportation infrastructure vulnerability', *Sustainable and Resilient Infrastructure*, doi: 10.1080/23789689.2020.1737785

Gibson, J 2017, *Built to last: challenges and opportunities for climate-smart infrastructure in California*, Union of Concerned Scientists, Cambridge, MA, USA.

Gippsland Regional Strategic Fire Management Planning Committee n.d., 'RSFMPC Roads Classification Working Group outcomes', GRSFMPC, Sale, Vic.

Government of South Australia 2021, *South Australia state bushfire management plan 2021-2025*, Government of South Australia, Adelaide, SA, viewed 15 December 2021, <https://safecom-files-v8.s3.amazonaws.com/current/docs/SASBMP.pdf>.

Government of Western Australia 2016, *Reframing rural fire management: report of the special inquiry into the January 2016 Waroona fire*, Government of Western Australia, Perth, WA.

Hampton, S, Knowles, G & Collins, S 2016, 'Traffic woes for at least a week from Southwest bushfire', *The West Australian*, 8 January 2016, viewed 15 December 2021, <https://thewest.com.au/news/wa/traffic-woes-for-at-least-a-week-from-south-west-bushfire-ng-ya-134976>.

Insurance Council of Australia 2021, *Insurance catastrophe resilience report: 2020-2021*, ICA, Sydney, NSW.

Kaviani, A, Thompson, R, Rajabifard, A, Griffin, G & Chen, Y 2015, 'A decision support system for improving the management of traffic networks during disasters', *Australasian transport research forum, 2015, Sydney, New South Wales*, ATRF, Sydney, NSW.

Kiel, J, Petiet, P, Nieuwenhuis, A, Peters, T & van Ruiten, K 2016, 'A decision support system for the resilience of critical transport infrastructure to extreme weather events', *Transportation Research Procedia*, vol. 14, pp. 68–77.

Leon, J & March, A 2013, 'Urban structure and evacuation times in a city fringe bushfire: modelling three scenarios in Bendigo Victoria', PhD thesis, University of Melbourne, Parkville, Vic.

Main Roads Western Australia 2004, *Revegetation planning and techniques*, MRWA, Perth, WA.

Main Roads Western Australia 2013, *Vegetation placement within the road reserve*, MRWA, Perth, WA.

Main Roads Western Australia 2019, *Guidelines: climate change risk assessment*, ver 2, MRWA, Perth, WA.

Main Roads Western Australia 2020, *Bushfire risk management and mitigation*, operational procedure 108, D17#522023, MRWA, Perth, WA.

Mancini, J 2020, *Our 2020 bushfire support mandate*, webpage, Jason Signmakers, Welshpool, WA, viewed 17 December 2021, <https://www.jasonsigns.com.au/blog/jasonsigns-bushfire-support/>.

March, A, Riddell, G, Nogieria de Moraes, L, Stanley, J, van Delden, H, Beilin, R, Dovers, S & Maier, H 2020, 'Urban planning capabilities for bushfire: treatment categories and scenario testing', *Australian Journal of Emergency Management*, vol. 35, no. 3, pp. 32–40.

MFB 2014, *Planning guidelines for emergency vehicle access and minimum water supplies within the metropolitan fire district*, Metropolitan Fire Brigade, Melbourne, Vic.

Morrison, P 2007, *Roads and wildfires*, Pacific Biodiversity Institute, Winthrop, WA, USA.

NSW Rural Fire Service & Planning 2001, *Planning for bushfire protection: a guide for councils, planners, fire authorities, developers and homeowners*, NSW Rural Fire Service, Sydney, NSW.

Queensland Department of Transport and Main Roads 2020a, *Climate change risk assessment methodology*, engineering policy 170, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2020b, *Climate Change Risk and Adaptation Assessment (CCRAA) Framework for Infrastructure Projects*, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2021a, *Roadside bushfire risk assessment model: summary report 511265*, rev 4, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2021b. *Hazard reduction burns within the state-controlled road corridor,* TMR, Brisbane, Qld.

Regional Roads Victoria 2020, *The road to recovery*, RRV, Traralgon, Vic, viewed 17 December 2021, <https://regionalroads.vic.gov.au/bushfires>.

Roads and Maritime Services 2008, *Timber bridge manual*, RMS, Sydney, NSW.

Robichaud, P, Ashum, L & Sims, B 2010, *Post-fire treatment effectiveness for hillslope stabilisation*, RMRS-GTR-240, US Department of Agriculture Forest Service, Fort Collins, CO, USA.

Schartel, B, Bahr, H, Braun, U & Recknagel, C 2010, 'Fire risks of burning asphalt', *Fire and Materials*, vol. 34, no. 7, pp. 333–40.

Setunge, S, Mendis, P, Karunasena, K, Zhang, K, Amaratunga, D, Lokuge, W, Herath, N, Shi, L, Mohseni, H, Trans, H & Atapattu, K 2021, *Enhancing resilience of critical road structures: bridges, culverts and floodways under natural hazards*, Bushfire and Natural Hazards CRC, Melbourne, Vic.

Signore, J 2020, *The unseen impact of California wildfires on affected roadway pavements*, PowerPoint presentation, Public Works Officers Institute, Monterey, CA, USA.

Standards Australia 2017, *Bridge design, Part 1: Scope and general principles,* AS5100.1, Standards Australia, Sydney, NSW.

Standards Australia 2018, *Construction of buildings in bushfire-prone areas*, AS3959, Standards Australia, Sydney, NSW.

State Emergency Management Committee 2020, *State hazard plan: fire*, SEMC, Perth, WA.

State Emergency Management Committee 2021, *State hazard plans*, webpage, SEMC, Perth, WA, viewed 17 December 2021, <https://semc.wa.gov.au/emergency-management/plans/state-hazard-plans>.

Stephenson, C 2010, *A literature review on the economic, social and environmental impacts of severe bushfires in south-eastern Australia*, report no. 87, Bushfire Cooperative Research Centre, Melbourne, Vic.

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

Sustainable Built Environment National Research Centre 2016, *A stakeholder engagement approach to enhancing transport network resilience in Australia: a sustainable built environment national research centre industry report*, SBEnrc, Curtin University, Perth, WA.

Terramatrix 2013, 'Roadside fire prevention inspections: eastern region', Terramatrix, Collingwood, Vic.

Thorne, J, Boynton, R, Hollander, A, Whitney, J & Shapiro, K 2021, *2020 critical update to Caltrans wildfire vulnerability analysis*, University of California, Davis, CA, USA.

Van Staden, R & Fragomeni, S 2017, 'Finite element analysis of fire-damaged flexible pavement deterioration', *Journal of Structural Fire Engineering*, vol. 8, no. 2, pp. 106–16.

VicRoads 2011, *Fire damaged reinforced concrete: investigation, assessment and repair*, technical note 102, VicRoads, Kew, Vic.

VicRoads 2013, *Bushfire risk assessment guideline and risk mapping methodology*, VicRoads, Kew, Vic.

Victorian Bushfires Royal Commission 2010, *2009 Victorian bushfires royal commission: final report*, State of Victoria, Melbourne, Vic.

Withanaarachchi, J, Setunge, S & Bajwa, S 2010, 'Strategic planning to protect critical infrastructure systems', *ARRB conference, 24th, 2010, Melbourne, Victoria*, ARRB Group, Vermont South, Vic.

Wong, SD, Broader, JC, Walker, JL & Shaheen, SA 2020, *Understanding California wildfire evacuee behaviour and joint choice-making*, University of California, Berkley, CA, USA.

WWF, 2020, *Impacts of the unprecedented 2019-20 Bushfires on Australian Animals*, WWF, Ultimo, NSW.