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Fauna Sensitive Road Design Guidelines

Version 1

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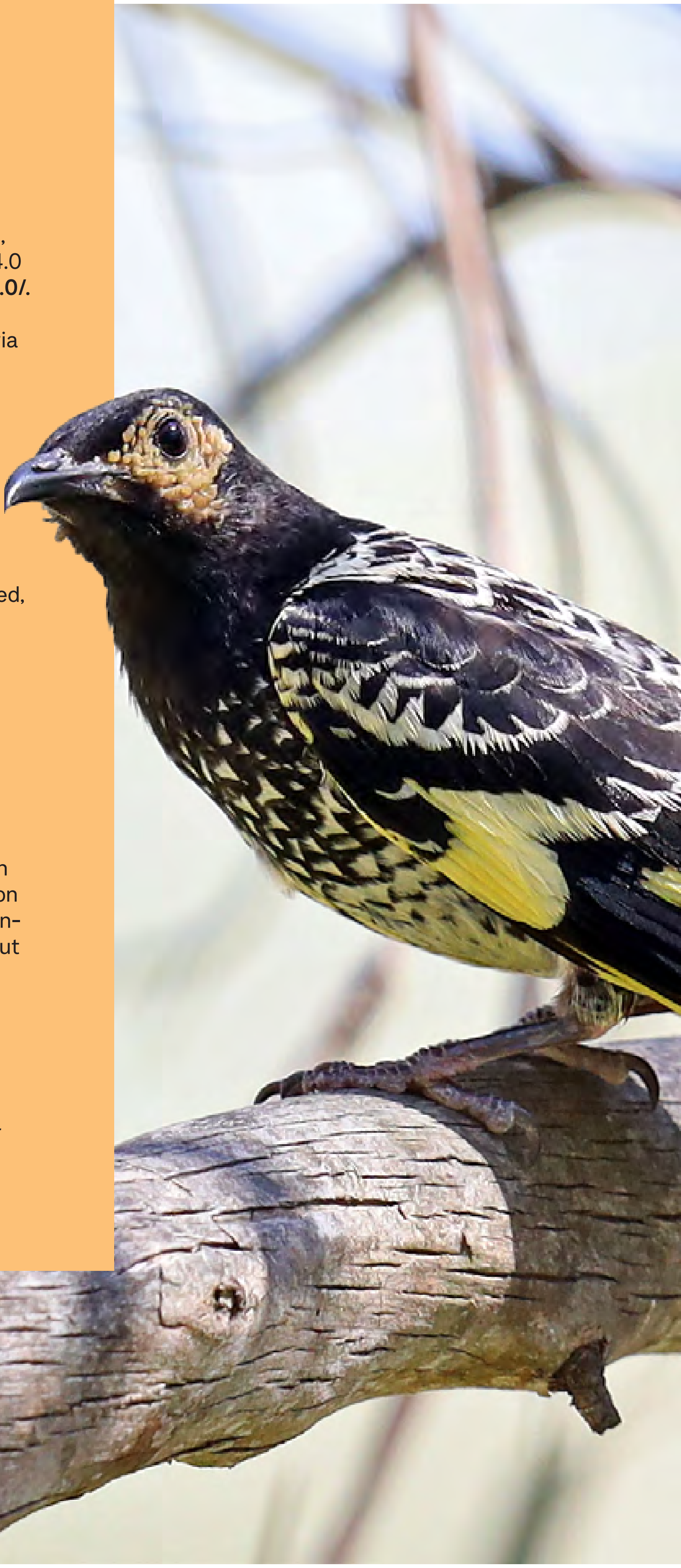
Resources

VIDA Roads acknowledges the following document which informed content in these Guidelines: Fauna Sensitive Transport Infrastructure Delivery Manual (2024), Queensland Department of Transport and Main Roads.



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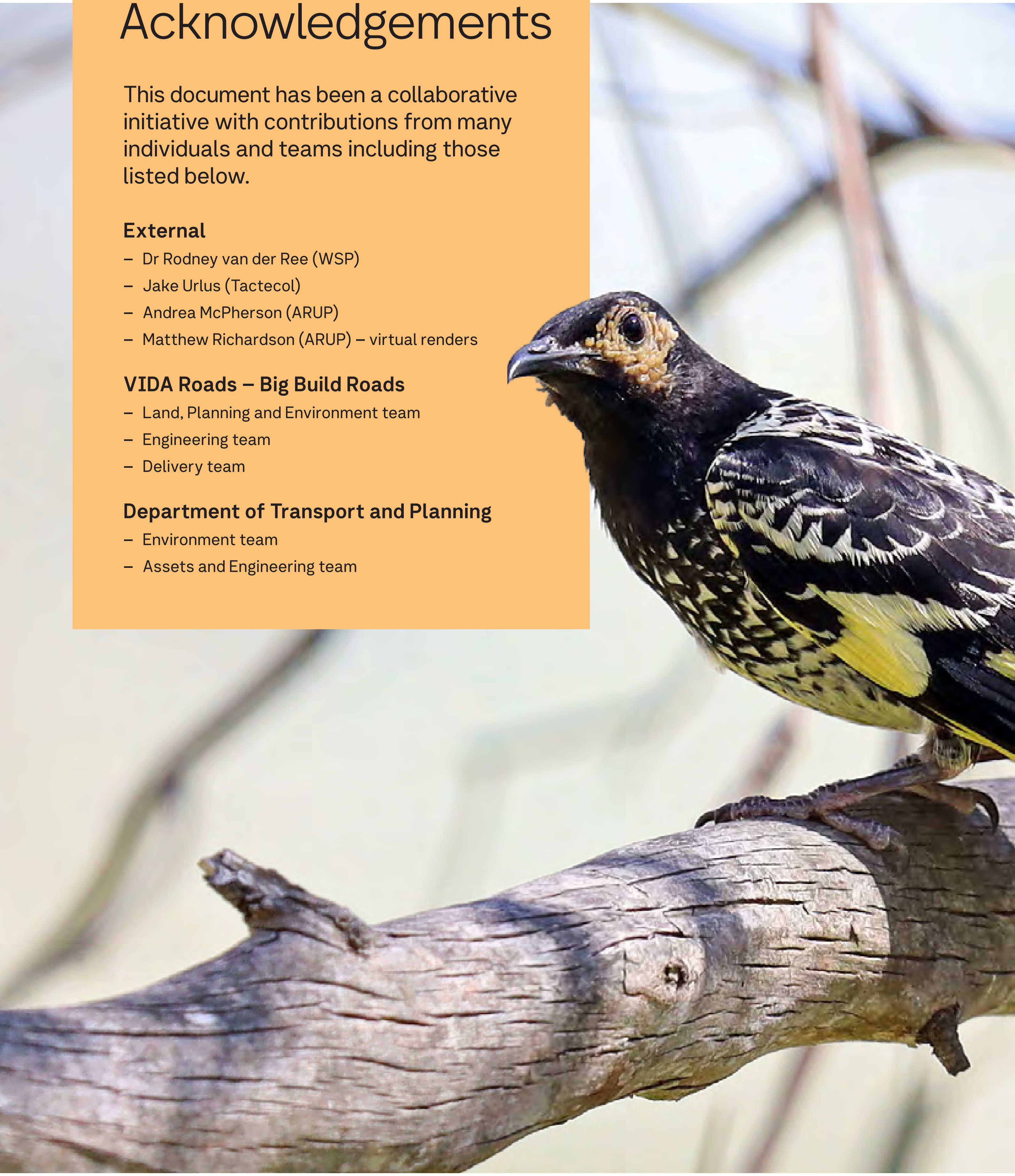

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Glossary and abbreviations

Behavioural barrier: A non-physical barrier (such as light, darkness or sound) that prevents or alters wildlife movement.

Biodiversity: A number, variety and genetic variation of plants and animals found within a specific geographic region.

Bridge: Can include single span bridges, multi-span bridges and viaducts.

Chytrid fungus: An infectious disease Batrachochytrium dendrobatidis that affects amphibians worldwide.

Coarse woody debris (CWD): Standing or fallen branches, logs, or dead trees or woody shrubs.

Concept Design: Conceptual design to enable the determination of project feasibility.

Connectivity (ecological): The degree to which habitat in a landscape is linked and facilitates or impedes movement of fauna among habitat, populations, and resources. A highly connected landscape facilitates gene flow and general fauna movement (including dispersal, migration and day-to-day foraging, etc) throughout the landscape.

DCCEEW: Department of Climate Change, Energy, the Environment, and Water (Commonwealth).

DEECA: Department of Energy, Environment and Climate Action (Victoria).

DTP (Transport): Department of Transport and Planning (Victoria).

EMF: Project-level Environmental Management Framework.

EPBC Act: *Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth).*

EPR: Environmental Performance Requirement.

FFG Act: *Flora and Fauna Guarantee Act 1988*.

FSRD: Fauna Sensitive Road Design.

Fragmentation: Breakup of continuous habitat into smaller populations.

Functional connectivity: The degree to which fauna movement occurs between discrete areas of habitat that supports populations, particularly exchange of individuals and genes among populations. See structural connectivity.

Indigenous: Plants endemic to a given area or geological zone.

Instream Woody Habitat (IWH): Consist of branches, logs and whole trees that fall or are placed into waterways and create essential habitat for aquatic fauna and help maintain the health of waterways (DEPI, 2013).

Large Woody Debris: Branches, logs and whole trees that fall into waterways.

LPE Team: Land, Planning and Environment Team in VIDA Roads.

Overpass: An overpass is a structure that allows wildlife to pass above or over the top of road infrastructure. It includes land bridges, canopy bridges and glider poles.

Perching: A perched culvert is a culvert where the inlet or outlet elevation is higher than the streambed elevation, thereby effectively reducing or eliminating fish migration and fish passage.

Phytophthora: A plant pathogen, Phytophthora cinnamomi, which kills susceptible taxa by attacking the root system. Also known colloquially as 'dieback'.

Reference Design: Subsequent to Concept Design, this is a more detailed design to enable and inform the procurement process.

REZ: Road Effect Zone.

SMART goals: Specific, Measurable, Achievable, Realistic, Time-framed.

Stepping-stone: A type of isolated structural connectivity feature, such as an isolated paddock tree or patch of habitat that fauna can use to 'step' between large areas of habitat. See 'structural connectivity'.

Structural connectivity: Features in a fragmented or heterogeneous landscape that physically link other features and aids movement of fauna, especially discrete areas (patches) of habitat occupied by any species in question, wildlife linkages/corridors, and stepping-stones (Doerr *et al*. 2014). Can include macro elements such as scattered trees, habitat patches and corridors, and micro habitat features, such as logs, hollows, rocks, or dense vegetation, that a fauna species requires to move through an area. Structural connectivity aids in achieving 'functional connectivity'.

Substrate: Surface or layer of sediment on an object such as a bridge, river or within a culvert.

Underpass: An underpass is a structure that allows wildlife to pass beneath road infrastructure. It includes bridges and culverts.

VIDA Roads: Victorian Infrastructure Delivery Authority Roads (previous referred to as Major Road Projects Victoria)

VIDA Roads and its representatives: Includes VIDA Roads staff, consultants and contractors i.e., anyone operating on behalf of VIDA Roads.

WVC: Wildlife-vehicle collision.

1. Introduction

VIDA Roads is a dedicated government body charged with planning and delivering major road projects for Victoria. VIDA Roads is a project office of the Victorian Infrastructure Delivery Authority (VIDA). VIDA was established on 2 April 2024 to deliver the state's transport and health infrastructure in coordination with the Department of Transport and Planning (DTP).

Photo 1 Australian Wood Duck parent with ducklings on a roadside (Source: VIDA Roads)

1.1. Purpose

Roads are an integral part of human landscapes, cover large areas of the Victorian landscape, and form a significant amount of the hard infrastructure we place in it. They play an essential role in connecting towns, cities, populations, and people but also have a large impact on the natural environment and the native animals that we share the landscape with. Roads and road creation can create barriers to animal movement and migration, remove and fragment wildlife habitats, displace native animals, and disrupt ecological processes and systems. In some cases, road delivery may also provide opportunities for enhancement of wildlife habitat values and connectivity, particularly in highly degraded, fragmented, or urbanised landscapes.

Fauna-sensitive road design (FSRD) is a process that considers the impacts of roads on wildlife populations and seeks to address them through modified road design and delivery to allow safe movement of wildlife across roads (Johnson *et al*. 2022; see **Section 1.4**).

The purpose of these Fauna Sensitive Road Design Guidelines is to provide essential technical advice on how to design and deliver roads to minimise impacts on wildlife populations and their habitats. This includes detailed technical design and delivery guidance for fauna crossing structures and other FSRD measures to achieve defined ecological objectives for different fauna groups.

These guidelines also provide advice on how VIDA Roads can incorporate and implement Fauna Sensitive Road Design (FSRD) into the various stages and existing processes of road development and delivery. Importantly, this advice is for both VIDA Roads teams and to our partners who together deliver Victorian road infrastructure projects.

The Guidelines are to be used by relevant VIDA Roads teams and partners (consultants and contractors) to inform designs and delivery of appropriate FSRD measures. It may be applied in full, or elements may be adopted depending on the project scope and specific circumstances. Advice in this document, including design specifications and recommendations, are only concerned with requirements to fulfill the defined ecological or connectivity objective for wildlife. Other considerations will ultimately influence the final FSRD measures possible on any project, such as road function, costs, design standards, feasibility, regulatory obligations, and community needs amongst many others.

This document builds on other FSRD guidelines, both in Victoria and interstate, with a key focus on specific design guidance and fauna crossing structures.

1.2. Policy Context

VIDA Roads is a dedicated government body that oversees the construction of the North East Link, the West Gate Tunnel Project, and the Big Build Roads program that includes a host of other essential freeway, road, bridge and intersection upgrades across Victoria.

Along with meeting legislative and regulatory obligations, this document can support several commitments relating to biodiversity and the natural environment under relevant policies at the project office level.

Under sustainability, this includes an aspiration to be *'leaders in infrastructure sustainability and deliver projects that optimise social, economic and environmental outcomes over the long term.'*

To achieve this vision for environmental outcomes, there is commitment to:

- ***Avoid and minimise harm to biodiversity and the natural environment***.
- *Seek opportunities to enhance biodiversity and the natural environment.*
- *Facilitate innovation across the transport infrastructure construction industry.*

Amongst several actions, these outcomes are implemented by the commitment to:

- *Establish robust sustainability objectives and targets, and implement systems to monitor and measure sustainability performance in order to drive continuous improvement.*
- *Support our staff to achieve our goals, pursue best practice and demonstrate leadership through delivering appropriate education and training, and fostering a culture of innovation, collaboration, knowledge sharing and continuous improvement.*

Also acknowledged is the concept of 'sustainable development' as defined by the Victorian Commissioner for *Environmental Sustainability Act (Vic) 2003:*

- *Ecologically sustainable development is development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends.*

One of the objectives of ecologically sustainable development is:

> 'To protect biological diversity and maintain essential ecological processes and life support systems.'

The practice of fauna sensitive road design can support these commitments being achieved through:

- Reducing or preventing animal injury and mortality from **wildlife-vehicle collision (WVC)**.
- Maintaining or enhancing ecological connectivity.
- Minimising direct and indirect impacts on flora and fauna, including from habitat clearing, noise and artificial light at night, chemical pollution.

Gang-gang Cockatoo, Dean Ingwersen

1.3. Impact of roads on biodiversity

Wildlife and ecosystem processes operate on large spatial and temporal scales. For example, fauna home ranges and dispersal vary greatly among species, ranging from tens of metres to hundreds of kilometres. The development of new roads and road infrastructure is one of the leading causes of contemporary habitat fragmentation. As such VIDA Roads is committed to ensuring that new road developments employ best practice strategies to avoid, minimise and mitigate biodiversity impacts.

The road network has the potential to have a significant effect on wildlife and ecosystems. A summary of some of the impacts of roads to biodiversity is provided below:

- **Habitat loss**: Construction of roads and associated infrastructure usually involves the direct and indirect loss of wildlife habitat. The physical encroachment on the land gives rise to disturbance and barrier effects that contribute to overall fragmentation.
- **Disturbance**: Roads, associated infrastructure and traffic disturb and pollute the physical, chemical and biological environment, altering habitat suitability for a range of species across a much wider area than the width of the road itself. This is called the road effect zone (REZ).
- **Loss of habitat connectivity and wildlife corridors**: Across Victoria, historical broad scale native vegetation removal has resulted in many wildlife populations being restricted to isolated patches of habitat. In many areas, remaining native vegetation and other fauna habitat (sometimes exotic vegetation) along waterways and roadside vegetation constitutes the only remaining habitat or connectivity within the landscape. Other features such as scattered paddock and roadside trees may also provide the only 'stepping-stones' in the landscape facilitating movement of fauna.

  Consequently, linear strips or areas of habitat along roadsides provide refuges, new habitats or serve as movement corridors or stepping stones for wildlife. Road development can result in the loss of these and other corridors, reducing habitat and inhibiting movement and dispersal of fauna.

  Where roads dissect intact patches of habitat, they divide wildlife populations, reducing their functional size and viability, while also reducing gene flow and capacity for sites to be recolonised through emigration. As fragmentation increases and patch size decreases, the remaining patches of habitat may be too small to support populations of some wildlife species. In these ways, further fragmentation of habitat patches also results in reduced landscape connectivity for wildlife.
- **Wildlife mortality**: Traffic interactions can cause the injury or death of many animals. Traffic mortality has been growing constantly over the years. Collisions between vehicles and wildlife are also an important traffic safety and animal welfare issue.
- **Barrier**: For many fauna species (including birds and bats), road infrastructure can inhibit movement throughout an animal's usual range, make habitats inaccessible and can lead to the isolation of populations. The barrier effect is the most prominent factor in the overall fragmentation caused by road infrastructure.
- **Financial costs**: Broken roadside infrastructure, insurance claims relating to both human and animal mortality and various repair or liability costs are key considerations.

Photo 2 Eastern Grey Kangaroos have high rates of vehicle-collision (Source: VIDA Roads)

1.4. What is Fauna Sensitive Road Design?

FSRD is the process whereby roads are designed to avoid, minimise and manage impacts with an aim to facilitate fauna movement across landscapes and prevent wildlife mortality from WVC. FSRD can also incorporate opportunities for ecological enhancements, such as through creating additional habitat (or values) and improving ecological connectivity, such as through retrofitting or replacing previous infrastructure to remove barriers and facilitate wildlife movement.

By improving wildlife connectivity and reducing mortality, FSRD aims to protect ecosystem function, reduce pressure on species threatened by habitat fragmentation and improve the viability of wildlife populations. In these ways FSRD contributes to meeting the objective of more ecologically sustainable infrastructure.

1.4.1. Mitigation hierarchy

FSRD is applied through the first two steps of the widely accepted 'mitigation hierarchy' applied in environmental impact assessment and management, and in efforts to meet environmental legislation protecting biodiversity:

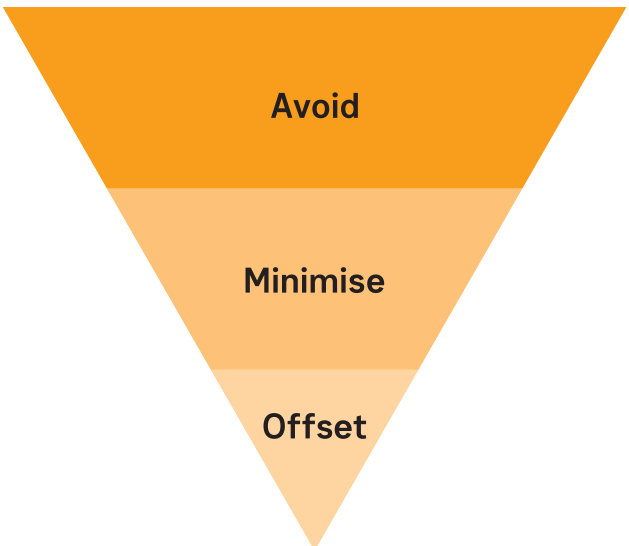
1. Avoid
2. Minimise-Mitigate
3. Offset

These are often depicted in a pyramid diagram to emphasise the stepped approach and priority of each approach and where the greatest effort should be expended (**Figure 1**).

Two additional steps can be included in the hierarchy, namely:

1. Restore
2. Enhance

Figure 1 The Mitigation Hierarchy



Restoration activities are increasingly being considered as part of the mitigation hierarchy. This includes actions to restore native vegetation or fauna habitat and can either form part of minimising and mitigating impacts (Step 2) or as an additional measure beyond formal offsets to achieve a 'net positive impact' for biodiversity.

Restoration includes re-establishing native vegetation, ecosystems, or wildlife habitats to an area in a healthy functioning state and as close to the original composition as possible. Most often this refers to restoration activities on previously cleared areas of land. This can be aimed at restoring ecosystem function and can be aimed at specific populations of threatened wildlife species or specific ecological objectives. For example, connecting two or more areas of habitat or populations through various FSRD measures.

Enhancement of existing biodiversity/wildlife values beyond existing conditions is another additional step that can be taken as part of FSRD and the mitigation hierarchy, extending above measures to mitigate the impacts of road development. Enhancement could include adding missing or reduced habitat values for fauna, like hollow logs, tree hollows, additional plant species, microhabitats, or waterbodies.

Restoration and enhancement are increasingly being realised as 'net positive' actions essential to avoiding further decline of biodiversity, addressing historical losses, and mitigating the threats of climate change to wildlife populations and species.

These actions are best stepped through sequentially as part of the process of applying FSRD to VIDA Roads' road development and construction process.

> This document outlines FSRD mitigation measures to minimise direct and indirect habitat loss, reduce the barrier effect created by road infrastructure, increase connectivity, and reduce mortality (human and fauna) and personal or financial loss through WVC reduction.

1.4.2. Setting FSRD goals for the project

A key step in FSRD is the setting of SMART goals (Specific, Measurable, Achievable, Realistic, Time-framed) as this will inform all avoidance, minimisation, mitigation, offsetting, and restoration/enhancement aspects of the project.

Overarching FSRD goals for projects can include:

- Reducing WVC and wildlife mortality.
- Reducing habitat loss, fragmentation, and degradation.
- Improving wildlife connectivity.
- Maintaining ecosystem services and ecological processes.
- Conserving and enhancing fauna habitat.

These may be adopted in entirety or in part depending on the project scope and context, and serve to guide the development of project-specific goals that respond to likely regulatory requirements.

Project-specific goals are required to inform the detailed actions that take place and are a refinement of the broad goals and will reflect:

- Project scope and context.
- Identified potential impacts on wildlife.
- Regulatory context and requirements.

c. Project constraints and opportunities.

Application of SMART goals in FSRD will (Van der Grift *et al*. 2015):

- Identify the specific road impact(s) that need to be addressed.
- Quantify the reduction in impacts being targeted or enhancements aimed for.
- Ideally be agreed upon by all stakeholders.
- Match available resources.
- Specify when the reduction/enhancement is to be achieved.

Also see **Section 8.1** for setting objectives for a project Fauna Management Plan.

1.5. Legislation

VIDA Roads, like all agencies, is bound by relevant state (VIC) and Commonwealth (federal) law and is responsible for seeking the appropriate approvals for its actions. It may also require representatives (e.g. contractors) to obtain appropriate approvals in some instances.

Legislation and policy that pertain to FSRD and the management of biodiversity include:

- *Environment Protection and Biodiversity Conservation Act 1999*
- *Environment Effects Act 1978*
- *Planning and Environment Act 1987*
- *Flora and Fauna Guarantee Act 1988*
- *Water Act 1989*
- *Wildlife Act 1975.*

Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)

The Commonwealth EPBC Act is Australia's primary federal environment legislation, providing a framework for managing and protection of biodiversity and its natural and culturally significant places. The EPBC Act is the administered by the Minister for the Environment and Water (Commonwealth) and the federal Department of Climate Change, Energy, the Environment and Water (DCCEEW).

Under the Act there are a range of protections for listed ***Matters of National Environmental Significance (MNES)***:

- World Heritage properties
- National heritage places including overseas places of historic significance
- Wetlands of international importance (Ramsar wetlands)
- Nationally threatened species and ecological communities
- Migratory species
- Commonwealth marine areas
- The Great Barrier Reef Marine Park
- Nuclear actions (including uranium mining &building of nuclear waste repositories)
- A water resource, in relation to coal seam gas development and large coal mining development.

Of these MNES, Ramsar wetlands, migratory species, and nationally threatened species and ecological communities are of most relevance to VIDA Roads projects.

If there is potential for a 'significant impact' to one or more MNES, an EPBC Act referral to the federal Environment Minister and their department may be required for further assessment and approval. If the federal Environment Minister determines there is potential for a significant impact on an MNES (based on the magnitude/uncertainty of impacts or mitigation measures), the action may be determined to need further consideration and oversight, resulting in a 'Controlled Action' decision.

Both the mitigation hierarchy (avoid, minimise, restore, and offset) and precautionary principle are important elements of decision — making under the Act. As defined under the EPBC Act:

> The **precautionary principle** is that lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment where there are threats of serious or irreversible environmental damage.

FSRD measures on VIDA Roads projects are often in response to requirements to avoid or reduce impacts to nationally threatened species, particularly in 'Controlled Action' approval outcomes. They are also an essential part of avoiding and mitigating impacts to reduce them below the threshold of significance on MNES and avoiding further assessment and approval under the Act.

Environment Effects Act 1978 (EE Act)

The Victorian EE Act addresses activities and proposed projects that could have a significant effect on the Victorian environment. The EE Act provides an assessment process for impacts to be assessed called the Environmental Effects Statement (EES). Proponents undertake a self-assessment to determine whether there is potential for significant effects. Referral to the Minister administering the Act is required to determine whether an EES will be required for a project. Guidance on specific criteria for referral and processes for an EES assessment process are defined in the Ministerial guidelines for assessment of environmental effects under the *Environment Effects Act 1978 (DTP 2023).*

Under the Guidelines, there are a number of ecological *'referral criteria'* that are relevant to native fauna species and populations. This includes potential impacts to threatened species and fauna communities listed under the *Victorian Flora and Fauna Guarantee Act 1988* such as:

- Potential clearing of an area determined as 'critical habitat' under the Flora and Fauna Guarantee Act 1988.
- Potential loss of a genetically important population of an endangered or threatened species (listed or nominated for listing), including from loss or fragmentation of habitats.
- Potentially significant effects on habitat values of a wetland supporting migratory bird species.
- Potential for loss of a significant proportion (e.g. 1 percent or greater) of known remaining habitat or population of a threatened species within Victoria.
- If wildlife populations or threatened species have potential to be significantly impacted, then mitigation measures, such as those described in these Guidelines, may be required to be implemented on a road project. These measures are first recommended in a Ministers Assessment under the EE Act and then considered in permit conditions under state planning approvals. An EES is also an accredited assessment process under the EPBC Act and often provides the basis for decision and resulting EPBC conditions placed on a project if it is approved.

Planning and Environment Act 1987 P&E Act)

The P&E Act is the main piece of Victorian legislation relating to planning and approvals for development, including road projects. Project planning permits and approvals are issued under the P&E Act with various instruments under the Act of potential relevance to FSRD. One of these are planning overlays which may specify particular planning requirements or considerations for planning decisions in a specific area. These may consider wildlife corridors, important sites for biodiversity, or significant values for wildlife.

Victoria's native vegetation regulations

The other major instrument under the P&E Act is *Victoria's Native Vegetation Removal Regulations (2017)* which are implemented under various Clauses under the Victorian Planning Scheme but mainly Clause 52.17 and for VIDA Roads Clause 52.35. A permit is required for the removal of native vegetation and the regulations account for important values that this vegetation provides to Victoria's wildlife and ecological function. Assessment and planning applications must be in accordance with the Guidelines for the removal, destruction or lopping of native vegetation (DELWP, 2017).

Under Victoria's Native Vegetation Removal Regulations proponents are required to consider impacts on biodiversity values. Importantly, the native vegetation regulations require proponents to avoid, minimise, and offset impacts on native vegetation. Habitat for rare and threatened species is considered and acknowledged as an important value that native vegetation provides.

Flora and Fauna Guarantee Act 1988 (FFG Act)

The FFG Act is Victoria's primary legislation for the listing and conservation of threatened species and communities, and management of threatening processes to biodiversity. The Act is supported by the Flora and Fauna Guarantee Regulations 2020.

The FFG Act requires consideration of biodiversity and protected values in decision — making across government. There are specific controls for protected and threatened flora and fish listed under the Act and permits or authorisations are required for their removal. Decision-makers are required to give due consideration to the objectives of the Act (see below), the acceptability of impacts, and any instruments made under the Act (e.g. FFG Action Statements, management plans, or agreements). Under the Act, there are also powers enabling the determination of critical habitat for listed species.

Under the Victorian FFG Act, due regard extends to all public authorities under the Public Authority (Biodiversity) Duty (PAD). The Duty requires public authorities — as far as consistent with their function — to give proper consideration to the Act's objectives, and any instrument made under the Act, in performing any function that could reasonably be expected to impact on biodiversity. This includes both decisions made by government proponents along with those with regulatory functions, such as the issuing of permits under the FFG or Wildlife Acts.

The FFG Act objectives are to:

- *Guarantee that all of Victoria's flora and fauna (species)…can persist and improve in the wild and retain their capacity to adapt to environmental change (4a).*
- *Prevent taxa and communities of flora and fauna from becoming threatened and to recover threatened taxa and communities so their conservation status improves (4b).*
- *Protect, conserve, restore and enhance biodiversity species, ecological communities, genetic diversity, and ecological processes (4c).*
- *Identify and mitigate the impacts of potentially threatening processes to address the important underlying causes of biodiversity decline (4d).*
- *Ensure the use of biodiversity as a natural resource is ecologically sustainable (4e); and*
- *Identify and conserve areas of Victoria in respect of which critical habitat determinations are made (4f).*

Instruments made under the Act include:

a. The Biodiversity Strategy (*Biodiversity 2037*); and

b. (FFG) action statements; and

c. Critical habitat determinations; and

d. Management plans.

Under the Act, due regard must be given to the full range of potential biodiversity impacts, including:

- Long and short term
- Direct and indirect
- Detrimental and beneficial
- Cumulative
- Potentially threatening processes (as listed under the FFG Act) must also be considered, such as weed invasion.

It is also important to note that other public authorities (including those with environment regulatory functions) must also give due consideration to the PAD in exercising their functions.

The FFG Act is administered by the Department of Energy, Environment and Climate Change and is overseen by the Office of the Conservation Regulator.

Helping to meet regulatory obligations

The FSRD Guidelines provide advice on how impacts on protected biodiversity values, including threatened fauna species, can be avoided and mitigated through a range of measures. Conversely, where avoidance and mitigation measures for fauna and wildlife populations are required under planning or legislative approvals, these FSRD Guidelines can provide VIDA Roads project teams and partners with the specific technical detail to meet them.

Implementation of FSRD measures may assist in avoiding impacts on EPBC or FFG Act listed threatened (or migratory) fauna species and their habitats in the first instance. In this way, there may be less onerous assessment and approval requirements for a project.

For example, in avoiding significant impacts on MNES protected under the federal EPBC Act, a project may receive a 'not controlled' or 'particular manner' decision under the EPBC Act, or less onerous assessment method under a 'controlled action' decision. This includes the assessment methods of 'referral information only', 'preliminary documentation', or 'bilateral or accredited process' (Environmental Effects Statement) that reflect increasing level of assessment process, consultation and timeframes.

Uncertainty is also key consideration under EPBC Act self-assessments and regulatory decision-making, both in regard to the significance of impacts and any proposed mitigation measures for MNES. This is considered by decision-makers in determining whether the action needs to be a 'controlled action' and if so, the level of assessment (method) required based on the additional information required and level and complexity of impacts on MNES.

The more detail and certainty that can be provided on the effectiveness and feasibility of implementing proposed mitigation measures in avoiding or reducing impacts on MNES, the less uncertainty there is for decision-makers. This can assist in less onerous (post-referral) assessment requirements or approval decisions, in combination with other considerations as outlined above.

These FSRD Guidelines can inform advice, including avoidance and mitigation recommendations, provided in independent ecological assessments (by VIDA Roads' consultants) that may be required to support approval applications or referrals. In this way, the FSRD Guidelines can provide the technical detail to inform decisions on suitability and feasibility of implementing mitigation measures before these are committed to. It also provides a central document on which the review and test the practicality, feasibility, and any related requirements of FSRD mitigation measures before these are proposed in approval processes.

More broadly, implementation of FSRD can also assist in meeting avoidance and minimisation requirements under Victoria's native vegetation regulations and help meet VIDA Roads' PAD under the FFG Act.

1.6. Policy

Relevant government policy and strategy for biodiversity management and FSRD include:

- *Biodiversity 2037 (VIC)* — Victoria's biodiversity strategy
- *Nature Positive Plan (Commonwealth)* — current (2023) federal biodiversity policy position
- *Australia's Strategy for Nature 2019–2030 (Cth)*
- *Threatened Species Strategy 2021–2031 (Cth)*

These documents guide government decision — making and can influence requirements and opportunities for FSRD on VIDA Roads road projects.

1.7. Implementing Fauna Sensitive Road Design

The FSRD process aims to integrate ecological considerations across the road delivery lifecycle from the initial planning phases, through to the development and delivery project stages. This ensures the most efficient and effective design process to achieve the desired ecological outcomes.

FSRD is best implemented in coordination with all other road development requirements and processes including:

1. Road design and function.
2. Pedestrian and safety requirements — lighting, fencing, access, and movement.
3. DTP (Transport) and water authority design and maintenance requirements, e.g. safety, scour protection, and flood management.
4. Land procurement and access.
5. Planning and environment approvals.
6. VIDA Roads' Sustainability Policy and project-level Environmental Management Framework (EMF).
7. VIDA Roads Landscape and Urban Design Framework (April 2024).
8. VIDA Roads Integrated Water Management Guidelines (FINAL, May 2023).

As there are often multiple interacting or competing requirements through the design and delivery (construction) process, best-practice FSRD outcomes will involve iterative designs and solutions which requires collaboration and integration between road design, structures design, ecologists, arborists and urban design to name a few. This extends to both the avoidance and minimisation of impacts on biodiversity values but also equally to the design and implementation of wildlife crossing structures and other mitigation measures.

1.7.1. Early consideration

Early and well-developed integration of FSRD, and coordination with all other requirements, into the road design is fundamental to successful implementation of effective FSRD. The first-order priority of FSRD is to avoid impacts on wildlife and their habitat in the first instance. This may involve selecting a road design or route option which entirely avoids impacts on wildlife habitat or connectivity. For this to occur, consideration of FSRD should ideally commence early in the design process and Business Case phase (Table 1.1).

Where avoidance of impacts is not feasible,opportunities to mitigate impacts are best considered at the earliest phase of the project lifecycle. For fauna crossing structures, for example, early consideration is essential to ensure the proposed solution is fully integrated into the reference design, conflicting requirements (e.g. drainage) are identified early and resolved, feasibility of implementation is considered, and adequate costs are allocated to design and construct them.

Early phase consideration of FSRD in design planning and costing is essential to:

- Selecting road alignments with the least impact on biodiversity, fauna populations, and wildlife connectivity.
- Determining very early what fauna connectivity solutions, or FSRD measures, are required to achieve the best outcome for wildlife populations and ecological connectivity. This includes the optimal type of crossing structure required as this will inform route options, road design (e.g. road levels, bridge lengths etc.), and project costs (budgets).
- Understanding the ecological consequences of certain route/alignment or road design options, including on wildlife connectivity and FSRD opportunities.
- Ensuring the FSRD features are considered in early planning and design stages and high-level decisions can facilitate mitigation measures e.g. road is at sufficient level (height) to allow the installation of an optimal fauna crossing solution, like a fauna culvert under a road.
- Decisions made early in the route selection and road design/costing process are likely to lock in important elements of road development and for some structures or specific locations, consequently placing limitations on all future options for FSRD implementation.

1.7.2. Multi-disciplinary solutions

> Multi-disciplinary collaboration is also essential through all stages of FSRD implementation, from integration into Business Case processes to construction and maintenance.

This involves meaningful and proactive engagement among various technical delivery professionals including engineers, ecologists, environment managers, arborists, approvals specialists, project managers, and construction contractors.

This is particularly necessary when avoiding and minimising impacts as a first order priority before implementing mitigation measures like fauna crossing structures. Avoidance rather than mitigation will always produce a better outcome or biodiversity and fauna.

The importance of multi-disciplinary solutions also applies to FSRD mitigation measures where avoidance is not possible, such as wildlife crossing structures. Early engagement and collaboration between ecologists and engineers and/or designers are required to ensure:

- Crossing structures are fit-for-purpose and achieve their ecological objective and are e.g. can be used by target wildlife species.
- The road design enables the construction of wildlife culverts, underpasses or overpasses where these are required.

- Appropriate locations are selected.
- Design faults are identified early.
- Interactions with other road infrastructure are managed and integrated in the design at an early phase e.g. lighting, amenity, drainage.

Early integrated design will ensure projects can avoid poor outcomes both for wildlife and project delivery (costs and program) including:

- Road drainage flooding 'dry' culverts intended for terrestrial fauna.
- Ramps up to culverts and land bridges being too steep for animals to navigate or composed of unsuitable material (e.g. large rock beaching).
- Unsuitable locations or design of fauna furniture, e.g. ledges or ramps with steep or abrupt drop-offs.
- For example, interactions between fauna crossing structures and drainage design is one key example in which detail design and investigations, and between engineers and wildlife ecologists, are required to ensure the correct structures and levels are designed and constructed to achieve either wet passage for aquatic species (e.g. **Section 3.4.2, 3.4.3**) or dry passage for terrestrial fauna (e.g. **Section 3.4.1**).

1.7.3. Review and advice

Regular reviews points can be used to ensure that all FSRD measures are adequately checked at each project stage and conflicts among multiple design elements are identified and resolved. Some recommended review and hold points are included at each step in the project outlined in **Section 1.7.5** and **Table 1.1**, as well as at intermediate steps where required. Advice from technical specialists should be sought to ensure designs are ecologically sound and fit-for-purpose. Relevant specialist input is best applied at each stage of design and delivery.

1.7.4. Communication

Information and feedback from key stakeholders and community groups or members will occur through established VIDA Roads or planning consultation processes. Key stakeholders may include local councils, transport authorities, water authorities and regulators such as the federal Department of Climate Change, Energy, the Environment and Water (DCCEEW), Melbourne Water, Catchment Management Authorities, the state Department of Energy, Environment and Climate Action (DEECA), and DTP (Planning).

Consultation at an early stage can be essential in identifying any conflicts, additional requirements, or other considerations that should be accounted for in proposed FSRD measures for a road project. For example, Catchment Management Authorities or Melbourne Water requirements for drainage may conflict with optimal design for fauna culvert crossings and these are best addressed in the early design stage.

There may also be opportunities for collaboration that can be initiated early in project development. For example, timber reuse opportunities with Catchment Management Authorities are best planned well in advance of delivery.

Communicating outcomes of targeted research and monitoring surveys provides an opportunity to share project successes, results and lessons learnt with key stakeholders and community members and organisations. This enables changes to mitigation measures to be implemented if they are found to be less effective than desired and key learnings to be applied to new projects earlier in the project Development stage.

There are also key opportunities to further develop and improve on FSRD practices through communication and collaboration with wildlife and species experts, government agencies, and research organisations, which could include partnerships in monitoring and research activities.

1.7.5. Implementing FSRD

To support the delivery of FSRD and use of these FSRD Guidelines on VIDA Roads projects, a recommended process for implementation has been developed (**Table 1.1**). Not all phases or steps below will apply across all VIDA Roads projects so this should be reviewed and refined and applied with regard to project specific scope and context.

Brown Treecreeper, Dean Ingwersen

Table 1.1 Recommended process for implementation of Fauna Sensitive Road Design on VIDA Roads projects

Phase	Step	Action description
1 Business Case *Concept Design*	1.1	Undertake Detailed Ecology Assessment (**Section 2.1**).
	1.2	Complete targeted surveys for threatened species if required (**Section 2.2**) and ecological connectivity assessment (**Section 2.3**). Further specialist studies may be required to inform an impact assessment, appropriate FSRD measures, and opportunities for enhancement e.g. detailed habitat assessments, fauna movement studies, or WVC surveys.
	1.3	Complete impact assessment and appraisal of FSRD risks and opportunities.
	1.4	Ecologist recommends FSRD avoidance and mitigation measures and opportunities for ecological enhancements in reference to VIDA Roads FSRD Guidelines and project ecological assessments. Advice received on project-specific ecological enhancement goals and recommended FSRD measures (type and optimal locations).
	1.5	FSRD measures and goals for the project reviewed and confirmed.
	1.6	FSRD measures incorporated into Concept Design based on consulting ecologist recommendations made in the Detailed Ecology Assessment report, the VIDA Roads FSRD Guidelines, and VIDA Roads review outcomes including Land, Planning and Environment (LPE) and internal ecology subject matter experts (SMEs).
2 Business Case *Reference Design*	2.1	Use the VIDA Roads FSRD Guidelines to inform the detailed road and mitigation design requirements for the project reference design (**Sections 3, 4, 4** and **0**). Where appropriate, a draft project Fauna Management Plan (FMP; **Section 8**) is developed, detailing the specific FSRD goals and measures (type, location, and design requirements). ***Note****: the complexity of any FMP will vary depending on the complexity of FSRD measures, the project, and approval requirements. Not all projects will necessarily require an FMP or FSRD measures may be incorporated into an equivalent document.*
	2.2	First review of FSRD measures for potential conflicts or interactions with other assets and requirements e.g. lighting, drainage, landscaping, planning approvals etc. Interdisciplinary review by VIDA Roads subject matter experts (SMEs) including ecologists, engineers, planners, and other technical specialists as required. Integrated solutions and options proposed.
	2.3	Once conflicts and interactions resolved, final FSRD measures are incorporated into the Reference Design. Draft Monitoring, Evaluation and Reporting (MER) framework developed.
	2.4	FSRD measures and MER are fully costed and incorporated into Business Case. VIDA Roads ecologists and/or FSRD specialists consulted to confirm all elements appropriately included and costed.

Phase	Step	Action description
3 Pre-construction *Project approvals*	3.1	FSRD measures appraised against endorsed Business Case.
	3.2	Additional technical studies undertaken as required to confirm appropriate FSRD measures and to meet potential approval mitigation requirements as per Step 2.4.
	3.3	Proposed FSRD measures reviewed by internal detailed multi-disciplinary team with specialist technical support.
	3.4	FSRD measures confirmed, documented in project-level Fauna Management Plan (or equivalent) and Reference Design, and included in the final project costing.
	3.5	FSRD measures in FMP incorporated into project requirements.
	3.6	FSRD Guidelines, project FMP, and Reference Design incorporated into project approvals and EMF. FSRD measures relevant to statutory requirements, approved by regulators.
	3.7	Road design, including all mitigation measures, are included in tender documents for detailed design and construction.
	3.8	Pre-construction MER commenced. If not appropriate or applicable, go to step 4.1.
4 Delivery *Construction*	4.1	Detailed design developed with reference to FSRD Guidelines, FMP, previous ecological assessments and recommendations, and (any) requirements for FSRD elements incorporated into final, and any secondary, project approvals.
	4.2	VIDA Roads contractors engage suitable ecological and FSRD specialist support in the design, construction, and implementation of FSRD measures.
	4.3	VIDA Roads review of A) Detailed Design, B) proposed FSRD measures and C) FSRD costings/budgets (inclusions and exclusions) to ensure adequate and can meet FSRD goals and approval requirements. Obtain VIDA Roads LPE and ecology SME advice and technical reviews. An VIDA Roads engineering team review can be undertaken to ensure design is feasible, will meet requirements, and has adequately considered/integrated other design requirements or co-dependent design features (e.g. drainage, lighting).
	4.4	VIDA Roads ecologists, LP&E and Engineering teams to monitor implementation of endorsed plans and provide integrated review and specialist technical support during construction. VIDA Roads ecologist provides review and support at critical junctures of delivery including after construction of hard structures, prior to landscaping, and in instances of design or construction changes. VIDA Roads to monitor general compliance with FSRD commitments.
5 Delivery *Completion**	5.1	Post-construction audit and review of FSRD elements to confirm successful implementation and objectives (goals) met. Non-conformances, substitutions, challenges, and lessons learnt documented to inform future VIDA Roads projects.
	5.2	Where appropriate or required, implement monitoring and evaluation of FSRD measures and their effectiveness to inform adaptive management and/or design of future projects. Note that 'pre-construction' or 'before mitigation' data may need to be collected well before construction commences (**Section 8.5**).
	5.3	Handover of FSRD asset to DTP* with appropriate information on design objective, features, ongoing maintenance requirements, and any related approval obligations (completions checklist).

Note that some steps can be repeated when objectives, conditions, information or the design changes.

*The process of project delivery includes the post-construction completion period incorporating 24 months defects liability (VIDA Roads) and steps to support operations (DTP).

2. Ecological assessments

Ecological assessments are required to quantify the biodiversity values that are present and to assess the extent to which a proposed road development could impact them. They can also inform the development and application of FSRD.

Artist's impression

The following ecological assessments are required to adequately determine biodiversity values present and to meet the basic legislative requirements for a project, and are described in the sections below:

- Detailed Ecology Assessment.
- Targeted surveys for threatened species.

> **Biodiversity assessments should be completed EARLY in the road planning and development process.** Early identification of biodiversity values ensures that biodiversity is retained in the Concept Design, adequate space is accommodated in the project area for mitigation measures and habitat enhancement, and potential costs of FSRD measures are incorporated into prepared Business Cases.

2.1. VIDA Roads Detailed Ecology Assessment

A Detailed Ecology Assessment (in accordance with VIDA Roads' report template) includes the following sections and components relevant to informing FSRD:

- Database and literature review including a review of fauna records.
- Field/site assessment results (native vegetation, fauna habitats, threatened species and communities).
- Biodiversity value assessment.
- Impact assessment.
- Avoidance and mitigation measures.
- Biodiversity enhancement opportunities.
- See **Table 2.1** for further details.

In addition to these sections, the Detailed Ecology Assessment includes a section for an initial assessment of landscape connectivity, sensitive biodiversity values, and opportunities for enhancement.

Using all this information, a preliminary FSRD assessment can be undertaken to identify:

- Areas of habitat for wildlife populations, habitat corridors, and habitat 'stepping-stones'.
- Fauna groups and species impacted by roads, such as mortality from WVC, barrier effects, indirect habitat loss.
- Potential population/habitat connectivity and animal movement within the project area and surrounding landscape.
- Barriers to wildlife movement and habitat connectivity, both physical (e.g. roads or fences) and behavioural/perceptual (e.g. gaps between habitat which animals would be reluctant to move across).
- Potential impacts to wildlife populations and their habitat from the existing and future development of the road.
- Other risks to wildlife habitats and populations.

Recommendations addressing the following points can then be provided:

- Ways to avoid impacts on wildlife populations and their habitats. This would include options for designing around wildlife habitats or movement corridors.
- Ways to minimise and mitigate impacts on wildlife populations and habitats.
- Potential future enhancements to existing wildlife connectivity and road wildlife safety.
- Whether wildlife crossing structures or other FSRD measures could assist to mitigate the impacts of the road or enhance ecological values and function.
- The type of wildlife crossing structures or other mitigation measures that may be appropriate (based on species, fauna group, and site-specific factors).
- Optimal locations for wildlife crossing structures or other mitigation measures.

Several other specialist studies or assessments may be required at subsequent stages to inform FSRD measures. These include:

- Threatened species assessments (see **Section 2.2**).
- General fauna or fauna community surveys – to characterise the fauna community present.
- Wildlife-Vehicle Collision assessments – using previous wildlife injury records and/or undertaking WVC surveys to determine hotspots of wildlife injury/mortality.
- Wildlife movement studies e.g. wildlife camera monitoring to determine current fauna movement patterns and potential road crossing points.

Ecological connectivity assessment

A more detailed ecological connectivity assessment may be warranted in cases where impacts on wildlife populations or threatened fauna species are greater or in contexts with more complex connectivity requirements. See **Section 2.3** for further detail.

2.2. Threatened fauna

Understanding the potential impacts of road delivery on threatened species is an essential step in developing appropriate and informed FSRD measures.

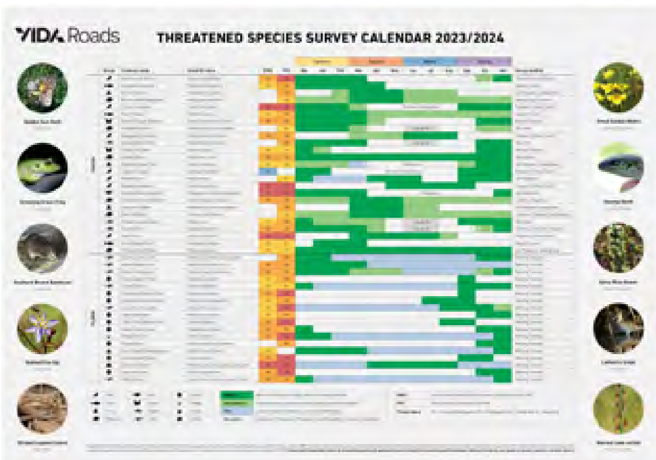
Threatened species assessments include specific and specialist surveys to determine the likely presence of the species in the project study area, the extent and quality of habitat, and the relative significance of any population or habitat present. They include the following essential components:

1. **Records**: Desktop searches of historical species records within the broader landscape (with 10km) and likelihood assessment.
2. **Habitat**: Mapping and quality assessments of potential threatened species habitat.
3. **Populations**: Species population (targeted) surveys to determine presence and undertaken in accordance with relevant state and federal survey guidelines.

This information is progressively collected across stages of ecological assessment (see **Table 2.1**) and used to inform the species likelihood of presence and whether it would make significant use of the project area. It also informs avoidance and mitigation including FSRD measures.

Targeted species (population) surveys may be required for state or federally listed species that have been identified during the detailed ecology assessment as having potential to occur and be impacted by the project. However, many threatened fauna species can only be confidently detected at a specific time of year and some under particular climatic conditions (e.g. after rain or warm weather). This often coincides with breeding periods or when the species is present at a location, such as migratory shorebirds that breed in the northern hemisphere and travel to eastern Australia over summer.

Figure 2 VIDA Roads Threatened Species Survey Calendar (Source: VIDA Roads)



As such, early planning for targeted surveys is important to scheduling targeted surveys at an appropriate time of year and avoiding project delays. Reference can be made to the VIDA Roads Threatened Species Survey Calendar (**Figure 2**) for the optimal time to survey a number of threatened fauna species with potential to be encountered on road projects in Victoria.

When a threatened species is considered likely to be present and has potential to be impacted by the project, mitigation measures may be required to reduce impacts. FSRD measures are often integral to avoiding and minimising impacts to threatened fauna species and are first considered in the impact assessment process.

Advice for avoiding minimising impacts on threatened species is provided by the consulting ecologist, and further developed in collaboration with VIDA Roads. The type of impact to a threatened species should be clearly specified and clearly linked to a specific mitigation measure. For example, a frog may be impacted by proposed street lighting and the mitigation measure is to use shielded lighting or relocate the position of lighting away from habitat. This process is mapped out in the **VIDA Roads Threatened Species Guide (Figure 3)**.

Obtaining and implementing this advice early in the road design and development process is critical to success and will ensure FSRD measures can be implemented efficiently and effectively (see further detail in **Table 1.1**).

Both the **Big Build Roads Detailed Ecology Assessment Report** template and **VIDA Roads Threatened Species Survey Calendar** provide guidance on the various steps and requirements involved in this process. The **VIDA Roads Threatened Species Survey Calendar** provides guidance of when to survey for some species more commonly encountered on VIDA Roads projects.

Figure 3 VIDA Roads Threatened Species Guide (Source: VIDA Roads)


Powerful Owl

2.3. Avoid and minimise impacts

As a priority, impacts to biodiversity should be avoided wherever possible, with the results from the biodiversity assessments informing the Concept Design.

The Detailed Ecology Assessment report will identify areas with high biodiversity value that should be prioritised for impact avoidance.

Impacts can be:

- Direct and indirect.
- Long and short term.
- Cumulative.

Impacts to wildlife and threatened fauna species and their habitats should be clearly defined with specific impacts matched to proposed mitigation measures e.g. impacts of street lighting on breeding behaviour of a frog species is mitigated by shielding or positioning of lighting. In this way, a clear link can be drawn between the identified specific impact and mitigation measure proposed. This is particularly important when there are changes or issues in design or delivery (construction) and the original objective must be understood to inform alternative solutions e.g. it is important to document the 'why' and carry this information through the process for future reference, particularly during delivery when ideal designs proposed in concept may require modification to suit existing conditions or conflicts.

Important biodiversity values

Generally, the following ecological features are of higher biodiversity value and roads should be designed and implemented in a way that avoids impacts to them. If avoidance is not possible, then the mitigation hierarchy detailed in **Section 1.3** should be applied to reduce impacts on each feature:

- Large, intact or high-quality areas of native vegetation (**Photo 4**).
- Land and vegetation providing ecological connectivity or acting as a stepping stone such as roadside vegetation (**Photo 5**).
- All native vegetation in highly cleared landscapes.
- Large (**Photo 6**) or hollow-bearing native trees (**Photo 7**) and fallen timber.
- Native vegetation providing flora or fauna habitat (**Photo 8**).
- Non-native vegetation providing fauna habitat (e.g. Blackberry providing habitat for the threatened and EPBC listed Southern Brown Bandicoot, non-indigenous large trees with hollows or nesting values).
- Habitat for rare, threatened or migratory species listed under state or federal legislation (FFG or EPBC Acts; **Photo 3** and **Photo 8**). This can include either native or exotic vegetation or other landscape features (waterbodies), depending on the species.
- Threatened ecological communities or endangered Ecological Vegetation Class (EVC) (**Photo 9**).
- Sensitive coastal areas and important listed wetlands for migratory birds.
- Wetlands, waterways, and adjacent riparian ecosystems (**Photo 10** and **Photo 11**)
- Vegetation playing a role in preventing land degradation, e.g. the land is unstable, steep, subject to soil erosion or slippage.

Most of these biodiversity values must be considered under Victoria's Native Vegetation Regulations (the Guidelines) — as defined in Appendix 1 of the Assessor's handbook Applications to remove, destroy or lop native vegetation (DELWP, 2017) — or under other state or federal legislation.

Under the Guidelines, an 'avoid and minimise statement' must be provided as part of applications to remove native vegetation:

> 'The statement describes any efforts to avoid and minimise the impacts on the biodiversity and other values of native vegetation, and how these efforts focussed on areas of native vegetation that have the most value.'
>
> **(DELWP, 2017)**

Where impacts are unavoidable, including habitat fragmentation, options should be sought to minimise the impact, for example bisecting a smaller area or directing impacts (losses) toward areas with poorer quality habitat.

Benefits of avoiding impacts to biodiversity

Avoiding impacts to biodiversity is not only the most environmentally beneficial approach to a road development, but can also be the most effective and beneficial approach as it may potentially contribute to:

- Reduced approval timeframes.
- Reduced offset requirements and costs.
- Fewer mitigation measures and costs.
- Less complex delivery requirements.

Photo 3 Native vegetation can support populations of threatened fauna species (Source: Austin O'Malley, VIDA Roads)

2.4. Other biodiversity assessments

A reduced level of assessment may be adequate for projects that are in the early planning or due diligence phase. Depending on project requirements, the following biodiversity assessments can be completed (**Table 2.1**):

- **Desktop assessment**: Includes a database and literature review only, no site assessment (see **Table 2.1**). May be useful for landscape-scale planning (e.g. by local governments), however when planning road infrastructure, a desktop assessment can be misleading.
- **Due diligence assessment**: Includes a database and literature review plus a modified site assessment (see **Table 2.1**). May be useful at very early-stage planning if the Project Area is only broadly defined and further refinement is required based on ecological values, other sensitive receptors, and constraints that may be present.

Note: Due diligence reports alone do not meet legislative requirements for a project and are not sufficient to determine whether biodiversity values (including fauna) are present or to what extent they will be impacted by the proposed road.

Table 2.1 Biodiversity information collected at different stages and levels of ecological assessment

Biodiversity information required to determine biodiversity values	Desktop assessment	Due diligence assessment	Detailed assessment	Targeted Surveys**
Database and literature review	✓	✓	✓	N/A
Field site assessment:				
– Map native vegetation	✗	✓	✓	N/A
– Map potential habitat for threatened species and communities	✗	✓	✓	✓
– Map other vegetation or habitat types (planted and non-native)	✗	✓	✓	✓
– Map 'large trees'	✗	✗	✓	N/A
– Native vegetation condition scoring	✗	✗	✓	N/A
Analysis and interpretation of results				
– Identify landscape connectivity and sensitive habitat	✓*	✓*	✓	✓
– Identify biodiversity areas that should be prioritised for retention	✗	✓*	✓	✓
– Implications under relevant biodiversity legislation and policy	✓*	✓*	✓	✓
– Further survey to confirm habitat for threatened species and communities	N/A	N/A	✓	✓

* High-level assessment only.

** Targeted species surveys should add further information and detail on fauna habitats and populations than collected at earlier phases of assessment.

1. During targeted surveys it is be expected that preliminary mapping of habitat for threatened species is further refined. This may involve collecting additional information relative to key habitat attributes for each, such as tree hollows, dense groundcover cover, waterbodies, or specific microhabitats, or meeting requirements under any relevant guideline e.g. species-specific EPBC significant impact assessment or referral guideline.
2. Broad fauna habitats (e.g. woodlands, grasslands, waterbodies, urban canopy/gardens etc) and features which provide potential habitat for fauna and can include exotic vegetation.
3. Detailed Ecology Assessments map 'large trees' in accordance with the definition under Victoria's native vegetation regulations (the Guidelines). Information from arboriculture tree assessments that extend to trees outside this definition may be available to inform habitat assessments and FSRD.
4. Additional information on habitat values, mainly tree hollows, may be collected for trees.
5. Collected using the Vegetation Quality Assessment ('Habitat Hectare' method) under Victoria's native vegetation regulations (the Guidelines).

Photo 4 Native vegetation
(Source: Austin O'Malley, VIDA Roads)

Photo 5 Roadside native vegetation
(Source: VIDA Roads)

Photo 6 Large old tree and fallen timber
(Source: Austin O'Malley, VIDA Roads)

Photo 7 Hollow bearing tree
(Source: VIDA Roads)

Photo 8 Threatened species and their habitat
(Source: Dean Ingwersen)

Photo 9 Ecological communities
(Source: Debbie Reynolds)

Photo 10 Wetland (Source: VIDA Roads)

Photo 11 Waterway Source
(Austin O'Malley, VIDA Roads)

2.5. Wildlife connectivity assessment

Estimating landscape movements of wildlife populations, and connectivity among habitats and populations, can range from relatively simple to highly complex. In some cases, interpretation of aerial imagery may be sufficient to identify linkages at a small (local) spatial scale involving a single species. More complex and larger-scale scenarios (such as projects with substantial connectivity impacts) may need to be informed by computer models.

2.5.1. Assessment steps

Regardless of the approach, there are some common key steps that can be followed in evaluating ecological connectivity and assessing potential project impacts, mitigation, and enhancements:

1. **Fauna present**: Identify the fauna groups and species (both common and threatened) that could occur, or move through, the project Study Area. Infer from an analysis of species records and assessments of habitat types, extent, and quality.
2. **Functional groups**: Identify main fauna functional groups reflecting their habitat, movement capabilities, and connectivity requirements. This includes their ability to cross gaps in habitat, how freely they can move through different types of landscapes and how far, and what they need in order to move freely, e.g. tall trees for gliders, dense groundcover for bandicoots, wet habitats for frogs, rocks for reptiles etc. (termed 'structural connectivity').
3. **Focal species/groups**: Select focal species or groups representative of each functional group to guide further connectivity assessment steps. These may also include threatened species.
4. **Habitat**: Map and assess habitat patches capable of supporting populations of focal species or groups.
5. **Stepping-stones**: Map structural connectivity features that facilitate animal movement e.g. scattered trees, roadside vegetation, or waterways. This may also include open areas of farmland for kangaroos or parks and gardens for other species.
6. **Barriers**: Identify potential barriers to movement (across and along the road corridor) for each fauna group.
7. **Habitat connectivity**: Assess potential habitat connectivity and fauna movement in the Study Area and broader landscape from information collected in Steps 1–6. Also identify existing constraints via lack of habitat connectivity or barriers.
8. **Impact assessment**: Evaluate which functional groups and threatened species could be potentially impacted by the current road or proposed development – these become the 'focal' or 'target' groups and species for the project.
9. **Connectivity assessment**: For each focal group/species evaluate the following questions for both the current road and proposed development:
   a. What species or faunal groups could be impacted by the road development or benefit through enhancements? These become the focus of further assessment.
   b. Are there any existing barriers to movement that could be removed/created?
   c. Are there habitat or movement corridors, or steeping stones, across or along the road corridor?
   d. Are there gaps in habitat which are/will be restricting or limiting movement?
   e. How could wildlife connectivity be improved, or impacts mitigated?
   f. Are there enhancements to existing habitat that could be made to increase structural connectivity? For example, adding ground logs, tree hollows, or rocks.
   g. Is there potential (or evidence) for WVC and animal injury/deaths?
   h. Are there any hotspots for WVC?

2.5.2. Tools for complex assessments

At larger landscape scales or when habitat connectivity is a key issue, more sophisticated spatial (computer) modelling and simulations may be required.

Many software and modelling tools have been developed for assessing habitat connectivity, and identifying the relative importance of wildlife habitat areas and the linkages (corridors) between them. These include commonly used software packages (amongst many others) that may be used or alone or in combination:

- **Circuitscape**: Predicts likely wildlife movement through varied or fragmented landscape using circuit theory.
- **Leastcostpath**: Calculates the least resistant pathway through a varied landscape (e.g. likely movement paths).
- **Graphab**: Models ecological connectivity networks
- **Linkage Mapper**: Automates mapping and prioritising wildlife habitat corridors to support regional-level planning.
- **Marxan Connect**: Allows connectivity to be included in protected area network planning.
- **GAP CLoSR**: Habitat connectivity assessment and prioritisation method using a dispersal guild model approach, which combines several software tools and reflects animal behavioural tolerances, including ability to cross gaps in habitat. Identifies which habitat patches are connected and likely animal movement pathways between them (Lechner *et al*. 2017). See **Figure 4**.

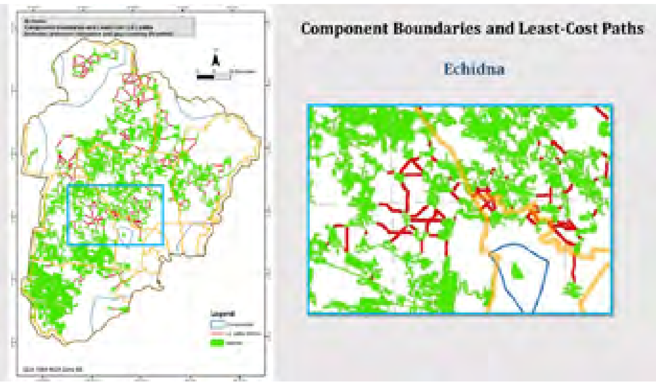
The most common modelling approaches used in research for assessing ecological connectivity for linear infrastructure is likely to be least-cost path analysis, graph theory and connectivity indices respectively (Tian Chin Fung *et al*. 2023; **Figure 4**).

Some of these software models require i) maps of habitat patches capable of supporting populations, ii) identification of potential 'stepping stones' or habitat corridors enabling animal movement, and iii) 'resistance surfaces' which attempt to represent the landscape from the view point of an animal in terms of how easy or hard parts of the landscape are to move through, e.g. a road is high resistance and habitat is low.

Other mechanistic modelling approaches combine these inputs with the behavioural and movement traits of fauna species for more explicit prediction of ecological connectivity at a landscape scale (Lechner *et al*. 2017; O'Malley and Lechner 2021). These can also be extended to assessing the impacts of road development proposals on ecological connectivity (Kirk *et al*. 2018). This includes weighing up various road alignment scenarios (options) and potential mitigation measures including crossing structures (Tian Chin Fung *et al*. 2023).

Regardless of the approach, a sound understanding of animal movement and behavioural ecology, habitat and wildlife connectivity concepts, environment impact assessment (EIA), and FSRD mitigation is required to adequately assess and advise on wildlife connectivity and road planning.

Figure 4 Example of landscape connectivity modelling for Echidna across north and west of Melbourne (Source: Austin O'Malley, VIDA Roads; O'Malley and Lechner 2021)



[8] See previous footnote on gap-crossing thresholds.

[9] Some information sources include Wildlife Victoria emergency callouts, Victorian Biodiversity Atlas, Atlas of Living Australia, and Victoria Police and VicRoads crash statistics.

[10] Some examples include Litvaitis and Tash 2008, Ramp and Roger 2008, Snow *et al*. 2014, Visintin *et al*. 2016, and Ang *et al*. 2019.

2.5.3. Relevant information and inputs

In their own right, these inputs (as maps) can be useful in identifying a) present location of wildlife habitat b) potential habitat or movement corridors, c) gaps in habitat connectivity, and d) potential barriers to movement. Considered together, this information can inform:

a. **Priority locations** for wildlife connectivity where impacts (losses of habitat or creation of barriers) should be avoided;

b. Estimating **potential impacts** of current and future road infrastructure and ancillary developments (e.g. utility relocations);

c. Options for **mitigating impacts** on habitat connectivity; and

d. Locations where habitat connectivity can be **restored** through either habitat creation, FSRD structures, or removal of barriers.

Ideally, ecological connectivity assessments can define and consider the following information:

1. **Lists of common and threatened fauna species likely to occur** within the Study Area and their potential to use habitat or land for movements (foraging, dispersal, and/or migration). Ideally assigned to functional groups and with key focal groups/species identified (see **Section 2.2**).
2. **Extent and quality of fauna habitat within the Study Area** (field assessments) and potential to support populations – this may require separate maps for different functional groups or species.
3. **Detail on the traits** of focal (target) wildlife species, particularly movement ecology, habitat requirements, and (habitat) gap-crossing tolerances[8].
4. Distribution of **potential fauna habitat, waterways**, and potential **movement corridors** in the **wider landscape** (desktop assessment).
5. Identified **core areas of fauna habitat** in local and wider landscape-size (ha) of habitat patches will vary depending on species or fauna focal group.
6. **Local or regional connectivity and biodiversity plans**, and state-level **biodiversity prioritisation** mapping (e.g. NatureKit).
7. **Rates, types, and locations (hotspots) of WVC using available databases**[9] and appropriate analysis methods[10] (**Figure 5**) that manage inherent spatial biases in WVC data). Consider need for location/ project specific assessment and monitoring to determine WVC risks and likely fauna movement (see **Table 1.1**).
8. Location of **present *and* future land uses** and infrastructure (see next section) and their **likely resistance to fauna movement** – this can include planning information, land use mapping, or specific fauna 'resistance maps' that classifies how easily (if at all) an animals can move through each part of the landscape-focal fauna group/species specific.

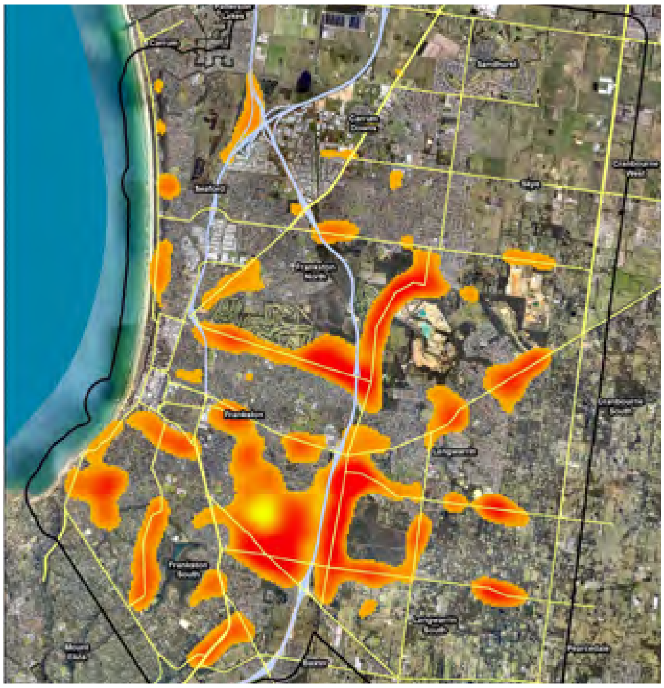
Much of this information can be drawn from the VIDA Roads Detailed Ecology Assessment, targeted species surveys, planning reports, and existing mapping resources, particularly those produced by state and federal government environment departments.

Some additional information and development of resources that may be required for individual projects or the broader VIDA Roads road program include:

- Biodiversity database searches and summaries of common fauna species records within Study Areas and surrounding landscape (not just threatened species).
- Landscape-level connectivity assessments which can inform multiple VIDA Roads projects.
- Spatial analysis to identify WVC hotspots (**Figure 5**).

This information and additional connectivity assessments can inform decisions of optimal road (route) alignments for avoiding or minimising impacts on wildlife connectivity. They can also inform the best location and design for FSRD mitigation measures, such as wildlife crossing structures and habitat creation, in response to the SMART goals for the project (see **Section 1.4.2**).

Figure 5 Example of a simple Wildlife-Vehicle Collision hotspot analysis (Source: Austin O'Malley)



Eastern Grey Kangaroo, Dean Ingwersen

Current and future land use considerations

Current and intended land uses should also be considered as part of wildlife connectivity assessments and recommendations. These can often be inferred from current planning zones, overlays, and other planning mechanisms under he Victorian Planning Scheme (e.g. Precinct Structure Plans). In some cases, the location and extent of current habitat may not reflect the optimal (or even viable) long-term connectivity solution. For example, native vegetation and/or habitat may be absent from an area zoned/planned as a public conservation area or for the creation of wetland habitats or similar. In contrast, other areas of land supporting existing vegetation/habitat are likely to be removed in the future based on planned and approved future land development or land uses. In these situations, particularly on the urban fringe, decisions need to also reflect the likely future land use and viability of a habitat corridor (or crossing structure) into the future. Nevertheless, while considering current and future land use is important, it should not be used as an excuse to not work to maintain or enhance ecological connectivity.

Technical advice

Ecological connectivity is a complex topic which requires specialist technical advice. This includes ecologists (zoologists) that have a sound understanding of wildlife ecology, movement behaviour, and ecological connectivity theory and practice. It may also require species expert advice or specific technical expertise (see **Section 2.6** for further information) with complex assessments requiring multi-disciplinary teams or collaboration.

2.6. Technical qualifications and support

Biodiversity assessments, including Detailed Ecology Assessments, should be conducted by a suitably qualified ecologist. Native vegetation assessments must be completed by an ecologist with current accreditation on DEECA's Vegetation Quality Assessment Competency Register. Fauna surveys should be completed by qualified and experienced zoologists and flora assessments by skilled botanists.

All flora and fauna surveys must also be conducted in accordance with regulatory requirements and with appropriate permits, including any relevant permits or authorisations needed under the *Wildlife Act 1975* and *Flora and Fauna Guarantee Act 1988* (and supporting *Flora and Fauna Guarantee Regulations 2020).* This may include survey or fauna salvage requirements, the ethically and under appropriate permits, and in accordance with recommended survey methodology. It is important to ensure that any consultants undertaking fauna surveys have all relevant permits under the (Vic), prior to commencement of fieldwork.

An ecologist/zoologist with experience in animal movement, behaviour, and ideally FSRD should be involved in the early stages of a project to identify potential impacts and effective solutions.

As the project progresses, expertise on specific threatened species, fauna groups, or management measures (e.g. habitat restoration, direct seeding, tree hollow creation) may also need to be engaged to provide reliable advice on the design and implementation of effective FSRD measures. Specialist ecology advice and assessments may also be required on ecological connectivity impacts (see **Section 2.3**) and proposed mitigation or enhancement measures.

Yellow-bellied Glider, Dean Ingwersen

Fauna Sensitive Road Design advice

An important rationale for this specialist ecological support is that many FSRD measures, particularly crossing structures, are relatively new and novel components of the Australian transport network and road infrastructure delivery. They can also be highly species-specific and context dependent.

Multiple re-iterations of designs may be required, and construction challenges surmounted and through this, the advice of an appropriately experienced ecologist will be critical to ensure the FSRD works meet their intended ecological objectives. Effective inter-disciplinary coordination between planners, ecologists, and engineers is also critical to overcoming technical challenges and achieving the intended FSRD objectives.

> Importantly, early and continued engagement with an experienced ecologist and other appropriate technical support will ensure that the FSRD measures meet their intended objectives.

High-cost or high-risk issues will also be identified at the earliest possible point and ideally early in the project planning phase and ensure sufficient funds are allocated accordingly and all conflicts are resolved.

Ecological connectivity advice

Connectivity assessments require a sound understanding of animal behaviour (particularly movement ecology), their habitat requirements, and landscape processes. Accordingly, ecological connectivity assessments should be undertaken by a qualified ecologist with demonstrated expertise/experience in these fields relevant to the target fauna group and/or species being targeted. Specialist species or fauna group experts may also be required to inform an assessment.

More complex assessments (see below) may require workshops with species or fauna group experts to define the important ecological values and assumptions that go into connectivity model development.

3. Wildlife crossing structures

Wildlife crossing structures facilitate wildlife movement by allowing animals to pass beneath or above roads. These structures are usually implemented in conjunction with other measures such as fencing and biodiversity enhancement. The primary aim of wildlife crossing structures is to maintain connectivity, and the primary aim of fencing is to prevent WVC. Fencing also functions to guide animals towards, and safely through, wildlife crossing structures.

Artist's impression

3.1. Context and application of advice

This section of the Guidelines provides general advice on the planning, design, and delivery of wildlife crossing structures, with subsequent sections dedicated to different types of structures.

> All advice relates only to the objective of achieving an intended ecological objective, which concerns facilitating successful movement of animals across a road barrier and reducing the risk of wildlife-vehicle collisions.

The use of the words 'must' and 'should' for example, are entirely concerned with achieving the intended ecological objective, as informed by the current state of knowledge, e.g. it is well established that fauna fencing must be buried below the ground to stop digging animals from breaching the intended barrier. It is not intended as a directive and does not restrict alternatives approaches being proposed – with justification (evidence) – that will achieve an equivalent outcome.

In addition, the practicality, feasibility, or costs of achieving these measures is **not considered** in these Guidelines. Additional or different methods or specifications may be requested through a regulatory approval process. Costs of implementing some measures may be impractical or undesirable. Potential conflicting requirements for road design and delivery (e.g. lighting, utilities, drainage) are also not addressed in their entirety, since these are many and varied and will be specific to each specific project context. As such, these are best considered at the project level, ideally with an integrated and multidisciplinary approach as recommended in **Section 1.7** and using the recommended approach for FSRD implementation (**Figure 6**).

Early FSRD consideration in engineering designs

Early phase decisions on preferred road alignment, design and costs have a profound (and potentially limiting) impact on options for FSRD and wildlife crossings placement and design that can facilitate connectivity for wildlife. **Impacts and opportunities or different options are best considered early in the design process and in the selection of a preferred option** (see **Section 1.7**).

3.2. Type of wildlife crossing structure

Wildlife crossing structures are commonly grouped into two categories:

- **Underpass**: An underpass is a structure that allows wildlife to pass beneath road infrastructure. It includes bridges and culverts.
- **Overpass**: An overpass is a structure that allows wildlife to pass above or over the top of road infrastructure. It includes land bridges, canopy bridges and glider poles.

Choosing an appropriate wildlife crossing structure requires consideration of the:

- Road project's ecological connectivity goal(s) and requirements.
- Species or fauna groups being targeted.
- Surrounding landscape connectivity, movement barriers, and land uses.
- Topographical, landscape and site context constraints and opportunities.
- FSRD structure type and size.

The guidance in **Figure 6** has been developed to illustrate the types of wildlife crossings required to accommodate different fauna groups and reflecting site context. Both a preferred (optimal) and suboptimal solution are provided.

Of particular importance, is careful consideration of the target species or groups and the appropriate crossing structure that can achieve the required ecological objective.

Sometimes different crossing structures can be combined to cater for multiple species, such as canopy bridges installed under road bridges, within culvert underpasses, or when integrated with vegetated land bridges to facilitate habitat connectivity for arboreal (climbing) marsupials until a tree canopy establishes.

3.2.1. Optimal and suboptimal solutions

It is critical to note that there is a very large difference between the preferred and suboptimal solution in terms of ecological outcomes and benefits. Many fauna species will use land bridges or bridge underpasses if continuous natural habitats (corridors) are created above or under the road. Fewer fauna groups and species are likely to use suboptimal crossing solutions. Some species will be either too sensitive to cross habitat gaps (of which many are) or be otherwise physically or behaviourally constrained to move through an artificial structure away from its natural habitat. Even for those that do, crossings are likely to be less frequent compared to preferred solutions of land bridges and bridge underpasses.

Suboptimal solutions vary in effectiveness and careful assessment is required to ensure there is sufficient evidence that the proposed structure will provide the intended ecological connectivity objective for the fauna group or species being targeted. For example, canopy bridges are known to be more effective for arboreal species than large culverts.

Optimal solutions should also cater for as wide a diversity of species as possible, thereby ensuring connectivity for the entire ecological community can be achieved. Optimal solutions should always be adopted where possible because:

- They are more effective for the target species.
- They allow maximum number of individual animals of the target species to cross.
- They cater for a wide diversity of species, ensuring connectivity for the entire ecological community.
- There is less risk of predation by target species and other species.
- They reduce the risk of population decline and extinction of the target species and other species in the area.

Figure 6 defines the appropriate crossing structure according to different functional fauna groups including an optimal and suboptimal option. Technical details for each crossing structure type, including target species and fauna group(s), is provided below in **Section 3**.

Ecological advice is required

Where required, each wildlife crossing structure will need to be tailored to the specific site, target species, landscape context, and ecological objective.

Although the technical design guidance provided in this document is comprehensive, it cannot accommodate all the various scenarios and requirements that can unfold across all projects and contexts, both in the design and delivery phases. Consequently, early and ongoing advice of an ecologist experienced in FSRD and potentially other specialists (e.g. species experts) is critical to ensure FSRD measures, including crossing structures, are fit-for-purpose. This advice will be required throughout the design and delivery process.

The ecologist can advise on which structure and supporting FSRD measures (e.g. habitat creation or landscaping) is necessary to facilitate wildlife movement in the landscape and to determine the specific ecological design requirements that are appropriate for the target species or group(s).

The type and number of mitigation measures required can be informed by the species and impacts identified in the biodiversity and impact assessments and the SMART goals for the project.

3.2.2. Design process considerations

The final design will be a product of integrated design that balances species needs, constructability, all other road design objectives and requirements, effectiveness in the long-term, maintenance impost, and cost.

In the design and materials used for FSRD structures, consideration needs to be given to DTP standards. All designs and materials of the structures which are designed to take road, rail, pedestrians and cyclists need to comply with AS5100, relevant DTP standard specifications and DTP guidance note BTN 011 v2.2 (Traffic Barriers for Structures) for structural adequacy, loading, durability, and other relevant structural requirements.

Best practice FSRD (particularly to minimise impact on existing habitats) will involve iterative designs involving collaboration between road design, structures design, ecologists, arborists and urban design.

Photo 12 Canopy bridge for possums and gliders (Yan Yean Road; Source: VIDA Roads)

Figure 6 Determining the wildlife crossing structure solution by fauna group and site context

Option 1 – Optimal (preferred) structure:

Terrestrial and arboreal fauna, birds, amphibians and bats		Amphibians and aquatic fauna
Land bridge	Bridge Crossing	Bridge Crossing [11]
Section 3.6	Section 3.3	Section 3.3

Option 2 — Suboptimal solution if preferred structure not possible due to landscape or project constraints:

Terrestrial mammals and reptiles	Arboreal mammals		Gliders	Birds and bats (limited use)	Amphibians	Aquatic fauna	
Terrestrial culvert	Terrestrial culvert (large)	Canopy bridge	Glider poles	Terrestrial culvert (wide, tall, and short in length)	Amphibian culvert	Aquatic culvert	Fish ladders and fishways
Section 3.4.1	Section 3.4.1	Section 3.7	Section 3.8	Section 3.4.1	Section 3.4.3	Section 3.4.2	Section 3.5

Important note: likely effectiveness of suboptimal solutions will vary greatly depending on the total length of the crossing structures (culvert, rope, and canopy bridges), target species, and specific site context. Careful assessment is required by an FSRD specialist.

[11] Built sufficiently elevated to support suitable habitat for each fauna group or target species to enable movement of animals under the carriageway. If a habitat element required for movement is missing (e.g. mature trees for arboreal marsupials), then additional FSRD features must be installed. The ideal is to allow sufficient height for these elements to be retained or develop over time.

3.2.3. Minimum dimensions

New bridges and wildlife culverts

Table 3.1 specifies the likely minimum dimensions for crossing structures to facilitate passage of different fauna groups, under two typical road width scenarios. These reflect dimensions required to facilitate daily wildlife movements along with dispersal opportunities, and for which there is some evidence of effectiveness from Australian road projects and research.

There will be contexts in which the minimum size is unable to be achieved, such as large underpasses where the road is at grade and unable to be sufficiently raised to accommodate them. In such highly constrained situations, smaller structures may still feasibly provide some connectivity albeit much less effective (e.g. infrequent dispersal only). However, this may still be a substantial improvement on having no crossing structure at all.

Smaller structures should, however, only be considered when **all other options** have been thoroughly explored (including raising the road level) and constraints documented and justified. Examination of options should also include alternate structures that can provide the required ecological connectivity goal (refer to **Figure 6**). This would include considering a bridge underpass over a culvert crossing structure where this might be more feasible from an engineering perspective and achieve a better or equivalent ecological outcome. One option may also provide a better outcome, such as a wider corridor of more structurally diverse habitat. See **Figure 6** for potential alternatives.

Any crossing structure built to a smaller size than shown in **Table 3.1** is best considered as a trial treatment and monitored accordingly for effectiveness.

Species or FSRD expert advice will likely be required to further justify specific dimensions and whether they can achieve the intended objective, reflecting the current state of knowledge. This will particularly be the case if proposed dimensions are less than those defined in **Table 3.1**.

Where a crossing structure is likely to be required to meet regulatory approval obligations, further evidence beyond these FSRD Guidelines may be needed to demonstrate that the proposed dimensions will still be effective in achieving the intended mitigation objective.

Retrofitting

The Victorian road network includes a large number and diversity of bridges and culverts that some groups or species of wildlife may already be using to some degree to cross safely under the road. There are also structures that could provide this connectivity by retrofitting fauna furniture and FSRD enhancements, such as wildlife fencing, fauna furniture (rails, ledges, and shelters), vegetation enhancements and/or earthworks to improve access and visibility.

In the case of retrofits, smaller existing structures could still benefit through addition of FSRD elements, particularly where the aim is to improve on 'existing conditions' for ecological connectivity rather than a specific objective to mitigate impacts, such as on a threatened species or effected fauna group. Such alterations could improve wildlife crossing rates and safety without the need for major construction works. In many situations, retrofits of existing bridges and viaducts can therefore be a viable approach to cost — effectively improve crossing rates and reduce wildlife mortality. An example of this includes adding ledges or shelves to existing waterway culvert structures that otherwise have no terrestrial corridor to facilitate movement of fauna.

However, if existing culverts and bridges are being replaced and/or upgraded, they should, where possible, adopt standard sizes for new infrastructure, particularly where threatened species are a concern or FSRD elements are required to mitigate impacts from road development.

The following design principles should be applied when determining dimensions for crossing structures:

- More open underpasses (H x W) are better than more enclosed structures.
- Shorter underpasses are better than longer.
- Culverts should always be straight and avoid bends to maintain line of sight — animals need to be able to observe the other side.
- Consider requirements for fauna furniture, appropriate to the target species.
- Road design, site context, and any interacting infrastructure needs to be considered e.g. ensuring (for example) that dry culverts do not become inundated and that gliders can glide across the road in both directions using glider poles.

3.2.4. Predation risk

There is little evidence that predators systematically target native animals at wildlife crossings, a theory termed the 'prey-trap' hypothesis (Little *et al*. 2002, Mata *et al*. 2015, Soanes *et al*. 2017; see **Section 6.4** for further detail). Numerous studies have demonstrated that the risk of predation is no greater at a wildlife crossing structure than at any other location in the landscape or that predators target crossing structures with higher wildlife (prey) use (Dupuis-Desormeaux *et al*. 2015; Martinig *et al*. 2020; Mata *et al*. 2020; Saxena and Habib 2022). This includes a multi-year study that monitored predator activities and prey events at 28 structures over 13 years and found no evidence of predator behaviour by wildlife movement at crossing structures (Ford and Clevenger 2010).

Recent Australian research has also demonstrated this in a local context for mammals and reptiles, with neither predator activity nor predation risk inherently increasing at wildlife crossing structures on the Oxley Highway and Pacific Motorway, NSW (Goldingay *et al*. 2022). Even where there is increased predation risk, this would need to sufficient to counter the important beneficial (potentially critical) and positive effects that ecological connectivity provides to wildlife populations.

Nonetheless, measures should be incorporated into FSRD design and management measures to reduce real and perceived (by animals) risks of predation. This can include both directly controlling (reducing) predator populations and FSRD features to reduce predation risks, notably providing mitigating fauna furniture, dense continuous habitat, shelter, and refuges, and increasing the width of crossing structures.

Of particular importance, is that protective vegetative cover is provided right up to crossing structure entrances and that heterogeneous complex structures (fauna furniture) are provided inside them (Saxena and Habib 2022). These measures will both reduce the actual risk of predation as well as the perceived risk of predation, as many arboreal and ground fauna do not venture far from protective dense cover that complex habitats provide.

Further detail is provided on these various mitigation measures throughout **Sections 3** and **6.4** ('Risk of predation in wildlife crossing structures').

Glider pole

Table 3.1 Minimum size of all new terrestrial culverts and new bridge terrestrial wildlife zones (Figure 7)

	Minimum [1] Size — Height x Width*			
	Culvert (H x W [5, 7])		Bridge (H x W [2, 3])	
Target species	**2-Lane [6]**	**4–6 Lane [4]**	**2-Lane**	**4–6 Lane [4]**
Eastern Grey Kangaroo	2.1 m x 2.4 m	2.4 m x 2.4 m	1.8 m x 1.2 m	2.1 m x 1.2 m
Wallaby	1.5 m x 2.4 m	1.8 m x 2.4 m	1.5 m x 1.2 m	1.5 m x 1.2 m
Koala (includes space for timber rail) [5]	2.4 m x 1.2 m	2.4 m x 2.4 m	2.4 m x 1.2 m	2.4 m x 1.2 m
Wombat	0.9 m x 2.4 m	1.2 m x 2.4 m	0.6 m x 0.9 m	0.9 m x 0.9 m
Amphibians [8]	1.2 m x 2.4 m	1.2 m x 2.4 m	1.2 m x 2.4 m	1.2 m x 2.4 m
Growling Grass Frog [8]	An opening that is at least the width of the 3-month ARI flow plus a minimum of 2 metres (horizontally) each side of the waterway. Minimum airspace of 600 mm f or any culvert across a waterway that will be inundated during baseflow conditions.			
Wetland walking birds	1.2 m x 2.4 m	1.8 m x 2.4 m	1.5 m x 1.2 m	1.8 m x 1.2 m
Possums (includes space for timber rail[4])	2.4 m x 2.4 m	3 m x 2.4 m	2.4 m x 1.2 m	2.4 m x 1.2 m
Microbats	1.8 m x 2.4 m	2.4 m x 2.4 m	1.8 m x 2.4 m	2.4 m x 2.4 m
Southern Brown Bandicoot, small mammals, reptiles	0.6 m x 2.4 m9	1.2 m x 2.4 m	0.6 m x 2.4 m	3.2 m x 1.2 m

**To be reviewed and updated based on current research and monitoring*

Notes on Table 3.1:

1. For the optimal ecological outcome, culverts and bridge underpasses should ideally be as large (H x W) as possible, and the maximum size that can fit into the road design (i.e. installing a 1.2 m high culvert into a 4 m high embankment is not realising the full ecological opportunity for connectivity). As most engineering constraints are on structure height, options for increasing culvert width could be explored, particularly where only the minimum height can be achieved, as this would provide additional ecological value (see **Photo 13** and **Photo 14**).
2. Underpasses should ideally aim to be as short as possible. Assumes roads with 4–6 lanes, including shoulders, verge and median are typically ~40 to 60 m wide, and 2-lane roads are typically ~20 m wide.
3. For bridge underpasses, the minimum width refers to the navigable and dedicated terrestrial wildlife zone (**Figure 7**) under a bridge that the target species will be likely to traverse and use. This applies to each bank for a waterway.
4. For very wide roads (6+ lanes), all dimensions may need to be increased by 1 standard size. Note there is also limited evidence for fauna using culvert crossing structures greater than approximately 40 metres in total length. In these instances, road design will likely need to consider solutions for alleviating decreased light levels on longer culvert structures and perceptual barriers to animals crossing (e.g. animals seeing or sensing habitat on the other side). This could include much larger median light wells or gaps in segments lengths of culverts that open onto vegetated islands (fenced) within central medians. Otherwise, a larger structure such as a bridge underpass (if practicable or feasible) may be more appropriate.
5. Koalas and possums can move along the ground, however, are at increased risk of dog attack. For new constructions, dimensions given are for when timber rails are used and are high enough for them to be high enough to prevent dog attack and for animals to feel safe. For retrofits, animals can walk along the ground but where possible, timber rails should also be installed.
6. Culvert dimensions for a single carriageway on a dual carriageway road should match the minimum size for the total number of lanes on both carriageways unless the median is wide and fully open.
7. Enclosed medians on dual carriageways to include a grated light well. Light wells for connected 'dry' terrestrial fauna culverts to be raised sufficiently above surrounding ground level to avoid surface water running into the culvert.
8. Amphibian dimensions are broadly based on the Victorian 'Growling Grass Frog Crossing Design Standards' (DELWP 2017) developed for application in Melbourne's growth areas. Where this design guideline is relevant to meeting project approvals, formal regulatory or approval prescriptions will take precedence over guidance in this document.
9. Smaller dimensions down to 0.5 m x 0.5 m (internal dimension) may provide passage over shorter distance than the standard with of 2-lane road with pedestrian walkways, such as side roads, exit ramps, or driveways. See example of effective crossing structure trialled at Royal Botanic Gardens Cranbourne.

Photo 13 Interior of a low and wide culvert – Healesville-Koo Wee Rup Road Stage 1b (Source: Austin O'Malley, VIDA Roads)

Photo 14 Interior of a low and wide culvert – Healesville-Koo Wee Rup Road Stage 1b (Source: Austin O'Malley, VIDA Roads)

Photo 15 Small pre-cast wildlife culvert under a narrow sealed access road in the Royal Botanic Gardens Cranbourne (Source: Royal Botanic Gardens Cranbourne)

Photo 16 A trial at Royal Botanic Gardens of a small pre-cast culverts demonstrated use by many species of wildlife. (Source: Tricia Stewart, Royal Botanic Gardens Cranbourne

Notes on photos: Although larger structures are always better, over very short distances (less than 2-lane standard road) in certain contexts, smaller structures may also provide effective passage and connectivity for many species of terrestrial wildlife. An example of this are small pre-casts culverts (H50 cm x W50 cm) recently installed under a sealed access road at the Royal Botanic Gardens Cranbourne, in south-east Melbourne (Photo 17). The culvert is integrated with wildlife fencing and has now been shown to be used by numerous fauna species including Koalas (pictured above with young), short-beaked echidnas, wombats, and the threatened Southern Brown Bandicoot (Photo 16).

3.3. Bridge crossing

Bridge crossings include all designs that use bridge-type structures to create a wildlife underpass under a road, most often with a natural substrate for wildlife to traverse. If designed appropriately for wildlife, they create a ground-level crossing for wildlife to move freely under the road, often involving an elevated road, and supporting vegetation and natural shelter. They include single or multi-span bridges, viaducts, and (if large enough) arch-type bridges. Bridges and viaducts are typically used when roads cross waterways, steep valleys, undulating terrain, or areas prone to flooding.

Bridges and viaducts are one of the most effective underpass options for wildlife when sufficient elevation of the carriageway above ground-level is possible. It is also the preferred method for waterway crossings for all vertebrate fauna because they are usually larger and more open than culverts. Larger and more open structures are typically used at higher rates by a greater diversity of species than smaller underpasses (Abson and Lawrence 2003, Bhardwaj *et al*. 2017, Denneboom *et al*. 2021, Jensen *et al*. 2023). Bridges also have a natural substrate and typically support more shrubs, logs and other cover than culverts, and bridge designs can be easily modified to accommodate the movement of wildlife.

In terms of aquatic habitats, bridges also have less impact on water flow, structure of the channel and availability of aquatic habitat compared to culverts (Slutzker 2015). They also reduce behavioural barriers caused by dark tunnels and physical barriers caused by poorly designed culvert crossing structures.

Photo 17 Bridges are the only crossing structure that provides connectivity for most fauna groups including many bird species (Australasian Bittern; Source: VIDA Roads)

Importantly, **bridges** and land bridges **are the only FSRD crossing structure** that can provide a natural terrestrial corridor (i.e. continuous vegetation/habitat) across a roadway for our native land animals like mammals/marsupials (e.g. koalas, kangaroos, wallabies, echidnas), reptiles, and birds (**Photo 17**). This is particularly important at waterway crossings or intersection with large habitat patches where roads block movement of animals and sever habitat connectivity at local and regional scales. They are also the only structure that can (potentially) provide functional connectivity over waterways for a wide variety of aquatic, wetland, and riparian fauna species such as waterbirds, frogs, and fish (**Photo 17** and **Photo 18**).

> Bridges or viaduct (fauna) underpasses are a better option than single or multi-cell culverts is contexts where wildlife movement is a high priority, such as along a waterway or habitat corridor.

> Early phase decisions on preferred road alignment, design, and costs have a significant impact on options for bridge placement and design and resulting outcomes for wildlife connectivity. Impacts and opportunities for different design options are best considered early in the design and preferred option selection process (see **Section 1.7**).

Bridge replacement and FSRD retrofitting

As described in **Section 1.4**, there are many opportunities to improve ecological connectivity at local and regional scales through enhancements to the existing road network. FSRD measures can be implemented on road projects to remove existing barriers to movement, particularly at interfaces with waterway or habitat corridors, and for areas supporting fauna habitat or other values. Bridges with suitable wildlife zones (**Figure 7**), either newly constructed or replacing pipe or box culverts, can substantially improve ecological connectivity for a range of fauna and threatened species. Many existing road-waterway crossings support pipe culverts which (unmodified) provide poor connectivity for aquatic wildlife and even less (or no) connectivity for all terrestrial fauna.

Retrofitting existing bridge infrastructure with FSRD features such as ledges and shelves can also improve rates of wildlife crossings both in terms of frequency and number of species and fauna groups accommodated (David *et al*. 2014, Dexter *et al*. 2016, Goldingay *et al*. 2018a).

Table 3.1 specifies the ideal minimum size requirements for all new bridge or terrestrial culvert construction. These are illustrated in a conceptual diagram in **Figure 7** and virtual render in **Figure 8**.

Photo 18 A bridge crossing on Mordialloc Bypass provides connectivity for waterbirds, fish, frogs, and many other fauna species (Mordialloc Freeway; Source: VIDA Roads)

Table 3.2 Bridge — design requirements for ecological connectivity and safe passage

Design aspect	Specifications and considerations
Target species	– Proven for aquatic species (fish, macroinvertebrates) and semi-aquatic species (platypus, turtles, amphibians). – Proven for most terrestrial wildlife (macropods, koala, small terrestrial mammals, reptiles) (Abson and Lawrence 2003). – If large enough and with appropriate features or furniture, target species can include arboreal species (with glider poles or canopy bridges), birds and microbats (Bhardwaj *et al*. 2017).
	1. Early planning should identify the optimal location for a bridge crossing that can accommodate the widest terrestrial zone on both banks and the greatest height above the water and natural embankments. Greater height clearance above banks will a) allow more light and rain through underneath the structure thereby facilitating vegetation (habitat) growth while also (if height is great enough) allowing tall shrubs and trees to establish. 2. The section of the bridge spanning the waterway should be single-span and ideally with no in-stream support structures. 3. If in-stream support structures are required (e.g. piles), these should be located outside of the low flow channel. This ensures suitable depth of water during base flow periods and prevents obstruction of the low flow channel. 4. Bridge abutments should be placed outside of the high bank where possible and set back as far as possible to accommodate a terrestrial wildlife zone on both banks (see **Figure 7**). Greater height clearance (1) may facilitate this. 5. Where bridges are over waterways, ensure both terrestrial and aquatic fauna are accommodated within a drainage and aquatic wildlife zone and a terrestrial wildlife zone.

Design aspect	Specifications and considerations
Design, dimensions and construction materials	To achieve an optimal ecological outcome, a wildlife zone will meet the following requirements: a. A dedicated corridor for terrestrial fauna movement excluding space required for pathways, vehicle access roads, rip-rap/erosion control, or other functional use. b. Be positioned (accommodated) on both banks of the waterway and as flat as possible. c. Set outside of the high bank to remain dry year-round except during flood events. d. Where Growling Grass Frog is a target species-bridge abutments set back a minimum of 5 m from the high bank. If the high bank is undefined, bridge abutments to be at least the width of the 3-month average recurrence interval (ARI) flow plus a minimum of 2 m horizontal distance each side of the waterway. e. **Be as wide as possible**. Optimal width depends on target species. For early planning purposes when target species may not be known, use an optimal minimum width of 5 m. For reference, an equivalent north American wildlife crossing structure guideline recommends 7 to 10 m width for fauna underpasses where there is no waterflow (Clevenger and Huijser 2011). A narrower width may meet the target species requirements once this is defined. f. **Be as tall* as possible**. Optimal clearance depends on target species and wildlife groups (refer to **Table 3.1** for guidance). However, clearance heights over the terrestrial wildlife zone that can accommodate the establishment of trees is optimal for all fauna groups in most cases and after this the highest possible vegetation stratum feasible (e.g. tree, shrubs, grasses) considering engineering and location constraints. For early planning purposes when target species may not be known, use a nominal minimum height of 2.4 m. g. The minimum height and width requirements for new bridge or terrestrial culvert construction to provide adequate space to accommodate terrestrial wildlife species are specified in **Table 3.1**. Other design specifications for terrestrial culverts are provided in **Section 3.4.1**.

*Refers to the height from the terrestrial zone ground/bank to the bridge underside.

Pacific Black Duck, Dean Ingwersen

Design aspect	Specifications and considerations
Design, dimensions and construction materials	6. Bridge abutments should be placed outside of the high bank where possible and set back with sufficient distance to accommodate a terrestrial wildlife zone on both banks (see **Figure 7**). This includes consideration of requirements for erosion management (rock beaching or equivalent), safety, and maintenance access. Where concrete access platforms or shelves (typically 1.0 m wide with safety rail in front of abutment) are required at bridge abutments, ensure that design can accommodate (and appropriately integrated with) both the wildlife zone and combined erosion measures and safety/maintenance access requirements. 7. Apply design measures to reduce and mitigate bird strike, particularly for elevated walls, fences, and noise walls. Incorporate design elements into transparent/translucent plastic panels (e.g. noise walls or screens) that make the structure more visible to birds and reduce risk of collision. This includes surface finishing of panels in accordance with DTP Bridge Technical Note (BTN) 007-Noise Attenuation Walls (**Section 6.3.1**): '*Have an intensely coloured and etched surface or internal horizontal filament to mitigate possible birds strikes. In locations where the noise walls are adjacent to areas of bird habitat, multiple mitigation measures must be adopted. Consider design options that will increase visibility in context of surrounding environment.*' 8. Implement design or structural features to allow the ingress of natural light and airflow. Lack of light beneath a bridge may create a behavioural barrier while lack of airflow can create temperature gradients that animals are reluctant to cross. Light requirements will be dependent on the height and length of the structure, along with the specific requirements of the species and expert advice is necessary to determine the importance of modifying design to consider light needs. Options to allow the ingress of natural light is provided below: a. *Separated carriageways (preferred)*: Build each carriageway onto two separated structures with an empty space between the carriageways (ideally at least 5 m). This will allow light and water (rain) to reach the ground and improve rates of use by wildlife through facilitating the growth of vegetation, improving airflow and climate conditions to ambient levels. Install wildlife fencing between the two carriageways to prevent wildlife from accessing the road and median strip from below. Ensure any rain or flood water that enters via the median can drain away. b. *Light wells/microclimate vents*: include grated light wells/vents in median or kerb and channel (**Photo 19**) at regular spacings along the bridge span. Ensure light well is sufficiently raised above ground level to avoid water entering crossing structures. 9. Of the two options above (a-b), separated carriageways will provide greater light penetration and is preferred. 10. Where Growling Grass Frog is relevant (including meeting regulatory requirements), minimum requirements for light wells/ventilation are set out under the Growling Grass Frog Crossing Design Standards (DELWP 2017).

Photo 19 Grate in kerb and channel functioning as light well (source: VIDA Roads)

Design aspect	Specifications and considerations
Inundation and dry passage	11. If an adequate terrestrial wildlife zone cannot be accommodated, an alternative dry passage option for terrestrial fauna should be provided. Dry passage requirements: a. Can be a ledge, shelf or alternative structure that provides equivalent dry passage, installed on or immediately adjacent to each bridge abutment. b. Ledge/shelf that extends to and connects to ground surface (habitat) at both ends with a maximum 1:8 slope i.e. does not terminate at any height above ground. c. Made from non-biodegradable material (e.g. concrete, recycled plastic). d. Minimum 500 mm wide, and ideally 1 m wide subject to hydrological constraints. Minimum 600 mm height clearance (distance) between ledge/shelf and bridge ceiling/underside (soffit) for smaller animals (e.g. koala, echidna) to at least 1.8 m for kangaroos. Ensure appropriate for target species/group. e. Ledge/shelf height as close to the natural ground level as possible while achieving dry passage most of the time e.g. set above the 1:10 year flood level if practicable.
Landscape position and fencing	12. General siting guidelines for bridges that cross a waterway: a. Minimise the total number of waterway crossings on each project. b. Avoid crossing waterways near sharp bends, sections of unstable banks or naturally strong "riffle" systems. These areas act as natural important bank stabilisers and often provide essential habitat pools. Any alteration of these systems may impact habitat, change bank stability and initiate riparian erosion. c. Avoid siting bridges in areas where the river is likely to continue meandering into the future. Rivers undergo natural reshaping and erosion, especially during times of strong flow. Meandering rivers can damage infrastructure and render wildlife crossing structures ineffective. d. Avoid works that change the frequency and spacing of existing natural habitat pools and riffle systems. 13. Avoid potential barriers that may limit access to the bridge (fauna underpass), such as adjacent farm fences, access roads or railways. 14. Install fencing to funnel the target species to the bridge wherever there is a risk that the target species may access the road. The length of fencing is site and species-dependent. Refer to **Section 4** for guidance. – Locate fencing as close to the road edge as possible to maximise roadside corridor vegetation/habitat available to animals to move along. – Roadside fencing must tie-in and connect to bridge abutment to achieve the objective of guiding animals to cross under the bridge and safely through the wildlife zone.

Design aspect	Specifications and considerations
Landscaping and vegetation	15. Where possible the channel should be maintained as natural as possible. 16. Any channel section diverted/ reprofiled/ created should be built to be as natural as possible allowing for natural features (vegetation, rocks, and coarse woody debris) to be present. 17. Banks upstream and downstream that are disturbed as part of the works should be reprofiled to be consistent with pre-existing natural state and revegetated with appropriate riparian vegetation. To achieve optimal FSRD outcome, landscaping specification to include locally indigenous species informed by the relevant pre-1750 Ecological Vegetation Class (EVC) and/or providing suitable habitat structure for focal (target) fauna species or groups. If existing banks are highly disturbed, then reprofile and revegetate to improve conditions. 18. Optimally, create a continuous vegetated habitat corridor (terrestrial wildlife zone) under the road, in accordance with Recommendation 1, and connecting to existing remnant vegetation at either side (where present). Landscaping specification to reflect habitat requirements of focal/target fauna species and relevant EVC, informed by guidance provided in **Section 7.2**. In addition: – Allow vegetation and habitat adjacent to the road to grow under the bridge as much as possible, maximising continuous protection and shelter under the road. – Consider how drainage or bridge structure could be designed to allow light and rainfall penetration sufficient to maintain a continuous vegetated corridor. – Where vegetation/habitat establishment under a bridge is not feasible (bridge structure is too low to provide sufficient light and rainfall), revegetate as far as possible to encourage and facilitate wildlife use. 19. Landscaping and habitat provision to be coordinated with scour design requirements. If erosion or scour control is necessary: a. Minimise scour protection in the terrestrial wildlife movement zone as this inhibits movement of terrestrial wildlife and can create traps/ barrier for fish movement during low flow periods. If scour protection is required, use concrete or small rocks instead. b. Where scour protection is required, place toping of soil and pocket plantings as final treatment to create surface that animals can move over and find shelter. c. Ensure there is a clear passage end-to-end, with no pools or puddles that can entrap fish. d. Channels where contiguous coverage of very large rocks (>30 cm diameter) is required, the rocks should be embedded into the channel bed to prevent water pooling beneath and trapping fish. e. Scour protection should be placed at or below bed level and not extend more than 20 m upstream and or downstream of the structure. Scouring and perching at the entrance or exit of the culvert should be avoided. f. Small piles of large rocks (e.g. greater than 30 cm diameter) may be beneficial for amphibians as they provide inter-rock shelter spaces and locations for basking.

Design aspect	Specifications and considerations
Furniture and enhancements to encourage use and reduce the risk of predation	Furniture and enhancements for aquatic habitat: 20. For retrofitting new structures and/or combination structures additional enhancements may be required to support the movement of fish including Fish ladders and Rock Ramps (see 3.5). These enhancements will help modify water velocity to encourage passage through areas of significant changes in elevation. 21. Instream Woody Habitat (IWH): Large woody debris can be an added benefit by creating suitable habitat and encourage species to access and utilise the crossing structures (consider appropriate placement and risk of woody debris becoming an obstruction). Furniture and enhancements for terrestrial habitat: 22. Fauna furniture installation at the bridge entrance and along length may be critical to ensuring use by the target species/group. Fauna furniture should be appropriate to the target species/groups with the aim of facilitating movement (e.g. elevated rails, ledges, poles or rope ladders for arboreal fauna) and protection from predators. Natural structures are preferred (e.g. rocks, hollow logs) although artificial structures may provide viable alternatives. 23. All fauna furniture must be securely attached by fixings, embedded or fabricated into structures. 24. Use a combination of wooden and non-biodegradable artificial shelters, in accordance with **Section 7.3.1**. If future access within the structure is likely to be restricted, with limited ability to replace or maintain fauna furniture, use only non-biodegradable furniture. 25. With sufficient clearance, bridges can include additional structures to provide alternative pathways and allow wildlife to avoid predators. These include: a. Canopy bridges (clearance greater than ~6 to 8 m) — see **Section 3.7**. b. Glider poles (clearance greater than ~6 to 8 m) — see **Section 3.8.1**. c. Elevated horizontal ledges/rails/logs for arboreal mammals or koala (see **Section 7.3.1**). d. Refuge poles with resting platforms to provide koalas refuge from dogs (see **Section 7.3.1**). e. Horizontal logs for small mammals (see **Section 7.3.1**). 26. If a bridge crossing is for arboreal mammals, retain trees as close to the road and bridge as possible, and retain a strip of lopped trees under the structures. If trees can't be retained, undertake strategic revegetation and/or re-install pruned trunks or standard poles as glider poles or for canopy bridges.
Lighting	27. No artificial lighting installed within 100 m of bridge crossing and wildlife underpass entrances (e.g. Wildlife Zone). 28. Where lighting is required to meet safety standards: a. Ensure lighting is the lowest intensity possible. b. Avoid use of lights within the blue, violet and ultraviolet wavelengths. c. Use light shields to prevent light spill under the bridge or into adjacent habitat, and underpass entrances.
Maintenance	29. Inspections to assess the structural integrity of bridges and related structural FSRD elements can be conducted at the same frequency as for bridges described in Road Structures Inspection Manual (VicRoads 2022). 30. Inspections should aim to consider whether the structure continues to perform the intended ecological function. Ecological failure of a structure could result in loss of ecological connectivity for potentially long periods of time, which could have severe consequences for local wildlife. 31. Inspections are best conducted by an ecologist experienced in the assessment and design of FSRD and provide the greatest value if integrated into a monitoring and evaluation program (see **Section 8.4**).

Design aspect	Specifications and considerations
Monitoring and performance evaluation	32. Develop and implement a performance evaluation plan, in accordance with **Section 8.4**
Temporary construction structures and work	33. Ensure works are undertaken in accordance with EPA Publication 275 — Construction Techniques for Sediment Pollution Control. 34. Where possible, channels should not be blocked or diverted (e.g. bypass pumping). Use of bund around area of work is recommended to maintain channel connectivity. 35. Ground disturbance should not occur during periods of heavy rain fall, to limit direct sedimentation into the waterway. 36. Considerations for seasonally important periods should be considered when planning and commencing construction (i.e., if the waterway is blocked during the annual migration period this may directly impact the viability of that cohort of fish in that waterway). 37. Disturbed bank and bed sediments should be exposed only for short periods. Temporary sediment controls and replanting should commence as soon as practically possible. 38. If temporary pads are required to access the middle of the waterway channel the fill material used should be natural and not recycled waste concrete and or asphalt in case material is not completely removed.

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Photo 20 Slaty Creek Bridge on the Calder Freeway (Source: VicRoads)

Photo 21 Vegetated habitats under Slaty Creek Bridge (Source: VicRoads)

Photo 22 Echuca Moama Bridge has an extended elevated section over riparian habitats on the Murray River, facilitating wildlife movement and ecological connectivity along the riparian corridor (Source: VIDA Roads)

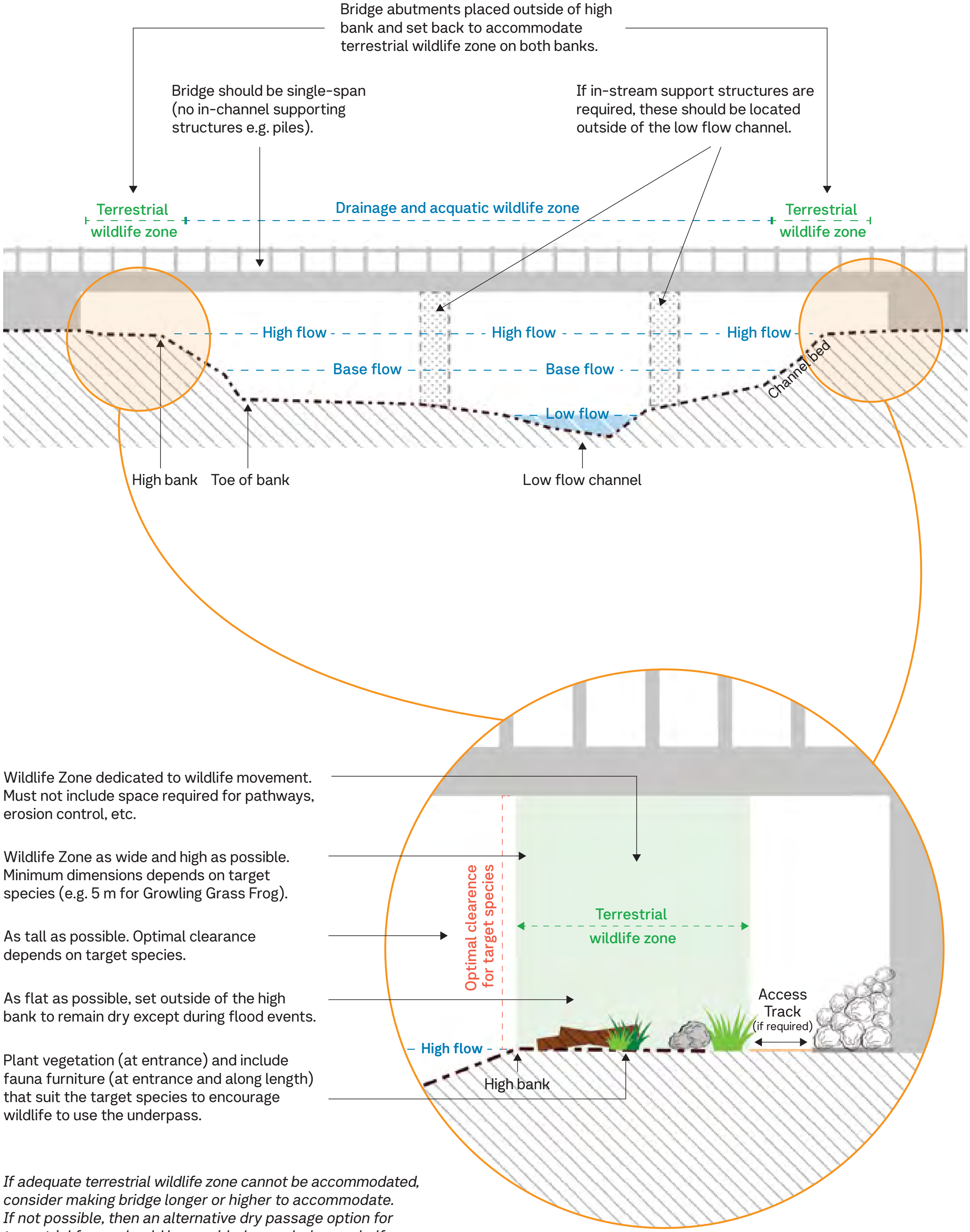
Photo 23 Example of a well-designed bridge underpass – open with natural substrate and continuous vegetation (Source: Rodney van der Ree, WSP)

Photo 24 Example of a sub-optimal bridge underpass – lack of terrestrial wildlife zone and over-use of large rocks for erosion control (Source: Austin O'Malley, VIDA Roads)

Photo 25 Example of a sub-optimal bridge underpass – minimal terrestrial wildlife zone and over-use of large rocks for erosion control (Source: Rodney van der Ree, WSP)

Freeway was designed to be higher and longer than required simply for drainage, to encourage wildlife movement. In this example, the vegetation has been planted underneath the structures, and tall trees retained between the two carriageways. This is an example of a very large bridge – most do not need to be this large. (Source: Rodney van der Ree, WSP).

Figure 7 Bridge over waterway design



If adequate terrestrial wildlife zone cannot be accommodated, consider making bridge longer or higher to accommodate. If not possible, then an alternative dry passage option for terrestrial fauna should be provided e.g., a ledge or shelf (see Multi-use culverts for example).

Figure 8 Virtual render of a bridge wildlife underpass with separated carriageway (top) and dedicated 'wildlife zone' for movement of fauna (bottom)

Note in Figure 8 above the separated carriageway allowing light to penetrate into wildlife zone below (top image); dense plantings of native vegetation to provide protective cover for fauna and encourage movement under the bridge (middle image) and allowance for access/maintenance tracks and integrated wildlife exclusion fencing (bottom image).

3.4. Fauna culverts

Fauna culverts are versatile structures that can permit the movement of wildlife under the road. Culverts are typically used in road construction for drainage purposes and where roads cross drainage lines or waterways, however they can be modified to provide passage for wildlife in many different contexts.

Culverts come in many shapes and sizes depending on the target fauna species, the width of the road it is traversing, and intended function for ecological connectivity (see **Photo 26** and **Table 3.3**).

> If a culvert is used for the movement of wildlife, the culvert should match the specific form and function required by the target species. Table 3.3 summarises the types of culverts that are appropriate for each fauna type.

Retrofitting existing culverts with logs, shelves and rails can also increase rate of use by wildlife (Goldingay *et al*. 2018a).

Although culverts can be an effective conduit for fauna, bridges are the most effective underpass option for wildlife because they are large and open, have a natural substrate and typically support more shrubs, logs and other cover than culverts. Therefore, bridge underpasses should be used instead of culverts whenever wildlife movement through an underpass is a high priority.

Photo 26 Terrestrial culvert for small mammals under construction. Note ramp up to ledge (Healesville-Koo Wee Rup Road Upgrade; Source: Austin O'Malley, VIDA Roads)

Table 3.3 Summary of culvert types and target species

Culvert type	Target species	Primary function	Inundation	Typical shape of culvert	Typical no. of cells
Terrestrial culvert	Terrestrial fauna	Movement of terrestrial wildlife	Dry year-round	Box or slab-link box culverts	Single (can be multiple)
Aquatic culvert (fish passageway)	Aquatic and semi-aquatic fauna	Movement of water and aquatic species in a waterway	Inundated year-round	Box or slab-link box culverts	Single (can be multiple)
Amphibian culvert	Frogs	Movement of frogs between dams (not in a waterway)	Inundated year-round	Box or slab-link box culverts	Multiple (can be single)
Multi-use culvert	Terrestrial fauna in dry section and aquatic and/or amphibian fauna in aquatic section	Movement of terrestrial fauna, aquatic fauna, people and/or stock	Mixed inundated and dry	Box or slab-link box culverts	Multiple (can be single)
Incidental use culvert	Potentially incidental use by wildlife	Movement of water, people or stock	Inundated or dry depending on primary function	Box, slab-link box or pipe culvert	Single or multiple depending on primary function

3.4.1. Terrestrial culvert

Terrestrial culverts are typically box-shaped concrete underpasses that facilitate the movement of wildlife under roads (**Photo 27**). Culverts typically target terrestrial wildlife, mostly mammals, reptiles, and some amphibians. Very large culverts over short distances (i.e. short lengths) may also accommodate occasional use by bats and some bird species.

Terrestrial culverts may allow the movement of water during occasional floods, but the placement, design and management is always optimised for use by wildlife. Multi-use culverts (single culverts or an array of multiple culverts) allow the movement of wildlife and other purposes, most typically water, and are described in **Section 3.4.4**.

Box culverts (**Photo 27; Figure 9**) are preferred over pipes (**Photo 28**) and arches (**Photo 29**) for terrestrial fauna crossing passage because they have horizontal floors, larger openings, require less cover, can easily accommodate fauna furniture — such as ledges and rails — and can be made wider (at the same road height).

Precast arch structures, such as BEBO™ arches, can also provide effective crossing structures if they can provide a level floor and retain the natural substrate over a waterway (see **Photo 29**).

However, box culverts can accommodate greater passage widths (at equivalent road elevation), higher ceilings across their width, and fauna furniture fixtures, and are the optimal structure in most instances.

Pipes have smaller openings compared to box culverts of the same height and often curved floors and walls, both of which may deter may species and limit the additional of fauna furniture (such as ledges and rails). Consequently, pipes structures are a poor substitute for culverts, and should only be considered as a last resort (option) if a flat/level floor can be provided along with permanently dry conditions for terrestrial fauna passage (**Photo 28**).

It is always better to install larger culverts than the minimum required for the target species because most studies evaluating the effectiveness of underpasses from Australia and around the world indicate that larger (tall and wide) and shorter (length) underpasses are better than those that are smaller and longer (Clevenger *et al*. 2001, Denneboom *et al*. 2021).

Design requirements for ecological connectivity and safe passage are detailed below in **Table 3.4** and illustrated in **Figure 9** (concept diagram) and **Figure 10** (virtual render).

Table 3.4 Terrestrial culvert — design requirements for ecological connectivity and safe passage

Design aspect	Specifications and considerations
Target species	– Proven for most terrestrial wildlife, including macropods (Goldingay *et al*. 2018c, Harrison and van der Ree 2012), koala (Goldingay *et al*. 2018a), small terrestrial mammals (Goldingay *et al*. 2018a), reptiles (Chambers and Bencini 2015, Goldingay *et al*. 2018c, Harris *et al*. 2010). – If large enough and over short distances, target species can also include arboreal species (with appropriate furniture), birds and microbats (Bhardwaj *et al*. 2017). – Dry culverts may be used by some amphibian species; however, they are not an acceptable structure type for this group.

Design aspect	Specifications and considerations
Design, dimensions and construction materials	1. Terrestrial culverts should be as wide and tall as possible. This is best achieved using square or rectangular culverts (i.e. box culverts or slab-linked box-culverts), and potentially arch bridges or culverts (e.g. BEBO™ arch ; **Photo 29**). Pipe culverts are not acceptable as culverts dedicated to wildlife movement. 2. The minimum height and width requirements for new terrestrial culvert or bridge construction to provide adequate space to accommodate terrestrial wildlife species are specified in **Table 3.1**. Design specifications for bridges are provided in **Section 3.3** and **3.4.1**. 3. Culverts should aim to be straight and as short as possible and should allow unobstructed views of the other side (end). 4. The base of dedicated wildlife culverts should be as natural as possible, such as soil or mulch. Where a concrete base is required, consider adding a surface cover of a natural substrate (e.g. dirt or rocks) or for aquatic (wet) culverts, embedding some small-medium sized rocks into the substrate. Ensure the substrate does not hinder animal movement. Loose soil/rocks should only be used in situations where the culvert base is elevated well above ground level and unlikely to experience flooding. 5. There must be an allowance for at least 1 m of dry and level surface (soil and not large rocks or beaching) extending beyond the culvert wing/end wall and concrete apron. This must connect to the adjacent roadside embankment at a shallow grade (1:5) from the culvert apron. This will ensure that animals, particularly small-medium mammals, can move from the roadside embankment around the culvert end wall and into the culvert without entering any adjacent swale drain. 6. Implement design or structural features to allow the ingress of natural light and airflow. Lack of light within an enclosed structure may create a behavioural barrier. Light requirements will be dependent on the height, width and length of the structure, along with the specific requirements of the species and expert advice is necessary to determine the importance of modifying design to consider light needs. Three options to allow the ingress of natural light into culverts are: a. **Maximise** height and width of the culvert. b. **Minimise** length of culvert and distance between culvert entrance and natural shelter/habitat (e.g. may include adjacent landscape plantings or habitat restoration). c. **Separate carriageways**: Build each carriageway onto two separated structures with space between the carriageways (ideally 5 metres or more). This will allow light and water to reach the ground and improve rates of use by wildlife through facilitating the growth of vegetation. Install wildlife fencing between the two carriageways to prevent wildlife from accessing the road and median strip from below. Ensure any rain or flood water that enters via the median can drain away. d. **Light wells**: Light wells or microclimate vents (i.e., grated lids) can be installed from the median into the culvert below to allow the ingress of natural light. Light wells should be a minimum 1 m x 1 m in size, be located in the centre median (if applicable) and where possible, should be spaced at intervals less than 10 m from each other. For multi-cell culverts, a light well is required for each cell. Light wells should have grills to prevent rubbish and debris from entering and also be built higher (raised above) than the surrounding ground and should never be used for drainage. Any rain or flood water that enters via the light well must be able to drain away. Grates and grids embedded in the road may be used on roads with very low traffic volume and speeds, especially at night when most fauna are active, such as at the Royal Botanic Gardens Cranbourne (Terry Coates, pers. comm.). Trials of the impacts of traffic noise and disturbance on open-topped culverts on high speed and high traffic volume roads are needed before they can be recommended on major roads.

Design aspect	Specifications and considerations
Inundation and dry passage	7. The culvert must remain dry year-round, ideally set above the 1:10 year flood level. The culvert must be designed to be free draining such that any rainfall or flood waters will rapidly dissipate. Ensure that adequate flood modelling and ground levels has been undertaken to inform the correct culvert size (minimum) and levels required to achieve a dry culvert which freely drains. 8. Do not position culverts intended for dry terrestrial passage at the lowest level along a road alignment that would the likely result in frequently flooding and ponding of water within the culvert or at its entrance. Position at higher levels where practicable. 9. Direct connections between terrestrial dry culverts and road drainage (or swales) should be avoided. Designs should aim to clearly demonstrate this objective can be met or demonstrate measures to mitigate risk of culverts being inundated. In most instances to achieve a functioning crossing structure, there should be >1 m separation between culvert end/wing walls (and apron) and the edge of a drain swale to limit movement of water into the culvert, along with sufficient levels (culvert floor relative to drain level) to limit entry of water most of the time. A 1-metre-wide corridor must be provided around the end of the wingwall for animals to move from the road embankment and into the culvert entrance. This separation will also ensure that animals can move along the road embankment and into the culvert entrance without entering a drain. Alternative engineering design methods may be feasible, as long as there is a dry passage corridor around the wing wall and into the crossing structure most of the time. 10. If the culvert cannot be set above the 1:10 year flood level or is likely to be inundated during high-flow or flood events, an alternative dry passage option for terrestrial fauna should be provided. Dry passage requirements: a. Can be a ledge, shelf or alternative structure that provides equivalent dry passage, installed on the culvert wall. b. Must connect to terrestrial habitat at both ends and be designed to gradually terminate (ramp) at a shallow grade (no more than 1 in 5 slope) to the ground surface. c. Made from non-biodegradable material (e.g. concrete, recycled plastic). d. Minimum 500 mm wide, ideally 1 m wide subject to hydrological constraints. Minimum 600 mm clearance from the culvert ceiling for smaller animals (e.g. koala, echidna) to at least 1.8 m for larger animals (e.g. kangaroo). Ensure appropriate dimensions for target species/group. e. Height to be as close to the natural ground level as possible while achieving dry passage most of the time (set above the 1:10 year flood level if practicable). 11. If the culvert is likely to be inundated more frequently than during flood events (e.g. during base or high flow), install a multi-use culvert (see **Section 3.4.4**). The two outer cells must be set higher than the middle cell(s) which is the focus for water flow. The outer cells must meet terrestrial culvert requirements described in this section.

Design aspect	Specifications and considerations
Landscape position and fencing	12. Place terrestrial culverts at known or likely movement pathways (e.g. where suitable habitat is present on both sides of the road) and mortality hotspots (known or likely) for the target species. 13. The position and spacing of culverts must consider the ecology of the target species, its home range size, and the distribution and type of intersecting habitat along the road alignment. Where a road intersects a large area of habitat or corridor, species with small home ranges will likely require culverts placed along the road at more frequent intervals (e.g. shorter distances between culverts) compared to larger more mobile species with larger home ranges. 14. Crossing spacing intervals must a) be sufficient to facilitate movement of multiple individuals of a population, b) be based on the home range size and movement capabilities of the target species, and c) provide connectivity along the road-habitat interface. This will ensure that movement of most individuals within the population is facilitated. 15. Avoid potential barriers across or near to culverts, such as farm fences, access roads or railways. 16. If drainage channels are required parallel to the road and across the culvert entrance, the channel should be connected via a pipe beneath the culvert entrance to minimise disruption to access. If an open swale structure is unavoidable the location should not fill with water for extended periods that will restrict access to the culvert and/or dry access should be provided across the channel. 17. Install fencing to funnel the target species to the culvert wherever there is a risk that the target species may access the road. The length of fencing is site and species-dependent. Refer to **Section 4** for guidance.
Landscaping and vegetation	18. Minimise erosion or scour control at the culvert entrances as this inhibits movement of terrestrial wildlife and discourages use of the culvert. If scour protection is required, use concrete or small rocks instead. 19. Vegetation planted up to culvert entrance will facilitate use by wildlife. It will guide animals to the culvert entrances and mitigate real or perceived risks of predation. Refer to **Section 7.2** of this document for further guidance.

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Design aspect	Specifications and considerations
Furniture to encourage use and reduce the risk of predation	20. Culverts to include additional structures required by the target species/group. These are often termed 'fauna furniture' and are aimed to facilitate connectivity by enabling and encouraging animal movement through a culvert. They either simulate the natural features that animals move across, like elevated rails, ledges or logs for arboreal fauna, or provide other features that animals need to move through an area. Essentially, it includes any feature added to the main structure that further facilitates connectivity by replicating habitat structures (either natural or artificial) that aid movement. This can include shelter from predators as many animals are reluctant to move long distances over open ground. Depending on the target species or fauna group(s) these can include: a. Elevated horizontal logs for arboreal mammals or koala rails (**Section 7.3.1**). b. Ledges for terrestrial or arboreal fauna (see **Photo 26**). c. Hollow ground logs for small mammals (see **Section 7.3.1**). d. Terracotta pipes or similar artificial structures for small mammals, reptiles, and frogs. e. Terracotta tiles for small reptiles (lizards and skinks). f. Refuge poles with resting platforms to provide koalas refuge from dogs (see **Section 7.3.1**). These structures replicate what is called 'structural connectivity' in natural habitats which are features that fauna species need in order to move through an area. This might be tree branches or limbs for arboreal fauna or dense ground cover needed by some small marsupials, like bandicoots. They may also provide protection from predators, such as foxes and cats. 21. Fauna furniture can be installed at the entrance (to encourage animal use) and along the length of the structure, appropriate to the target species (see ecological advice). Fauna furniture can be a combination of artificial shelters and natural features that suit the target fauna group/species (e.g. logs, rocks, wood piles) to provide shelter from predators and improve habitat suitability. Furniture can be installed on the ground, attached to walls, or built into the structure itself (e.g. bat roosts built into culverts). 22. Ledges need to connect to the ground and adjacent terrestrial habitat at a shallow (maximum 1:8) gradient and be at least 500 mm wide. See **Photo 26** for example gabion basket ramp down to ground surface from an elevated culvert ledge. 23. For terrestrial and arboreal fauna, align ledges, horizontal poles/rails and other furniture along one side of the structure to retain line of sight views from end to end, noting this should consider the perspective of the target fauna species. For a bandicoot, this would equate to a height of 20 cm from ground level. Ensure they do not obstruct passage for other fauna or reduce its perceptual or actual width relative to the fauna being targeted. For example, a koala rail centred in the middle of a box culvert could either physically or perceptually block passage for wallabies and kangaroos compared to one aligned along one side (wall) of the culvert. Many terrestrial native animals, particularly mammals, will also avoid moving over open ground and will move along the edge of structures, natural or otherwise. Consequently, they would be reluctant to move across a ledge or rail which is elevated in a more open context, due to perceived risk of predation (in many instances). 24. Use a combination of wooden and non-biodegradable artificial shelters, in accordance with **Section 7.3.1**. If future access within the culvert is likely to be restricted, with limited ability to replace or maintain fauna furniture, use only non-biodegradable furniture along the length of the culvert.

Design aspect	Specifications and considerations
Lighting	25. No artificial lighting within 100 m of culverts. 26. Where lighting is required to meet safety standards: a. Position as far away as practicable from the fauna crossing and habitat. b. Use light shields to prevent light spill into the culvert, adjacent habitat, underpass entrances and light wells. c. Ensure lighting is the lowest intensity possible. d. Avoid use of lights within the blue, violet and ultraviolet wavelengths.
Maintenance	27. Inspections to assess the structural integrity of wildlife culverts can be conducted at the same frequency as for culverts described in *Road Structures Inspection Manual* (VicRoads 2022). 28. Consideration should be given to whether the structure continues to perform the intended ecological function. Ecological failure of a structure could result in loss of ecological connectivity for potentially long periods of time, which could have severe consequences for local wildlife. 29. Involvement and advice from an ecologist experienced in the assessment and design of FSRD is desirable. 30. Information from inspections will have the greatest value if they feed into, or form part of, a monitoring and evaluation program (**Section 8.4**).
Monitoring	31. Develop and implement a performance evaluation plan, in accordance with **Section 8.4**.

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Photo 27 Terrestrial wildlife culvert located under the Calder Freeway in central Victoria (Source: Rodney van der Ree, WSP)

Photo 28 Terrestrial wildlife culvert located under East Evelyn Rd in Far North Queensland (Source: Rodney van der Ree, WSP)

Photo 29 The first arch underpass for birds, located on the Hume Highway at Woomargama NSW (Source: Rodney van der Ree, WSP)

Photo 30 Microclimate vents within the centre median of the Princes Highway, Victoria (Source: Austin O'Malley, VIDA Roads)

Photo 31 Small terrestrial culvert for bandicoots (Western Port Highway; Source: Austin O'Malley, VIDA Roads)

Photo 32 Drainage requires consideration to ensure terrestrial fauna culverts remain dry and free draining after flooding (Western Port Highway; Source: Austin O'Malley, VIDA Roads)

Photo notes: The terrestrial wildlife zone in Photo 29 free of large rocks and retains a largely natural waterway profile. The microclimate vents in Photo 30 are raised above surface level. This ensure that untreated surface runoff is not entering the culvert. This is important for reducing sediment entering aquatic and amphibian culverts and importantly, for keep terrestrial culverts dry. Photo 32 shows creation of dry passage for fauna at a culvert entrance where it intersects with a drainage line using an elevated apron surface and concrete ledge along both wing walls.

Figure 9 Terrestrial culvert design

CROSS-SECTION FRONT VIEW

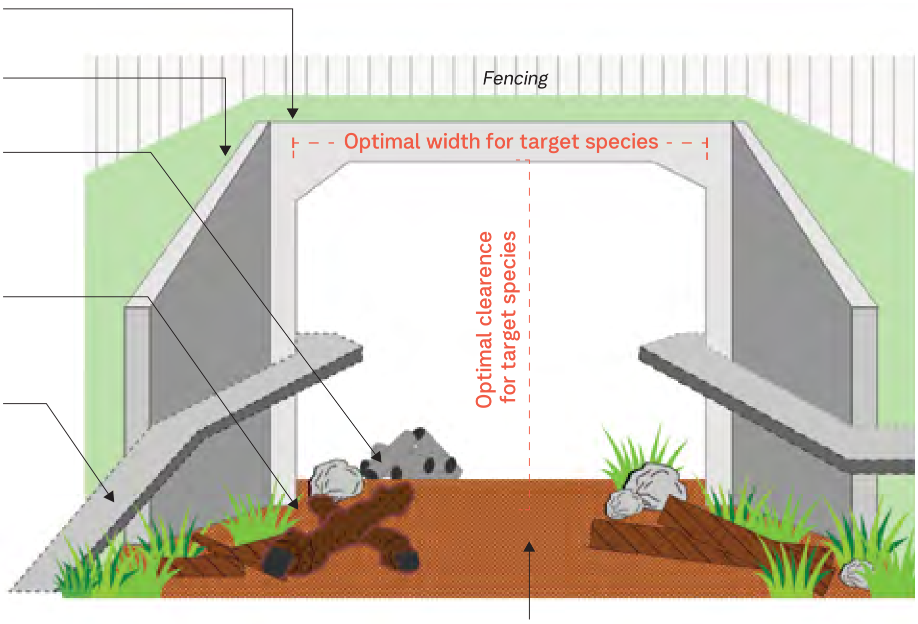
Use square or rectangular culverts (i.e., box culverts or slab-linked box-culverts).

As wide and tall as possible. Minimum height and width depends on target species.

Include shelters for fauna at culvert entrance and along length to encourage fauna use and protect from predators. Design according to target fauna species and can include logs (ideally hollow), tiles, and terracotta pipes.

Dry year-round, surface level set above 1:10 year flood level. Free draining so flood waters will rapidly dissipate. Must be **not** be connected to roadside drainage.

Ledges or shelves must be installed for ground-dwelling fauna if culvert could be inundated during flood events (see also Multi-use culverts for example). Must connect to bank or slope down to ground surface at shallow 1:8 gradient. Wood rails may also be required for arboreal fauna – see cross-section view.

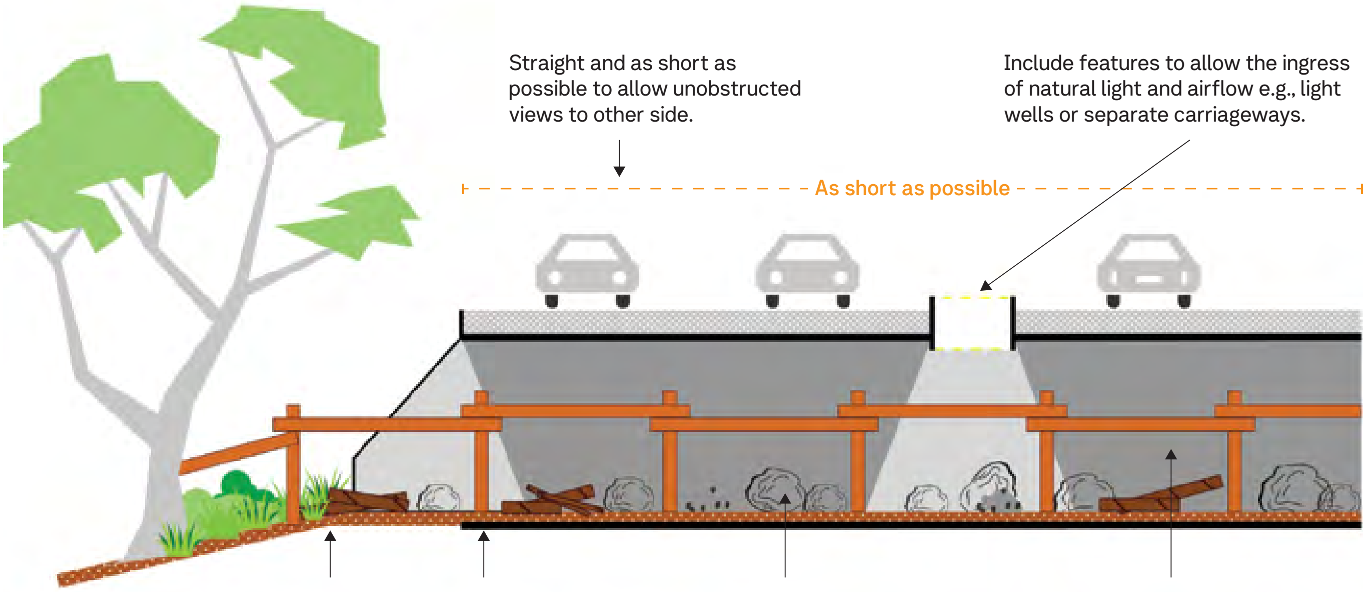


Natural base e.g., soil or mulch. Where possible, use culverts without a concrete base.

CROSS-SECTION SIDE VIEW

Straight and as short as possible to allow unobstructed views to other side.

Include features to allow the ingress of natural light and airflow e.g., light wells or separate carriageways.



Plant vegetation (at entrance) and include fauna furniture (at entrance and along length) that suit the target species to encourage wildlife to use the underpass.

Use a combination of wooden and non-biodegradable shelters. If future access within culvert likely to be restricted, use only non-biodegradable furniture along the length of the culvert.

With sufficient clearance, culverts can include additional structures to provide alternative pathways and allow wildlife to avoid predators e.g., elevated horizontal logs or koala rails.

Figure 10 Virtual renders of large terrestrial culvert with lightwell and elevated wooden rail for arboreal fauna

Note in **Figure 10** above the integrated wildlife fencing over top of structure to guide animals through crossing and away from the road and traffic (top image); elevated wooden rail for arboreal fauna positioned to one side for terrestrial fauna passage; (middle image); and native vegetation plantings up to culvert entrance, fauna furniture/shelter in the form of logs, and the wooden rail extending to adjacent tree canopy (bottom image).

3.4.2. Aquatic culvert

Culverts designed specifically to accommodate passage of fish and other aquatic species have become more common in their application in road design. Poor connectivity has a significant effect on aquatic species, particularly those that rely on access to upstream and downstream migrations for breeding and life cycle stages (Doehring *et al*, 2011, Harris *et al*. 2016).

Most of the understanding in aquatic habitat connectivity comes from international studies, with only a relatively small number (respectively) of studies having been completed in Australia. Generally, these studies have focused on establishing connectivity for specific species in specific contexts (i.e. threatened Galaxias fish species in remediated pipe culverts; **Photo 33**) (Harris *et al*. 2016). However, it is well understood that a decline has occurred in freshwater fish numbers as well as local extinctions from various reaches across Australia (Amtstaetter, *et al*. 2017, O'Connor 2017b). The general effectiveness of more recently installed structures is not often publicly accessible and or monitoring has not been undertaken to look at before and after-effects.

There is a general understanding that improved connectivity for most fish and other aquatic species can be achieved by following a few simple principles in design that allow suitable passage in most situations (**Table 3.5**).

Aquatic passage designs that restrict fish movement include those that create behavioural or physical barriers including:

- Higher water velocity and turbulence.
- Lower light.
- Reduced temperatures.
- Physical barriers to movement (e.g. weirs, channel drops or steps).
- No or limited vegetation.
- No in-stream shelter structures (e.g. wood).
- No natural streambed.

Photo 33 The threatened Eastern Dwarf Galaxias (Source: Rhys Coleman)

More is becoming known and understood how various species are affected by these barrier effects, and each location will be unique and based on the site constraints and target species. As such, it is vital to consider the swimming abilities of the target species of fish when designing culverts, bridges and fishways as this determines flow velocities and depth of water (**Photo 34**). It is, therefore, Important to understand not only the local fish species but the size of the waterway (stream order), the flow regime (ephemeral, intermittent or perennial) and the natural profile of the channel. Understanding the habitat and the species requirements will inform the level of connectivity that needs to be designed.

Aquatic culverts at some locations may need to cater for species groups with different culvert requirements (e.g. fish and frogs); in such scenarios, a hybrid design may be warranted, and expert ecological input into the design will be required.

Design requirements to facilitate fish passage are detailed below in **Table 3.5** and illustrated in **Figure 11** (concept diagram) and **Figure 12** (virtual render).

Photo 34 Aquatic culvert for incidental fish passage in low-flow contexts (Mordialloc Freeway; Source: Austin O'Malley, VIDA Roads)

Table 3.5 Aquatic culvert — design requirements for ecological connectivity

Design aspect	Specifications and considerations
Target species	– Proven for fish, semi-aquatic mammals, semi-aquatic reptiles and macroinvertebrates; likely to be effective for many highly aquatic frogs.
Design, dimensions and construction materials	1. Bridges are the preferred crossing structure. However, if a typical bridge design is not feasible, then an arch structure or culvert (**Photo 29**) is the next preferred option. This design may provide better integration into natural channel structures than box culverts and provides the most flexibility in design to meet the fish passage requirements. Where this is not feasible to implement, larger sized box culverts (ideally with baffles) is the next best solution (**Figure 11**). Ideally a natural base would be used rather than a concrete base. 2. Pipe culverts are the least preferred option as they can be restrictive in natural flows, turbulent in velocity and are prone to malfunction (i.e. perching; see **Photo 38**). Also, a much larger pipe diameter is necessary for pipe culverts to meet the bed sediment and flow requirements of an aquatic culvert. Pipe culverts can be used (or retrofitted if already installed and seeking to improve conditions for aquatic fauna) but require additional considerations to manage velocities and access by fish. 3. Where possible, one large culvert should be used rather than multiple small culverts. If multiple culverts are required: a. Use few large culverts rather than numerous small culverts. b. Minimum culvert width is 600 mm. c. One of the culverts must directly align to the low flow channel (ensures suitable depth of water during base flow periods and that the low flow channel of the creek is not obstructed). 4. Culvert height should be as high as practicable to allow maximum egress of light. The culvert or culvert array should be equally as wide as the natural channel width observed, with a minimum height of 1.2 m and must meet the following height and vertical position requirements: a. Ideally, wider is better as this will allow greater light penetration and reduced water velocities. Where constrained, there should be a minimum height of 600 mm above base flow conditions. b. Must remain inundated year-round, ensuring a minimum of approximately 200–300 mm of water depth during base flow events. *Alternative standards may be acceptable where the waterway is demonstrated to be ephemeral*. c. Set at 300 mm below bed level to allow for natural accumulation of bed sediments. 5. Culverts should be as short (in length) as possible. If culvert exceeds 6 metres in length, then baffles or other roughening techniques should be applied. The longer the culvert the higher the water velocity and laminar flow (water flow without turbulence), which can make a culvert difficult for fish to navigate. 6. Suitable flow rates are generally considered to be 0.3m/s for small-to medium-sized fish. If flow rate exceeds 0.3m/s baffles or other roughening techniques can be applied. 7. Culverts are to have no slope or installed to match the bed gradient where the culvert is recessed into the bed sediments. Match the upstream and downstream depths of stream channels and consider dropping below to encourage the formation of a natural streambed surface (where a concrete base is required). Ensure there are no vertical drop-offs of channel bed in design (inclusive of interface between culvert floor and natural streambed. 8. Headwalls, tail walls or wingwalls should be at 90° (perpendicular) to the culvert. Diagonal walls produce poor hydraulics for fish passage.

Design aspect	Specifications and considerations
Design, dimensions and construction materials	9. Implement design or structural features to allow the ingress of natural light and airflow. Lack of light within an enclosed structure can impact aquatic vegetation and create a behavioural or physical barrier to movement, including through: a. Reduced water temperatures (for fish and amphibians) and light levels. b. Reduced air temperatures and circulation. c. Inhibiting aquatic or terrestrial vegetation growth important for shelter and habitat. **Options to mitigate include**: d. adding light wells – applicable to culverts and must be installed in each box cell to be effective; e. increasing the size of the crossing structure (e.g. box culvert or arch structure design) and optimal orientation to maximise light penetration and ventilation; and/or f. an alternative design such as separated bridge carriageway. 10. Light requirements will be dependent on the height and length of the structure, along with the specific requirements of the species and expert advice is necessary to determine the importance of modifying design to consider light needs. Two options to allow the ingress of natural light into culverts are: a. *Separate carriageways*: Build each carriageway onto two separated structures with space between the carriageways (ideally five metres). This will allow light and water to reach the ground and improve rates of use by wildlife through facilitating the growth of vegetation. Install wildlife fencing between the two carriageways to prevent wildlife from accessing the road and median strip from below. Ensure any rain or flood water that enters via the median can drain away. b. *Light wells*: Light wells or microclimate vents (i.e. with grated lids) can be installed from the median into the culvert below to allow the ingress of natural light. These should be a minimum 1 m x 1 m in size, be located in the centre median or potentially the kerb and channel where space is limited (**Table 3.2**) and should be less than 10 m apart from each other.
Inundation and dry passage	11. Aquatic culverts must remain inundated year-round, ensuring a minimum of approximately 200–300 mm of water depth during base flow events. 12. Aquatic culverts must include a dry passage option for terrestrial species. Dry passage requirements: a. Can be a ledge, shelf or alternative structure that provides equivalent dry passage, installed on the culvert wall on each side of the culvert. b. Must connect to terrestrial habitat at both ends. c. Made from non-biodegradable material (e.g. concrete, recycled plastic). d. Minimum 500 mm wide, ideally 1 m wide subject to hydrological constraints. Minimum 600 mm clearance from the culvert ceiling for smaller animals (e.g. koala, echidna) and at least 1.8 m for larger animals (e.g. kangaroo). e. Height to be as close to the natural ground level as possible while achieving dry passage most of the time (set above the 1:10 year flood level if practicable). 13. If the aquatic culvert is in a location that is likely to be highly trafficked by terrestrial fauna, install a multi-use culvert with the two outer cells set higher than the middle cell which is the focus for water flow (see **Section 3.4.4**). The outer cells should meet terrestrial culvert requirements (see **Section 3.4.1**).
Landscape position and fencing	14. Fencing needs to tie into the top of the crossing structure to minimise debris becoming lodged in the fencing and obstructing the flow of water.

Design aspect	Specifications and considerations
Landscaping and vegetation	15. Any channel section diverted/reprofiled/created should be rebuilt to be as natural as possible allowing for natural features (vegetation, rocks, leaves, and course woody debris to be present). 16. Banks upstream and downstream disturbed as part of the works should be reprofiled to be consistent with existing banks and these must be revegetated with locally appropriate riparian vegetation. If existing banks are highly disturbed, then reprofile and revegetate to improve conditions. 17. Where appropriate, vegetation can be planted to encourage wildlife to use the structure, in accordance with **Section 7.2**. 18. If erosion or scour control is necessary: a. Minimise scour protection in and around the culvert entrance and ensure it does not block or impede passage through (or access to the entrance of) the culvert crossing structure, noting that large rock piles/scouring can create traps/ barrier for fish movement during low flow periods. If scour protection is required, use concrete or small rocks instead. Alternatively overlay larger scour protection rocks with smaller sized rocks and/or concrete to fill all gaps. b. Scour protection should be placed at or below bed level and not extend more than 20 m upstream and or downstream of the structure. Scouring and perching at the entrance or exit of the culvert should be avoided. c. Small discrete piles of large rocks (e.g. greater than 30 cm diameter) are generally beneficial for amphibians as they provide inter-rock shelter spaces. d. Ensure there is a clear passage end-to-end, with no pools or puddles that can entrap fish. e. Any very large rocks should be embedded into the channel bed to prevent water pooling beneath and trapping fish.

Yarra Pygmy Perch, Tarmo A. Raaduk

Design aspect	Specifications and considerations
Enhancements to encourage use	**Enhancements for fish:** 19. *Baffles*: Baffles installed on one or both sides of the culvert (and or on outer culverts) aid the creation of eddies and act as energy dissipators, slowing water velocity. They also change the flow pattern in the vicinity of the culvert, creating zones of fast — and slow — moving water. This allows fish to use short bursts of energy while allowing periods of rest. 20. *Fish ladders*: Fish ladders are structures on or around artificial barriers such as culverts and weirs and can be used to facilitate movement of fish upstream. The velocity of water falling over the steps must be great enough to attract the fish to the ladder but cannot be too strong that it washes fish back downstream or exhausts them to the point that they can't maintain the energy needed to move through the stream system. Fish ladders include fish pools, fish elevators and rock ramps. 21. *Rock ramps*: In Australia, rock ramps are commonly used to facilitate fish movements and are a good tool for slowing water velocity down and encouraging fish movement through culverts. Rock ramps are constructed by placing large rocks within streams to form a fish ladder type system and they cater for a variety of fish behaviours and movement patterns and allow migration even during relatively low-flow events. Gradient and design are determined by maximum swimming speeds and duration of high-speed swimming bursts of the target species of fish. 22. *Wetlands, refuge pools or plunge pools*: A 0.5 m high, downstream sloped (30°) water retention end-sill (usually concrete) can be considered for raising the tailwater, thereby reducing turbulence and providing a refuge/plunge pool. 23. *Large woody debris*: Large woody debris (logs, large branches) can be an added benefit by creating suitable habitat and encourage species to access and utilise the crossing structures (must consider placement, and risk of woody debris becoming an obstruction) **Enhancements for amphibians**: 24. Where amphibians are a target species, aquatic culverts should include a rock gabion or rock platform running the full length of the culvert. a. Rock gabions should be positioned in one of the central culverts, along one side of the culvert as per Koehler and Gilmore (2014). Gabions should have a width of at least 500 mm, and a height approximately 100 mm above the base flow or normal water level (ideally set above the 1:10 year flood level). Rocks in the gabion should be sized between 100 mm to 250 mm in diameter to provide sufficiently sized nooks and crannies for refuge. b. Rock platforms consist of large rocks cemented to the ground, positioned centrally (where possible) to one of the central culverts. Platforms should have a width of at least 500 mm and a height approximately 100 mm above the normal water level (ideally set above the 1:10 year flood level). Rocks in the platform may need to be larger than for gabions to resist movement during high flows or be secured to the base of the culvert (e.g. concreted in). 25. Wetland habitat (i.e., frog ponds) at the ends of culverts are recommended for amphibians (see **Section 3.4.3**).
Lighting	26. No artificial lighting installed within 100 m of culverts. 27. Where lighting is required to meet safety standards: – Ensure lighting is the lowest intensity possible. – Avoid use of lights within the blue, violet and ultraviolet wavelengths. – Use light shields to prevent light spill into adjacent habitat, underpass entrances and light wells.

Design aspect	Specifications and considerations
Maintenance	28. Inspections to assess the structural integrity of aquatic culverts should be conducted at the same frequency as for culverts described in *Road Structures Inspection Manual* (VicRoads 2022). 29. Inspections to assess the ecological condition of the aquatic culverts must be conducted annually. Frequent inspections are necessary to ensure structures are performing their ecological function. Any significant failures (those that prevent use by target species) must be rectified within four weeks of inspection. Ecological failure of a structure could result in loss of ecological connectivity for potentially long periods of time, which could have severe consequences for local wildlife. 30. Inspections must be conducted by an ecologist experienced in the assessment and design of FSRD and should form part of the monitoring and evaluation program (**Section 8.4**).
Monitoring	31. Develop and implement a performance evaluation plan, in accordance with **Section 8.4**.
Temporary structures	32. Ensure works are undertaken in accordance with EPA Publication 275 – Construction Techniques for Sediment Pollution Control. 33. Where possible, channels should not be blocked or diverted (e.g. bypass pumping). Use of dry bund around area of work is recommended to maintain channel connectivity. Where bypass pumping is the only option, fauna salvage may be required to remove animals and filters used to restrict aquatic wildlife from entering piping. 34. Ground disturbance should not occur during periods of heavy rain fall, to limit direct sedimentation into the waterway. 35. Considerations for seasonally important periods should be taken into account when planning and commencing construction (i.e., if the waterway is blocked during the annual migration period this may directly impact the viability of that cohort of fish in that waterway). 36. Disturbed bank and bed sediments should be exposed only for short periods. Temporary sediment controls and replanting should commence as soon as practically possible. 37. If temporary pads are required to access the middle of the waterway channel, the fill material used should be natural and not recycled waste concrete and or asphalt in case material is not completely removed.
Rehabilitation of existing culverts	38. Existing culverts can be rehabilitated to improve fish passage conditions by: a. Reprofiling the channel to correct for scouring. b. Baffles added to the inside of the culvert to reduce water velocity. c. Increasing the size of culverts or replacing culverts with open span bridges. d. Upstream modifications to improve flow in to culverts by raising low-flow water levels within culverts. e. Upstream channel modifications could ameliorate issues associated with deep drops or excessively steep rock ramps.
Further guidance	39. The following documents are essential reference documents for the planning, design, construction, and maintenance of fish passage structures and fishways: a. Connor, J., Stuart, I. and Campbell-Beschorner, R. (2017) ***Guidelines for fish passage at small structures***. Arthur Rylah Institute for Environmental Research. Technical Report Series No. 276. Department of Environment, Land, Water and Planning, Heidelberg, Victoria. Online access available here. b. Connor, J., Stuart, I. and Jones, M. (2017) ***Guidelines for the design, approval and construction of fishways***. Arthur Rylah Institute for Environmental Research. Technical Report Series No. 274. Department of Environment, Land, Water and Planning, Heidelberg, Victoria. Online access available here. c. Kapitzke, R. (2010). Fish Passage Planning and Design. Culvert Fishway Planning and Design Guidelines: Part F–Baffle Fishways for Box Culverts. James Cook University, School of Engineering and Physical Sciences. Online access available here.

Photo 35 Aquatic culvert under Koo Wee Rup Bypass with suboptimal pole ledge for terrestrial fauna (Source: VIDA Roads)

Photo 36 Native waterbirds using a retrofitted shelf along a wall of an existing waterway culvert, Healesville-Koo Wee Rup Road (Source: VIDA Roads)

Photo 37 Aquatic culverts, Princes Highway, Victoria (Source: Austin O'Malley, VIDA Roads)

Photo 38 Example of poor culvert design for aquatic fauna (Source: Andrea McPherson, ARUP)

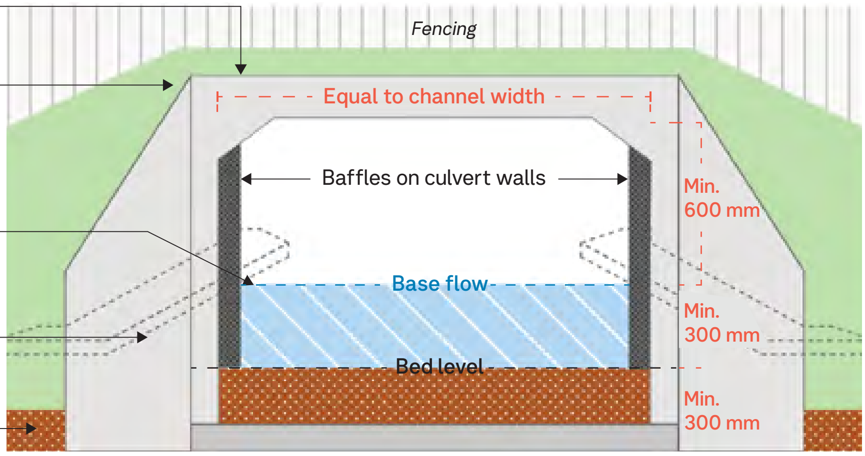
Photo 39 Existing or new pipe culverts can be drowned-out by the addition of a fishway downstream – Muddy Creek, southwest Vic (Source: Ivor Stuart, Arthur Rylah Institute)

Photo 40 Integrating light wells into culverts facilitates fish passage – Fish Point fishway overpass on the Little Murray River (Source: Frank Amtstartter, Arthur Rylah Institute)

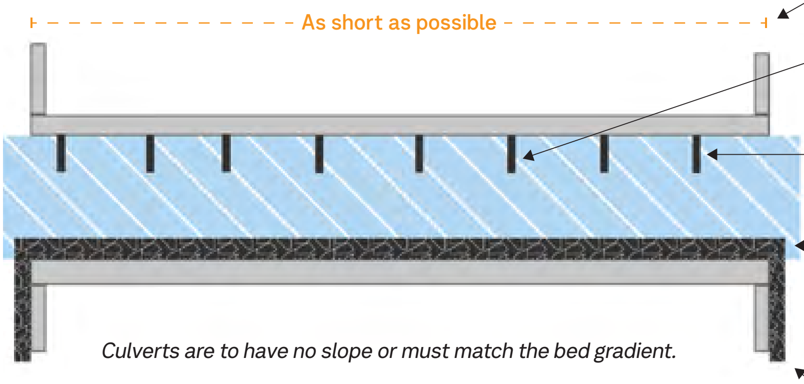
Photo 35 to Photo 40: Wider multi-cell culvert structures are preferred for aquatic fauna passage. Increasing size allows more light to penetrate and reduces water velocity which can impede fish passage (see **Photo 35** for example of larger box multi-cell design) while ledges can also be added to aid passage of other terrestrial fauna (**Photo 36**). Aquatic culverts should ideally have vegetation established near entrances (**Photo 35**) and remain inundated year-round (**Photo 37**). Waterway crossings that increase water velocity, reduce light egress, and create steps in the streambed will restrict fish passage, such as small diameter pipe designs which are elevated above the natural channel bed (**Photo 38**). Fishways can added downstream of existing or new pipe culverts to 'drown-out' culverts by backing up water and reducing water velocity (**Photo 39**) while adding light wells facilitates fish passage through increasing light levels and water temperature (**Photo 40**).

Figure 11 Aquatic culvert design

CROSS-SECTION FRONT VIEW



CROSS-SECTION AERIAL VIEW



MULTI-CELLED AQUATIC CULVERT

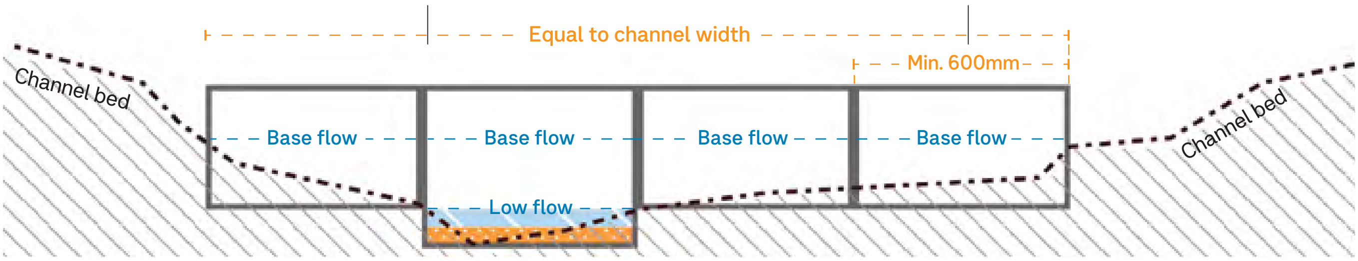
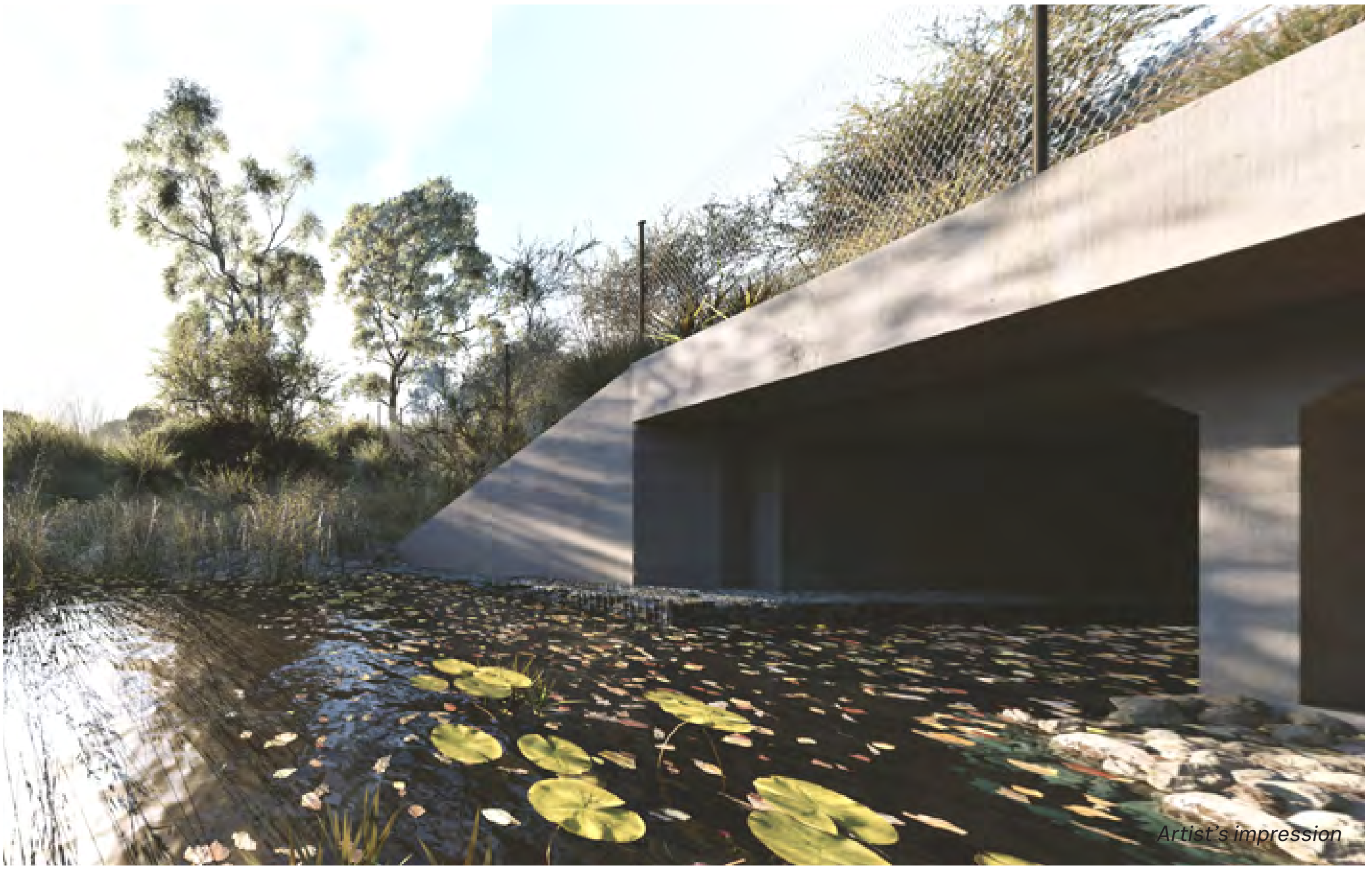


Figure 12 Virtual render of a multi-cell aquatic culvert concept design with baffles, light wells, and terrestrial ledge



Note in Figure 12 a recessed box cell culverts to reduce overall length of passage; b) side terrestrial ledge (gabion basket) connecting to waterway embankment and adjacent habitat; c) integrated fauna fencing; and d) light wells at midpoint of each box cell culverts to increase light levels, water temperature, and air ventilation.

3.4.3. Amphibian culvert

Amphibian culverts are specific culvert systems designed to facilitate the movement of frogs. They differ from 'aquatic culverts' in being designed specifically for amphibians, rather than fish and other aquatic vertebrates (including amphibians) and are distinct from 'terrestrial culverts' in that use by other vertebrate fauna groups (e.g. mammals, reptiles) is expected to be incidental and infrequent.

It is important to note that there are a limited number of studies specifically evaluating the characteristics and performance of crossing structures for amphibians in Australia (Taylor and Goldingay 2010, Smith *et al*. 2020; but see Hamer *et al*. 2014). Consequently, some recommendations provided here are necessarily inferred from international studies on taxa not occurring in Australia, in combination with ecological knowledge regarding the Victorian amphibian fauna.

Many amphibians are likely to successfully cross narrow roads or those with less traffic; the likelihood of success largely depends on the combination of traffic speed and traffic volume.

Internationally, amphibian culverts that are wider (i.e. larger) and shorter are most effective at facilitating crossings, as well as those with natural substrates (Woltz *et al*. 2008; Smith *et al*. 2020; Lesbarreres *et al*. 2004). Increasing the number of culverts, and hence the available area for passage, can also increase effectiveness (Dodd *et al*. 2004). Fencing that directs amphibians towards crossings is necessary to reduce road mortality (Malt 2011, Jarvis *et al*. 2019). Ensuring permanent or near-permanent inundation of the base of one or more culverts is also important for passage effectiveness, particularly for highly aquatic amphibians, such as Growling Grass Frog (Koehler and Gilmore 2014; Gleeson *et al*. 2019).

The detailed design elements for amphibian culverts described below align as far as possible with the Victorian Crossing Structure and Habitat Design Standards for the Growling Grass Frog (DELWP 2017), as well as a successful culvert system design for this species (Koehler and Gilmore 2014; **Figure 13**). Many of these design elements can also be incorporated into terrestrial and aquatic culverts to better facilitate amphibian movement.

Design requirements to facilitate amphibian movement and ecological connectivity are detailed in **Table 3.6** and illustrated in **Figure 14** (concept diagram) and **Figure 15** (virtual render).

Photo 41 The threatened Growling Grass Frog has specific culvert design requirements to facilitate passage/movement (Source: Dan Weller)

Table 3.6 Amphibian culvert — design requirements for ecological connectivity and safe passage

Design aspect	Specifications and considerations
Target species	– Primarily Growling Grass Frog (listed as threatened under the EPBC Act). – Potentially effective for other amphibian (frog) species. – Effectiveness higher when combined with wetlands or frog ponds at both ends of the culvert system.
Design, dimensions and construction materials	1. Amphibian culverts should be as wide and tall as possible. This is best achieved using square or rectangular culverts (i.e., box culverts or slab-linked box-culverts). Pipe culverts are not acceptable as culverts dedicated to amphibian movement. 2. Bridges over a waterway are the preferred option wherever a crossing structure for amphibians is required. A culvert system should be used in circumstances where a bridge is not feasible. 3. Amphibian culvert design requirements: a. Culvert systems consist of an array of up to four culverts, with total width depending on target species. b. If Growling Grass Frog is a target species, the required total width of the culvert array under current regulatory guidance must be 10 m (DELWP 2017). c. Each culvert should have minimum 1.2 m height and 2.4 m width. d. Remain inundated year-round and include a dry passage option (see below). e. Minimum of 600 mm airspace must be maintained between the normal water surface and culvert ceiling (see **Figure 13** for optimal design and poor design in **Photo 42**). 4. Culverts should aim to be as straight and as short as possible, allowing unobstructed views to the other side. 5. The base of amphibian culverts should ideally be a natural surface, i.e., bed sediments for inundated culverts and soil with embedded rocks for dry culverts. Mulch is not appropriate within or surrounding amphibian culverts. 6. At least some amphibian species are likely to benefit from allowing natural light and moisture to penetrate the culvert. Two options to allow the ingress of natural light into culverts are: a. *Separate carriageways*: Build each carriageway onto two separated structures with space between the carriageways (ideally 5 m or more). This will allow light and water to reach the ground and improve usage by wildlife through more favourable microclimatic conditions and by facilitating the growth of vegetation. Install wildlife fencing between the two carriageways to prevent wildlife from accessing the road and median strip from below. Ensure any rain or flood water that enters via the median can drain away. b. *Light wells*: Light wells or microclimate vents (i.e., with grated lids) installed from the median into the culvert below will allow the ingress of natural light (especially for Growling Grass Frog). These should be a minimum 1 m x 1 m in size, be located in the centre median, and be spaced at minimum 10 m intervals i.e. no more than 10 m apart from each other. Note that in multi-cell culvert crossings, **each cell** requires a lightwell to achieve the intended objective (DELWP 2017). c. *Light wells in kerb and channel*: In instances where space is highly constrained, grated lightwells could potentially be placed in the kerb and channel, noting this is a suboptimal solution as it allows polluted road runoff/stormwater to run directly into the aquatic culvert underneath. Roads requiring wildlife culvert crossings should be designed with sufficient medians to accommodate light wells.

Design aspect	Specifications and considerations
Inundation and dry passage	7. Amphibian culverts to remain inundated year-round, ensuring a minimum of approximately 200–300 mm of water depth during base flow events. 8. A supply of suitable water (e.g. treated stormwater, directed overland flows from vegetated areas) must be identified as part of the design. Water supply options must include fish exclusion measures, to prevent the introduction of predatory exotic fish (such as Eastern Gambusia) into the frog ponds. 9. Amphibian culverts to include an elevated dry passage that provide shelter and resting areas for amphibians (e.g. rock gabion or rock platform): a. Ideally positioned centrally to the culvert array (i.e., in one of the central culverts). b. Run the full length of the culvert, and slope to the ground or water level at both ends. c. Minimum width of 500 mm, and height approximately 100 mm above the base flow or normal water level (ideally set above the 1:10 year flood level). d. Rock gabions are a cage or mesh basket filled with rocks to create a small wall. Rocks in the gabion should be sized between 100 mm to 250 mm in diameter to provide sufficiently sized nooks and crannies for refuge. e. Rock platforms consist of large rocks cemented to the ground. Rocks in the platform may need to be larger than for gabions to resist movement during high flows or to be secured to the base of the culvert (e.g. concreted in). f. A dedicated dry culvert may be required in some instances for certain species. If a dry culvert is required as part of the culvert array, a structure that provides shelter for amphibians should run the full length of the culvert (e.g. a rock platform or gabion wall, width approximately 500 mm, and height approximately 300 mm). 10. Ideally, amphibian culverts should also include a dry passage option for terrestrial species (e.g. mammals, reptiles). Dry passage requirements: a. Can be a ledge, shelf or alternative structure that provides equivalent dry passage, installed on the bank side of the outer culverts in the array. b. Connect to terrestrial habitat at both ends. c. Made from non-biodegradable material (e.g. concrete, recycled plastic). d. Minimum 500 mm wide, ideally 1 m wide subject to hydrological constraints. Minimum 600 mm clearance from the culvert ceiling. Minimum dimensions can accommodate smaller animals (e.g. koala, echidna) but will not accommodate large animals (e.g. kangaroo). Smaller widths may be appropriate where only small mammals are target species. e. Height to be as close to the natural ground level as possible while achieving dry passage most of the time (set above the 1:10 year flood level if practicable). f. If part of a culvert array, the dry culvert can be positioned on the outside of the array to accommodate terrestrial species. 11. If the aquatic culvert is in a location that is likely to be highly trafficked by terrestrial fauna, install a multi-use culvert with the two outer cells set higher than the middle cell which is the focus for water flow and amphibian use (see **Section 3.4.4**). The outer cells should meet terrestrial culvert requirements (see **Section 3.4.1**).

<table>
<tr><th>Design aspect</th><th>Specifications and considerations</th></tr>
<tr><td>Landscape position and fencing</td><td>12. The position and spacing of culverts (t intervals along a road alignment) should consider the ecology of the target species, its home range size, and the distribution and type of intersecting habitat along the road alignment. Where a road intersects a large area of habitat or corridor, species with small home ranges will require culverts placed along the road at more frequent intervals (e.g. shorter distances between culverts) compared to larger more mobile species with larger home ranges.
Culvert spacing interval and number should consider:
a. home range width and movement capabilities of the target species;
b. sufficiency to facilitate movement of multiple individuals of a population; and
c. providing connectivity along the entire road – habitat interface.
This will ensure that movement of most individuals within the population is facilitated.
Note: there are specific requirements for spacing intervals of culverts for Growling Grass Frog within the Melbourne Strategic Assessment (MSA) conservation areas and instances when the Growling Grass Frog Crossing Design Standards (DELWP 2017) are applicable.
13. Avoid potential barriers across or near to culverts, such as farm fences, access roads or railways.
14. Place amphibian culverts in proximity to existing wet habitat were possible; metapopulation dynamics (i.e., dispersal and colonisation) will increase the likelihood of successful use of the culverts.
15. Install fencing to funnel the target species to the culvert wherever there is a risk that the target species may access the road. The length of fencing is site- and species-dependent. Refer to Section 4 for guidance.</td></tr>
<tr><td>Landscaping and vegetation</td><td>16. Appropriate vegetation should be planted surrounding the entrance of culverts and around associated habitat ponds to encourage frogs to use the culvert. Vegetation plantings should:
a. Be designed and shaped to funnel wildlife towards the underpass.
b. Consist of terrestrial and aquatic plant species and use indigenous stock wherever possible.
c. Consist of the preferred habitat of the target species, e.g. Appendix 1 in the Growling Grass Frog habitat design standards (DELWP 2017).
d. The planting of trees and shrubs should be minimised around entrances to amphibian culverts and culvert ponds, so as not to shade the water surface-shading reduces water temperatures and potentially facilitates the spread of amphibian chytrid fungus.</td></tr>
<tr><td>Furniture to encourage use and reduce the risk of predation</td><td>17. Wherever feasible, amphibian culvert systems should have a dedicated frog pond located at both ends of the culvert system, to which the inundated culverts are permanently hydrologically connected, except potentially during drought. Specific herpetological advice is likely to be required in the design of frog ponds. See Frog Ponds, Section 7.5, for further details.</td></tr>
</table>

Design aspect	Specifications and considerations
Lighting	18. No artificial lighting installed within 100 m of culverts (i.e., minimum length of frog fence). 19. Where lighting is required to meet safety standards: a. Ensure lighting is the lowest intensity possible. b. Use directional lighting and light shields to prevent light spill into the culvert, adjacent habitat/ponds, underpass entrances and light wells.
Maintenance	20. Inspections to assess the structural integrity of amphibian culverts should be conducted at the same frequency as for culverts described in *Road Structures Inspection Manual* (VicRoads 2022). 21. Inspections to assess the ecological condition of the aquatic culverts are ideally conducted annually. Frequent inspections are necessary to ensure structures are performing their ecological function. Any significant failures (those that prevent use by target species) should be rectified within four weeks of inspection. Ecological failure of a structure could result in loss of ecological connectivity for potentially long periods of time, which could have severe consequences for local wildlife. 22. Inspections must be conducted by an ecologist experienced in the assessment and design of FSRD and should form part of the monitoring and evaluation program (**Section 8.4**).
Monitoring	23. Develop and implement a performance evaluation plan, in accordance with **Section 8.4**.
Further guidance	24. The following documents define requirements for the threatened Growling Grass Frog within the Melbourne Strategic Assessment (MSA) area and can be a reference document for regulatory planning approvals. They must be referred to in combination with the VIDA Roads FSRD Guidelines concerning this threatened species. a. DELWP (2017) Growling Grass Frog Crossing Design Standards: Melbourne Strategic Assessment. Department of Environment, Land, Water and Planning. b. DELWP (2017) Growling Grass Frog Habitat Design Standards: Melbourne Strategic Assessment. Department of Environment, Land, Water and Planning. 25. The above documents and other standards can be found online on the Department of Environment and Climate Change (DEECA) MSA webpage: msa.vic.gov.au/conservation – in – action/growling – grass – frog – program 26. Note that design specifications advice for both amphibian (**Section 3.4.3**) and multi-use culverts (**Section 3.4.4**).

Southern Toadlet, Dan Weller

Figure 13 Successful culvert design for the threatened Growling Grass Frog (DELWP 2017); originally reproduced from Koehler and Gilmore (2014) and all images Daniel Gilmore, Biosis Pty Ltd.

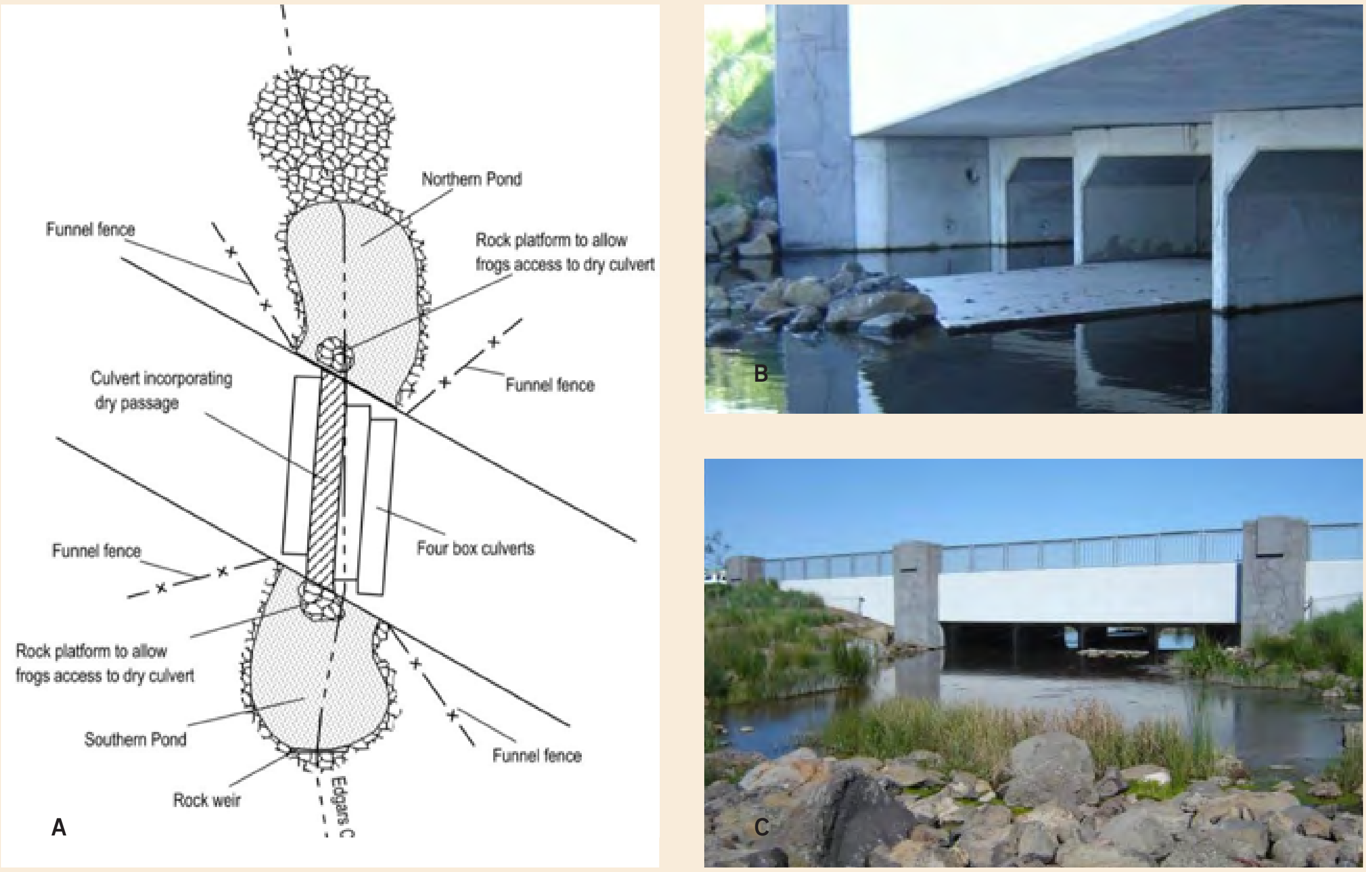


Photo 42 Sub-optimal Growling Grass Frog culvert, showing a lack of sufficient height/airspace and no dry passage options (Source: Jake Urlus, Tactecol)

Notes: The optimal design in Figure 13A includes setback of the culvert cells from the bridge structure (reducing culvert width) and ponds at either end. Also provided is a dry passage cell with a rock platform ramp for frogs from the water edge to the culvert cell floor (Figure 13B). Note rock jumbles and emergent aquatic vegetation around edge of pond in Figure 13C.

Figure 14 Amphibian culvert design

Example configuration

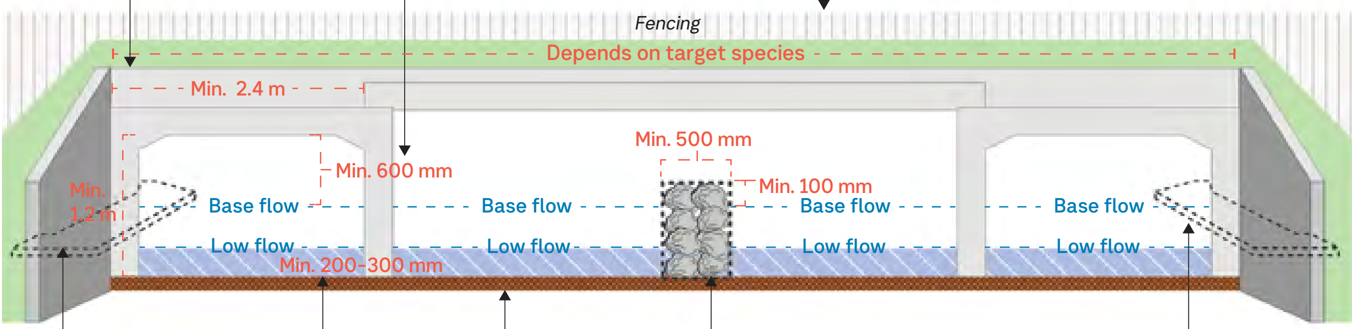
CROSS-SECTION FRONT VIEW

Numerous configurations are possible for amphibian culverts.
See Multi-use culverts for a variety of configurations options.

As wide and tall as possible. Ideally box culverts or slab-linked box culverts.

Min. 600 mm airspace above base flow.

Minimum height and width depends on target species. E.g. Min. total width for Growling Grass Frog is 10 m.



Min. 200–300 mm of water depth year-round.

Amphibian dry passage. E.g. rock platform or rock gabion. Must grade in to the water at both ends.

Ledge must connect/ramp down to terrestrial habitat at shallow (1:8) gradient.

Natural base such as bed sediments. Where possible, use culverts without a concrete base.

Terrestrial dry passage: either a multi-celled culvert or a concrete ledge on each side of the culvert (see *Multi-use culverts*).

CROSS-SECTION SIDE VIEW

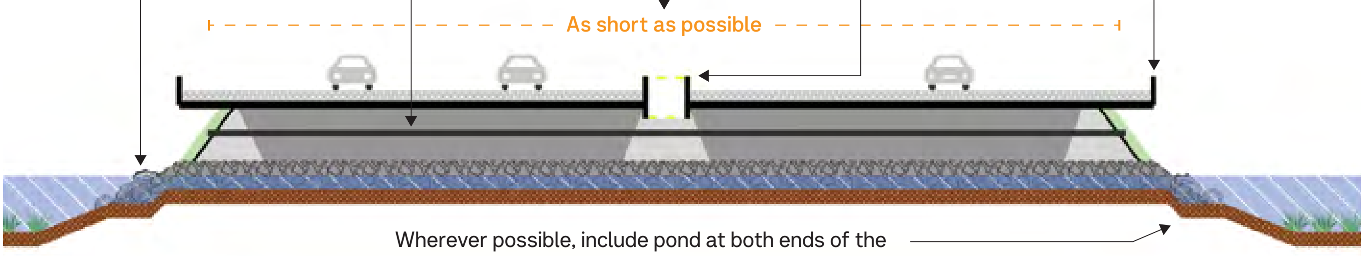
Amphibian dry passage. Grades in to water at both ends.

Straight and as short as possible to allow unobstructed views.

Culvert recessed under the road.

Terrestrial dry passage. Connects to terrestrial habitat at both ends.

Include features to allow the ingress of natural light and airflow e.g., light wells or separate carriageways.



Wherever possible, include pond at both ends of the culvert system. See Frog ponds for design specifications.

Figure 15 Virtual render of an optimal amphibian crossing design with a multi-cell configuration (top), deep ponds at either end (middle) furnished with aquatic vegetation and fringing rocks and logs (bottom)

The top image in **Figure 15** above shows (top) raised central terrestrial passage, light wells, and gabion baskets for frogs to rest on during passage. Note that the central culvert and gabion walls have shallow sloping ramps submerged at ends to facilitate movement of frogs from the water. Optimal amphibian crossings are paired with (middle image) ponds at either side with fringing, emergent, submerged, and floating native aquatic vegetation, and fringing logs and rocks to provide shelter and basking opportunities (bottom). Exclusion fencing must be solid or very fine mesh up to height defined in **Table 4.2.**

3.4.4. Multi-use culvert

Multi-use culverts allow the movement of wildlife under the road as well as permit one or more other functions such as drainage or the movement of people or stock or accommodate two or more functional groups of fauna (or species), such as frogs and small mammals (**Photo 43**). The degree of 'multi-use' ranges from intentional simultaneous use (i.e., both functions given equal priority in the design) to incidental use by wildlife (i.e., primary aim is something other than the movement of wildlife). **Section 3.4.5** describes incidental-use culverts.

Multi-use culverts can be a cost-effective approach to achieving wildlife connectivity however such structures should be carefully planned and designed to ensure that wildlife movement is not compromised.

> It is not acceptable to label a drainage culvert a multi-use culvert without including specific design features to facilitate the movement of wildlife.

Therefore, incidental-use culverts and standard drainage culverts do not qualify as multi-use culverts because they are not specifically designed to effectively cater for multiple uses.

In almost all cases, multi-use culverts should be box culverts or slab-linked box culverts (see **Section 3.4.1** for explanation). Multi-use culverts can be a single cell that caters equally for both wildlife and other uses (e.g. water, people or stock) or it can include an array of multiple cells. Multi-cell culverts are usually preferred over a single cell with shelf.

A significant challenge in multi-use culverts is standing water, which often occurs due to poor design, construction and/or maintenance (see **Photo 47** and **Photo 48**). Culverts that contain permanent water or water for many weeks of the year are less preferred by terrestrial wildlife than culverts which are dry or mostly dry for most of the year. Culverts intended for terrestrial fauna passage must be positioned well above peak water flow height and base level of any adjacent aquatic or amphibian culvert (see example in **Photo 44**). They must not receive, or be connected to, any road drainage.

The effectiveness of multi-use culverts for wildlife and people or stock depends upon the frequency and timing of use by both groups. For example, a culvert for a shared use path in a residential area is unlikely to function effectively for most wildlife because of the presence of people throughout much of the day, especially dawn and dusk.

Photo 43 Multi-use culverts can provide connectivity for two or more functional fauna groups (such as the threatened southern brown bandicoot and growling grass frog) (Source: Dan Weller)

In contrast, culverts on rarely used walking trails in more remote or regional areas may perform satisfactorily for wildlife if there are few walkers. However, there is insufficient data to identify compatible rates of use of crossing structures by people, and thus most recommendations indicate human use should not be combined with intended use by wildlife, especially for sensitive species (Clevenger and Waltho 2000, Denneboom *et al*. 2021, Van der Grift and van der Ree 2015b) Similarly, culverts used occasionally by stock (e.g. less than approximately once per week) may function satisfactorily for less sensitive species of wildlife.

Design requirements to facilitate terrestrial fauna movement and ecological connectivity are detailed in **Table 3.7**, illustrated in **Figure 16**, **Figure 17**, and **Figure 18** (concept diagrams) and key concepts communicated in a virtual render of an example structure (**Figure 19**).

Photo 44 Multi-use culvert for terrestrial small mammals (left) and amphibian (right) passage (VIDA Roads Healesville-Koo Wee Rup Road Upgrade project (Source: Austin O'Malley, VIDA Roads)

Table 3.7 Multi-use culvert design requirements for ecological connectivity and safe passage

Design aspect	Specifications and considerations
Target species	– Proven for most terrestrial wildlife, including macropods, koala, small terrestrial mammals, reptiles and fish. – Potentially effective for amphibians. – If large enough and with appropriate furniture, target species can include arboreal species, birds and microbats.
Design, dimensions and construction materials	1. Multi-use culverts can be a single cell or multiple cells. a. Multiple cell culverts are the preferred method to incorporate terrestrial and aquatic fauna or drainage. b. Single cell multi-use culverts should only be used if space or landscape constraints mean multiple cell culverts are not feasible. 2. Multi-use culverts should be as wide and tall as possible. This is best achieved using square or rectangular culverts (i.e., box culverts or slab-linked box-culverts). Pipe culverts are not acceptable as culverts intended for wildlife movement. 3. Minimum culvert height and width depend on the target species. 4. Culverts must be straight and as short as possible and should allow unobstructed views to the other side. **Multiple-cell multi-use culverts**: 5. An array of culverts comprising a combination of terrestrial, aquatic, amphibian and/or drainage culverts. 6. Terrestrial culverts should be positioned on the outside of the array, and the aquatic, amphibian or drainage culvert(s) positioned in the centre of the array, so that the middle cell is the focus for water flow and the outer cells remain dry. a. Terrestrial culverts should meet requirements described in **Section 3.4.1**. b. Aquatic culverts should meet requirements described in **Section 3.4.2**. c. Amphibian culverts should meet requirements described in **Section 3.4.3**. 7. Implement design or structural features to allow the ingress of natural light and airflow. Options to allow the ingress of natural light into culverts (separate carriageways and light wells) are described in **Sections 3.4.1, 3.4.2** and **3.4.3**. 8. Single cell multi-use culverts: 9. A single culvert with the primary purpose of conveying water (usually a drainage or aquatic culvert), in a location that is also likely to be used by terrestrial fauna. a. Aquatic culverts should meet requirements described in **Section 3.4.2**. b. Amphibian culverts should meet requirements described in **Section 3.4.3**. 10. Install a dry passage option for terrestrial fauna. Dry passage requirements: a. Can be a ledge, shelf or alternative structure that provides equivalent dry passage, installed on both culvert walls. b. Must connect to terrestrial habitat at both ends. c. Made from non-biodegradable material (e.g. concrete, recycled plastic). d. Minimum 500 mm wide, ideally 1 m wide subject to hydrological constraints. Minimum 600 mm clearance from the culvert ceiling for smaller animals (e.g. koala, echidna) and at least 1.8 m for larger animals (e.g. kangaroo). e. Height to be as close to the natural ground level as possible while achieving dry passage most of the time (set above the 1:10 year flood level if practicable). f. Under typical flows, dry passage should be possible for 90% of the time. 11. Implement design or structural features to allow the ingress of natural light and airflow. Options to allow the ingress of natural light into culverts (separate carriageways and light wells) are described in **Sections 3.4.1, 3.4.2** and **3.4.3**.

Design aspect	Specifications and considerations
Landscape position and fencing	12. The position and spacing of culverts depend on the target species and the location of intersecting habitat and/or wildlife corridors. Culverts for species with a small home range may need to be every few hundred metres, while culverts for species with larger home ranges may only need to be every few kilometres. Project-level connectivity analysis is required to determine and justify spacings and frequency of crossing structures and other supporting design features like fencing if deemed required. 13. Avoid potential barriers across or near to culverts, such as farm fences, access roads or railways. 14. The placement of multi-use wildlife culverts will be influenced by the multiple uses. In all cases, placement should consider and attempt to maximise use by all uses (e.g. drainage, stock, people and wildlife). 15. Install fencing to funnel the target species to the culvert wherever there is a risk that the target species may access the road. The length of fencing is site- and species-dependent. Refer to **Section 4** for guidance.
Landscaping and vegetation	16. The waterway channel should be maintained as natural as possible. 17. Any channel section diverted/reprofiled/created must be rebuilt as close to its natural form as possible including allowing for natural features (vegetation, rocks, and coarse woody debris) to be present. 18. Banks upstream and downstream that are disturbed as part of the works must be reprofiled to be consistent with existing and banks must be revegetated with locally appropriate riparian vegetation. If existing banks are highly disturbed, then reprofile and revegetate to improve conditions. 19. Vegetation suitable for the target species must be planted at the culvert entrance to encourage wildlife to use the structure, in accordance with **Section 7.2**. 20. If erosion or scour control is necessary: a. Minimise scour protection at culvert entrances as this inhibits movement of terrestrial wildlife and can create traps/ barrier for fish movement during low flow periods. If scour protection is required, use concrete or small rocks instead, or place small rock fill over larger rocks to fill all gaps between rocks. Small piles of large rocks (e.g. greater than 30 cm diameter) are generally beneficial for amphibians as they provide inter-rock shelter spaces. b. Ensure there is a clear passage end-to-end, with no pools or puddles that can entrap fish. c. Any very large rocks should be embedded into the channel bed to prevent water pooling beneath and trapping fish. d. Scour protection should be placed at or below bed level and not extend more than 20 m upstream and or downstream of the structure. Scouring and perching at the entrance or exit of the culvert should be avoided. 21. Multiple-cell multi-use culverts: a. For terrestrial culvert cells, add topsoil over rock beaching (scour protection) to create a smooth level surface for animals to move over, particularly where smaller animals (such a bandicoots) are being targeted. b. Ensure rock beaching and landscaping is level with the culvert floor (or concrete apron where applicable) and no step is created for animals moving between the roadside surface/habitat/drainage swale and the culvert concrete floor.

Design aspect	Specifications and considerations
Furniture to encourage use and reduce the risk of predation	22. If the combined use is drainage, any furniture that is not permanently attached will be washed away. Scattered large rocks in outer cells can be concreted into the floor of the culvert. Furniture should not present a blockage risk or significant impediment to water flow during flooding. 23. If the culvert is to accommodate terrestrial fauna, include appropriate fauna furniture as required for a terrestrial culvert (**Section 3.4.1**). 24. If the culvert is to accommodate aquatic fauna, include appropriate enhancements as required for an aquatic culvert (**Section 3.4.2**). 25. If the culvert is to accommodate amphibians, include appropriate furniture and enhancements as required for an amphibian culvert (**Section 3.4.3**).
Lighting	26. No artificial lighting within 100 m of culverts. 27. Where lighting is required to meet safety standards: a. Ensure lighting is the lowest intensity possible. b. Avoid use of lights within the blue, violet and ultraviolet wavelengths. c. Use light shields to prevent light spill into adjacent habitat, underpass entrances and light wells.
Maintenance	28. Inspections to assess the structural integrity of culverts should be conducted at the same frequency as for culverts described in *Road Structures Inspection Manual* (VicRoads 2022). 29. Inspections to assess the ecological condition of the culverts must be conducted annually. Frequent inspections are necessary to ensure structures are performing their ecological function. Any significant failures (those that prevent use by target species) must be rectified within four weeks of inspection. Ecological failure of a structure could result in loss of ecological connectivity for potentially long periods of time, which could have severe consequences for local wildlife. 30. Inspections must be conducted by an ecologist experienced in the assessment and design of FSRD and should form part of the monitoring and evaluation program (**Section 8.4**).
Monitoring	31. Develop and implement a performance evaluation plan, in accordance with **Section 8.4**.

Photo 45 A multi-use type crossing design for threatened Southern Brown Bandicoots (small marsupial) and Growling Grass Frog (amphibian) on the VIDA Roads Healesville-Koo Wee Rup Upgrade project. Note gabion basket ramps and terrestrial ledge on outside culverts. (Source: Austin O'Malley, VIDA Roads)

3.4.5. Incidental-use culverts

Incidental-use culverts are primarily designed for other purposes, usually drainage, and to a lesser extent people or stock. However, there are many minor and low-cost modifications that can make them suitable for some wildlife. Incidental-use culverts can be of any design-box, arch or pipe, and single or multi-cells. Incidental-use culverts are essentially at the lowest end of multi-use culverts and offer a cost-effective approach to increasing connectivity for wildlife when only incidental use is satisfactory.

The primary consideration with incidental-use culverts is to ask: is it important that this culvert is used by wildlife? If the answer is yes then it should be a terrestrial culvert, an aquatic culvert or a multi-use culvert. Nevertheless, wherever possible, drainage structures should be designed to also allow incidental movement of wildlife using the numerous design considerations outlined for other culvert types.

Sugar Glider, Dean Ingwersen

Diamond Firetail, Dean Ingwersen

Photo 46 Aquatic and terrestrial passage accomodated for by multi-use box culvert array (Source: Austin O'Malley)

Photo 47 Drainage culvert at Ettamogah provides incidental movement opportunities for wildlife (Source: Rodney van der Ree, WSP)

Photo 48 Drainage and ponding reduce culvert effectiveness; pipe culverts aren't ideal for fauna movement. (Source: Rodney van der Ree, WSP)

Photo 49 Drainage and ponding, as per photo 48 left (Source: Scott Watson)

Photo 50 Slab-link multi-use culverts on the Pacific Highway NSW. Middle cell designed to take water year-round, outer cells remaining dry except during flood events (Source: Rodney van der Ree, WSP)

Photo 51 Slab-link multi-use culverts as per photo 50 (Source: Rodney van der Ree, WSP)

Photo 52 Example of strategies that provide dry passage if the culvert contains standing or flowing water (Source: Rodney van der Ree, WSP)

Photo 53 Dry passage as per photo 52 (Source: Rodney van der Ree, WSP)

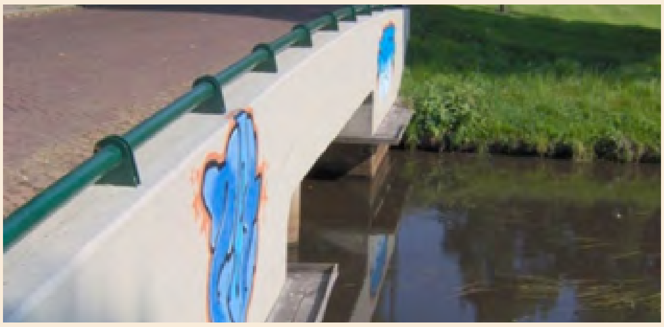
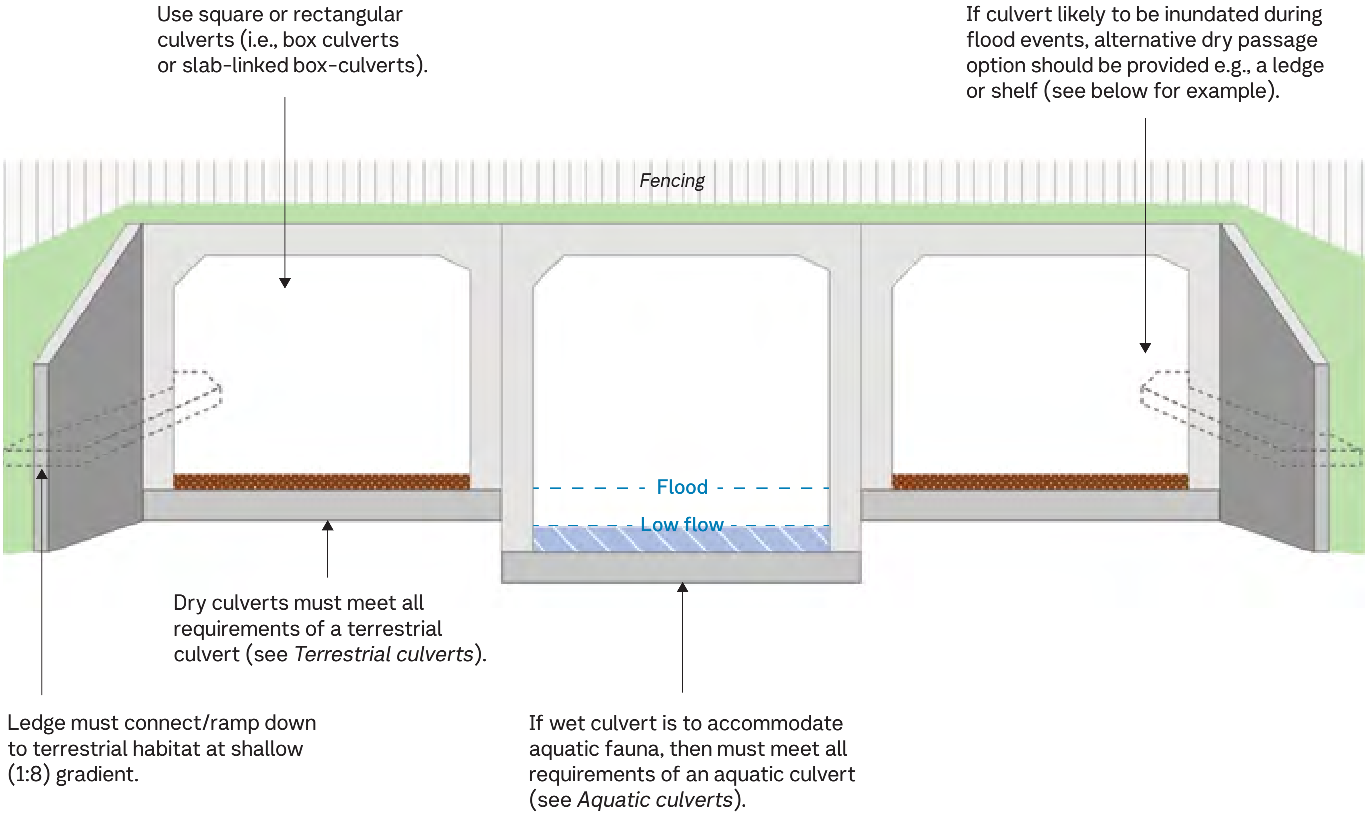


Figure 16 Multi-use culvert design (3)

MULTIPLE CELL MULTI-USE CULVERT

Terrestrial culverts should be positioned on the outside of the array, and the aquatic, amphibian or drainage culvert(s) positioned in the centre of the array, so that the middle cell is the focus for water flow and the outer cells remain dry.



SINGLE CELL MULTI-USE CULVERT

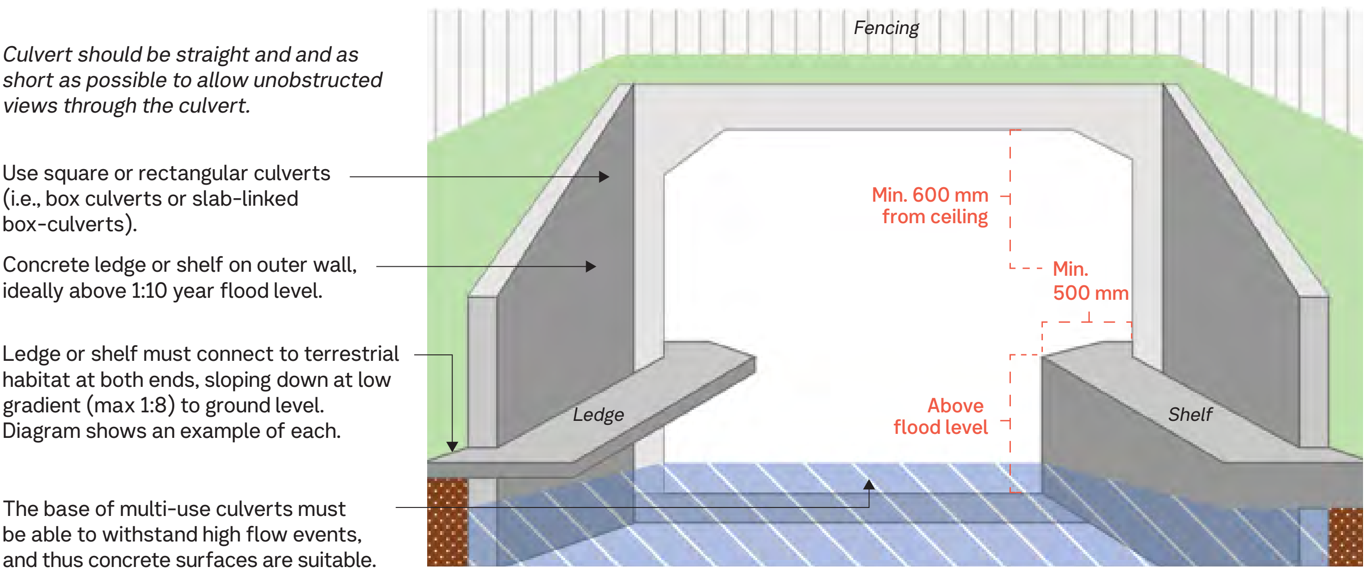


Figure 17 Virtual render of a multi-use culvert crossing design

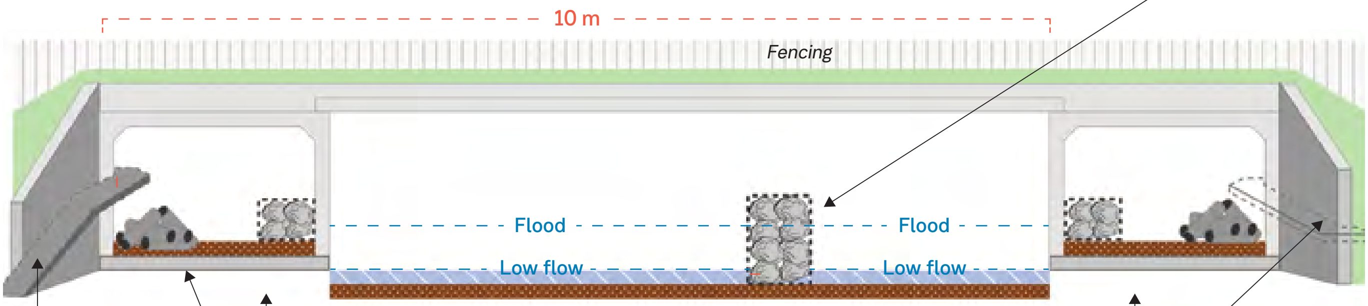
Example: Growling Grass Frog and Southern Brown Bandicoot

Diagrams show an example of a multi-use culvert designed for Growling Grass Frog and Southern Brown Bandicoot. Always refer to current policy to ensure that culverts meet any updated state or federal standards. Ensure culverts meet specific requirements included in state or federal approvals. Always consult with an ecologist to ensure culverts meet specific requirements for the target species.

CROSS-SECTION FRONT VIEW

Combination of wet and dry culverts for Growling Grass Frog (required minimum total width of 10 m). See *Amphibian culverts* for detailed requirements.

Include amphibian shelter in dry and wet culverts.



Ledge must slope (1:8 maximum gradient) down to ground surface.

Non-biodegradable bandicoot shelters placed every 5 m within culvert.

Dry culverts for Southern Brown Bandicoot on outside of culvert array. See *Terrestrial culverts* for detailed requirements.

If the dry culvert is likely to be inundated during flood events, include an alternative dry passage ledge option for Southern Brown Bandicoot.

CROSS-SECTION SIDE VIEW

Combination of wood and non-biodegradable bandicoot shelters at entrance to dry culvert. Shelters and rocks must not block the culvert entrance.

Shelter for amphibians runs full length of culverts.

Revegetation and habitat features to suit Growling Grass Frog.

Non-biodegradable bandicoot shelters placed every 5 m within culvert.

Revegetation and habitat features to suit Southern Brown Bandicoot.

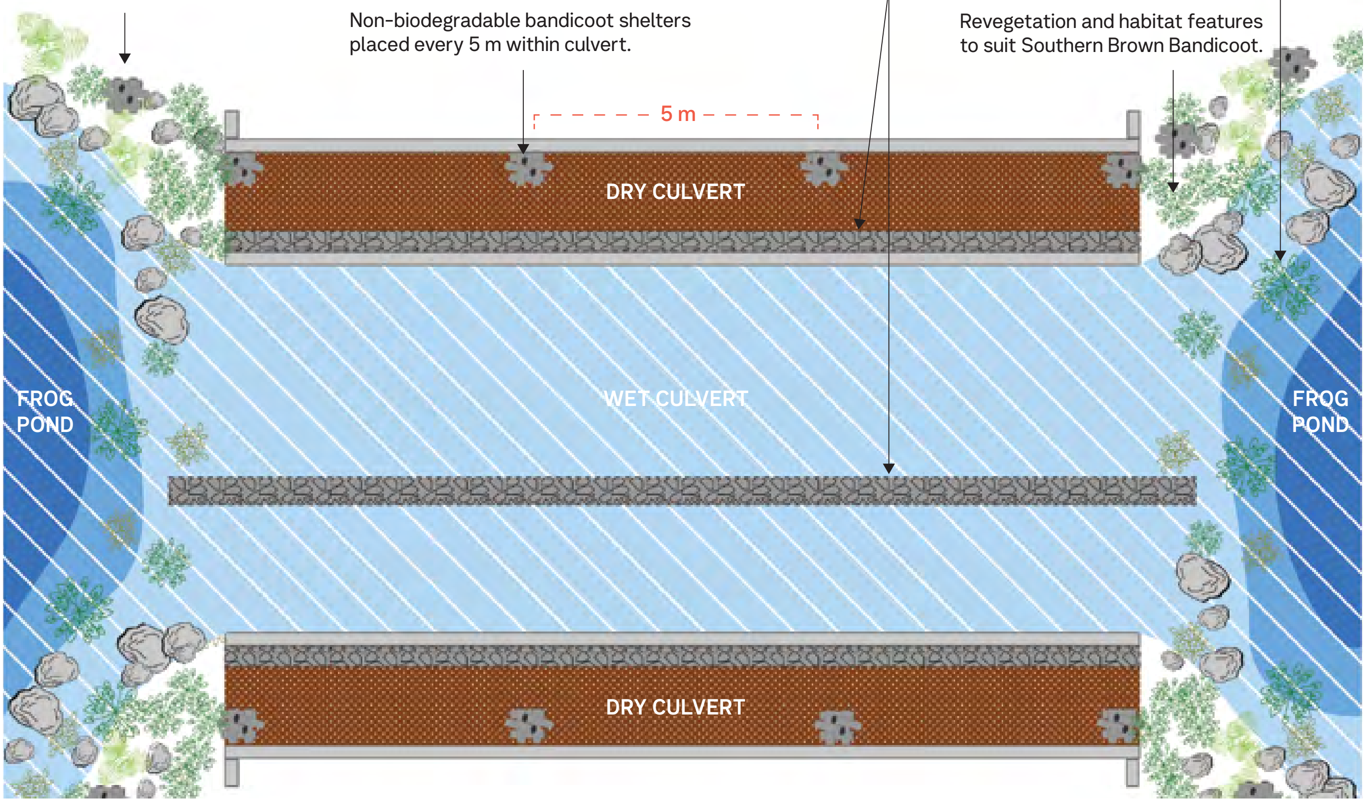
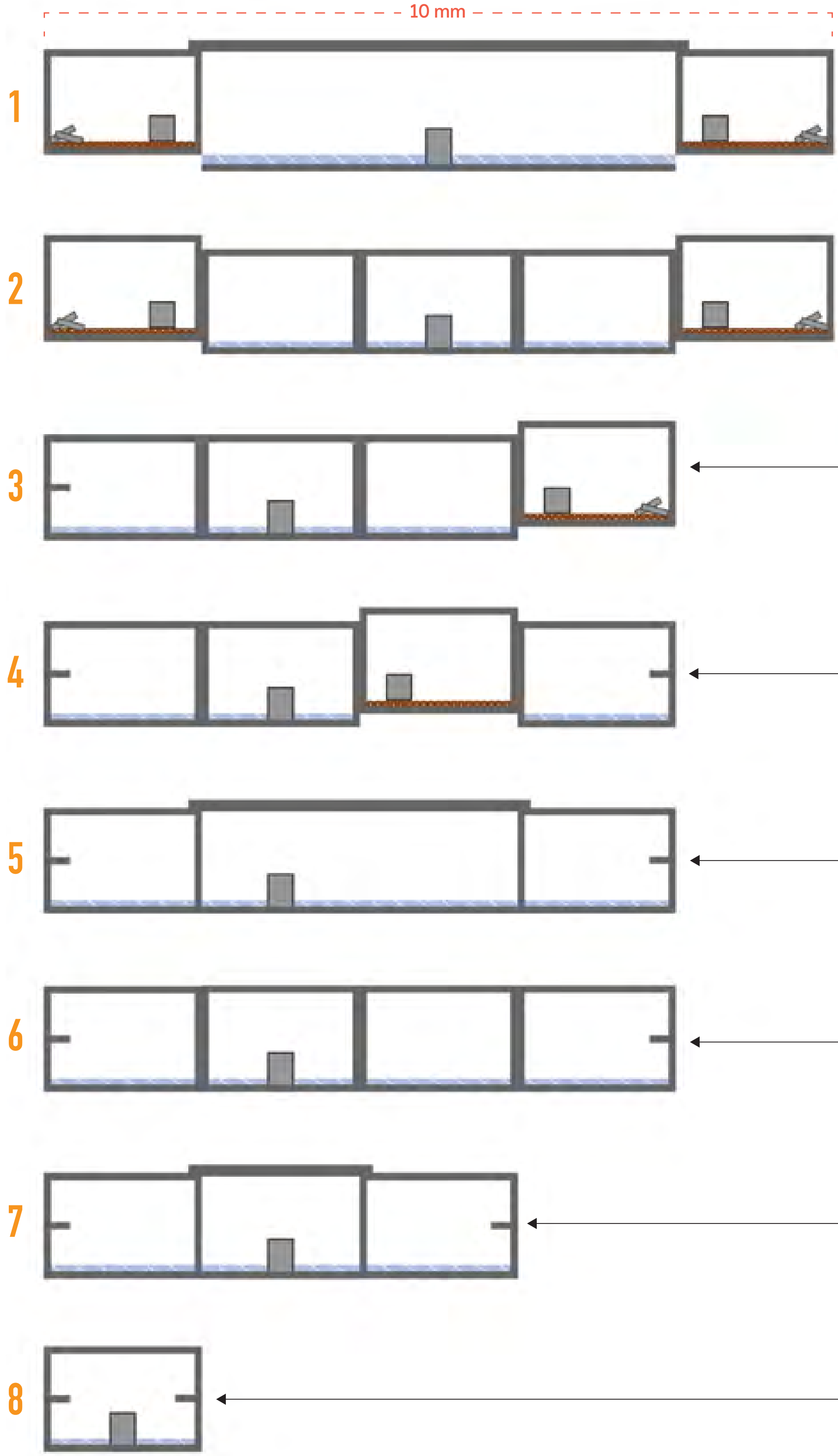


Figure 18 Multi-use culvert design (3)

Potential configurations for Growling Grass Frog and Southern Brown Bandicoot



1. Suitable for Growling Grass Frog. Suitable for Southern Brown Bandicoot.

2. Suitable for Growling Grass Frog. Suitable for Southern Brown Bandicoot.

3. Suitable for Growling Grass Frog. Partially suitable for Southern Brown Bandicoot on one side (bank) only – may limit connectivity (low-moderate likelihood of occurrence areas only).

4. Suitable for Growling Grass Frog. Not suitable for Southern Brown Bandicoot.

5. Partially suitable for Growling Grass Frog. Not suitable for Southern Brown Bandicoot.

6. Partially suitable for Growling Grass Frog. Not suitable for Southern Brown Bandicoot.

7. Partially suitable for Growling Grass Frog (low-moderate likelihood of occurrence areas only). Not suitable for Southern Brown Bandicoot

8. Not suitable for Growling Grass Frog or Southern Brown Bandicoot.

Refer to current policy to ensure that culverts meet any updated state or federal standards. Ensure culverts meet specific requirements included in state or federal approvals. Always consult with an ecologist to ensure culverts meet target species and site-specific requirements.

Figure 19 Virtual render of a multi-use culvert crossing design

The above conceptual design (**Figure 19**) shows (top image) three central dedicated box-cell culverts inundated with water for aquatic and amphibian fauna passage and one elevated (dry) side box cell on either side for terrestrial fauna. Note how both the terrestrial culvert and dry passage gabion wall ledge is level with and connecting to waterway embankments. Also incorporated are FSRD features (centre image) including a) ramped gabion walls in a central box cell for amphibians and fish; b) side gabion wall ledges in adjacent cells for both amphibians and terrestrial fauna dry passage during peak flows; and (bottom image) integration of c) fauna exclusion fencing and plantings up to terrestrial culvert entrance.

See **Photo 45** for an example of this design in built form.

3.5. Fishway

Fishways, also referred to as fish ladders, fish ramps and fish elevators, are any structure placed on or around barriers such as dams or weirs to enable fish movement.

Fishways are effective in improving access for fish and other aquatic organisms around structures in waterways that create barriers to fish movement (Amtstaetter *et al*. 2017, O'Connor *et al*. 2017). Ongoing trials and research can assess and improve the effectiveness of these structures and ensure that waterway connectivity for Australian fish continues to improve (Harris *et al*. 2016).

These structures also help address significant changes in elevation in and out of crossing structures, such as culverts.

Table 3.8 Fish ladders, fishways, elevators and ramps — ecological design requirements

Design aspect	Specifications and considerations
Target species	Effective for all fish species, macroinvertebrates and other aquatic and semi-aquatic species (platypus, turtles).
Design, dimensions and construction materials	1. The structure needs to account for a range of fish that may be small (20–100 mm) to medium-large (100–1400 mm) bodied fish. The requirements will vary dependent on the type and structure used at the specific location. 2. Design requirements to facilitate movement and safe passage are highly dependent on the target species, the requirements of those species to move and the space available for the structure. The project will need to consult with a specialist to establish the following:** a. Hydraulic performance (velocity, turbulence and related requirements). b. Physical performance (ecological and fish passage objectives). 3. Additional considerations include areas of rest and refuge within the fishway, the direction of migration, the flow requirements during these stages. 4. Minimum depth of water should be maintained while the fishway is functional (0.3 m–1 m depth) ** Recommended design requirements should be set in accordance with Table 2, 3 and 4 of Performance, operation, and maintenance guidelines for fishways and fish passage works (O'Connor *et al*. 2015).
Landscape position and fencing	5. Fishways bypass the road or other barrier, and thus fencing for fish are not required. However, fishways may be useful for turtles, platypus and rakali, and should be considered for these species. If fencing is used, it should be designed to withstand flooding and minimise debris becoming lodged in the fencing and obstructing water flow.

Design aspect	Specifications and considerations
Landscaping and vegetation	6. Where possible the channel should be maintained as natural as possible. 7. Any channel section diverted/ reprofiled/ created should be rebuilt to be as natural as possible allowing for natural features (vegetation, rocks, and coarse woody debris to be present). 8. Banks upstream and downstream disturbed as part of the works should be reprofiled to be consistent with existing and banks must be revegetated with locally appropriate riparian vegetation. 9. Vegetation plantings should: a. meet the habitat requirements for the target fauna species or groups (including plant species, structure, and form) and; b. be composed of native species matching the locally indigenous Ecological Vegetation Classes (EVC) and any adjacent remnant native vegetation (species composition and structure), providing a continuation of the natural landscape and habitats. c. use locally sourced indigenous stock wherever possible. d. include (where possible) trees that will grow to provide natural shade and reduce sun exposed section near the concreted structure to help reduce water temperatures.
Enhancements to encourage use	10. Natural/ local materials consistent with bed materials where available. 11. Large woody debris can be an added benefit by creating suitable habitat and encourage species to access and utilise the crossing structures (must consider placement and risk of woody debris becoming an obstruction).
Lighting	12. Artificial lighting around fishways should be avoided. 13. Abrupt changes in light conditions may create a behavioural barrier for fish. Projects should seek expert advice if such structures are being considered.
Maintenance	14. Inspections to assess the ecological condition of the structure must be conducted annually or after extreme flood events. Frequent inspections are necessary to ensure structures are performing their ecological function. Any significant failures (those that prevent use by target species) must be rectified within four weeks of inspection. Ecological failure of a structure could result in loss of ecological connectivity for potentially long periods off time, which could have severe consequences for local wildlife. 15. Fishway should be de-watered annually for a full inspection to assess structural integrity. De-watering should only occur during non-migratory and or non-spawning periods (e.g. Dwarf Galaxias spawning occurs August to September). Site and species requirements should be confirmed prior to any work.
Monitoring and performance evaluation	16. Develop and implement a performance evaluation plan, in accordance with **Section 8.4**.
Temporary structures	17. Ensure works are undertaken in accordance with EPA Publication 275 — Construction Techniques for Sediment Pollution Control. 18. Where possible, channels should not be blocked or diverted (e.g. bypass pumping). Use of bund around area of work is recommended to maintain channel connectivity. 19. Ground disturbance should not occur during periods of heavy rain fall, to limit direct sedimentation into the waterway. 20. Considerations for seasonally important periods should be considered when planning and commencing construction (i.e. if the waterway is blocked during the annual migration period this may directly impact the viability of that cohort of fish in that waterway).

Design aspect	Specifications and considerations
Temporary structures	21. Disturbed bank and bed sediments should be exposed only for short periods. Temporary sediment controls and replanting should commence as soon as practically possible. 22. If temporary pads are required to access the middle of the waterway channel the fill material used should be natural and not recycled waste concrete and or asphalt in case material is not completely removed. 23. Ground disturbance should not occur during periods of heavy rain fall, to limit direct sedimentation into the waterway. 24. Considerations for seasonally important periods should be considered when planning and commencing construction (i.e. if the waterway is blocked during the annual migration period this may directly impact the viability of that cohort of fish in that waterway). 25. Disturbed bank and bed sediments should be exposed only for short periods. Temporary sediment controls and replanting should commence as soon as practically possible. 26. If temporary pads are required to access the middle of the waterway channel the fill material used should be natural and not recycled waste concrete and or asphalt in case material is not completely removed.

Murray Cod

Photo 54 Example of fishway constructed in Werribee Park (Source: Pam Clunie, Arthur Rylah Institute)

Photo 55 Fishway, Coburg Lake, Victoria (Source: Clio Gates Foale, VIDA Roads)

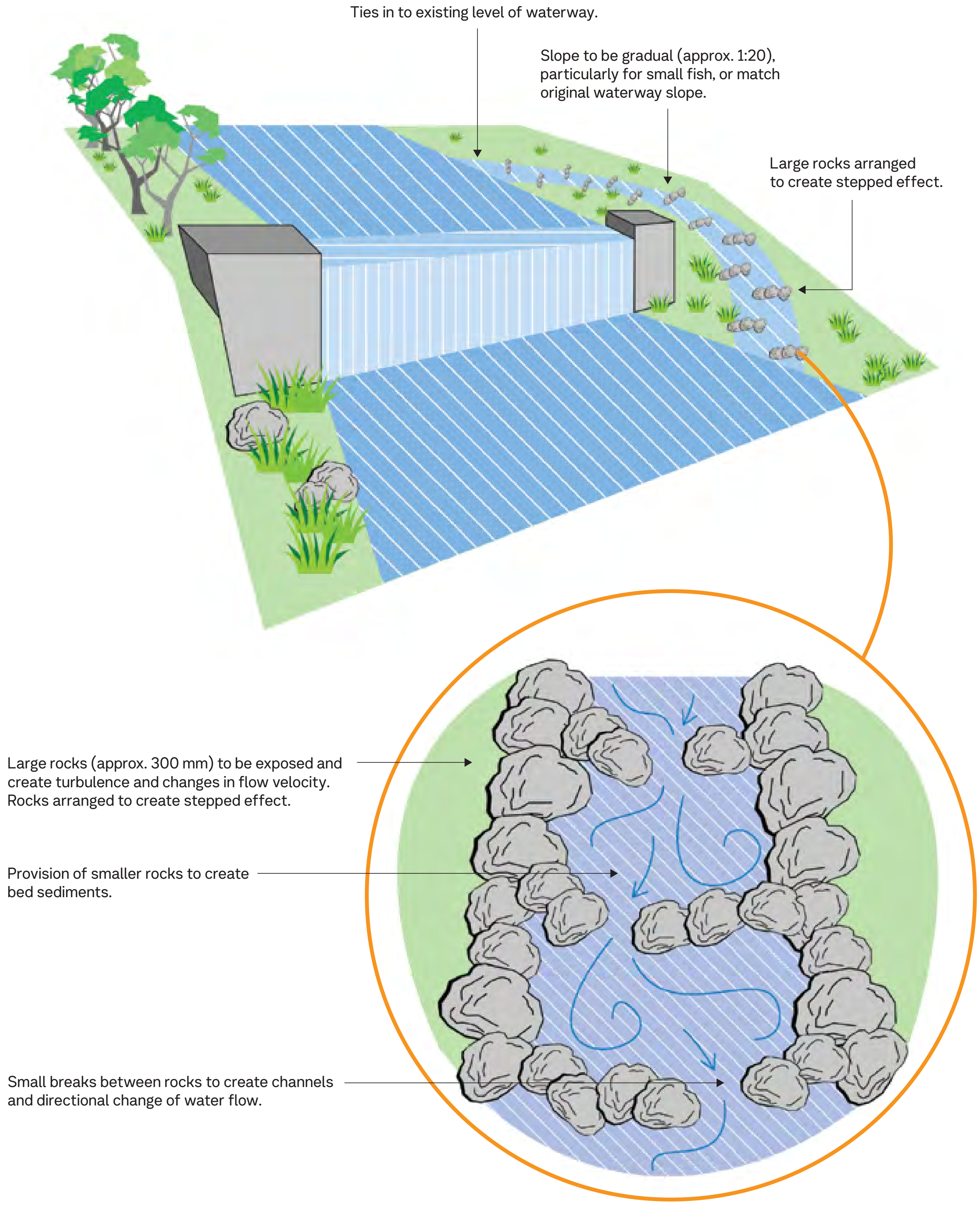
Photo 56 Fishway, Coburg Lake, Victoria (Source: Clio Gates Foale, VIDA Roads)

Photo 57 Fishway on Darebin Creek, Melbourne (Source: Pam Clunie, Arthur Rylah Institute)

Photo 58 Fishway, Slacks Creek, QLD (Source: Craig Chargulaf, ARUP)

Figure 20 Example fishway design

High-level example of features that might be required when creating a fishway



3.6. Land bridge

Vegetated land bridges are one of the most effective techniques to facilitate the movement of wildlife across roads. Land bridges are planted with native vegetation that blends in with the surrounding vegetation, providing a (seemingly) natural pathway for wildlife to cross above a road. Land bridges have the added benefit of providing habitat for wildlife and facilitating natural biodiversity and ecosystem processes. Land bridges include bridges, bored tunnels and cut and cover tunnels.

Vegetated land bridges have been shown to facilitate the movement of terrestrial animals, including macropods, koalas, arboreal mammals, birds and bats. There are currently three vegetated land bridges installed on the Pacific Highway in northern NSW, two in the suburbs around Brisbane, Queensland — all of which have shown high levels of wildlife use. Additional land bridges are being built in NSW and Queensland.

The land bridge over Compton Road in Brisbane (**Photo 60**) has been monitored regularly since its construction in 2005 and a diverse suite of taxa now regularly use the land bridge, including terrestrial and arboreal mammals, birds, reptiles and invertebrates (Bond and Jones 2008; Jones and Pickvance 2013; McGregor *et al*. 2015; Taylor and Goldingay 2010). The bridge has also been shown to minimise the road effect zone, facilitate activity of and provide habitat continuity for some Australian microbats (Mc Gregor *et al*. 2017).

To date, vegetated land bridges are the only type of overpass which have shown evidence of use by koalas. Recent evidence shows that koalas use the Compton Road bridge on a frequent and regular basis (Darryl Jones, unpublished data). A land bridge in Ellenbrook near Perth WA has recently been used by emus to cross the Tonkin Highway.

Design requirements to facilitate safe movement of fauna and ecological connectivity are detailed below in **Table 3.9** and illustrated in **Figure 21** (concept diagram) and **Figure 22** (virtual render).

Table 3.9 Land bridge — design requirements for ecological connectivity and safe passage

Design aspect	Specifications and considerations
Target species	– Proven for all groups of terrestrial wildlife, including macropods, koala, small terrestrial mammals, reptiles, amphibians and invertebrates, arboreal species, birds and bats.
Design, dimensions and construction materials	1. The land bridge should be as wide as possible, and ideally, sufficiently wide to support the creation of a continuous vegetated corridor **30–40 m in width** (e.g. **wildlife zone**) along the entire length of the structure and connecting to habitat to either side of the structure. No other infrastructure should be placed within the vegetated corridor and care should be taken to ensure there are (eventually) no gaps in habitat or barriers to movement. 2. No other human-related infrastructure should be accommodated/placed/designed into the land bridge e.g. pedestrian paths, bike trails, or equestrian trails. The land bridge is for wildlife only.[14] 3. Soil depth is related to the vegetation type of the target species, with a minimum depth of 1.5 m to 2 m required for trees. 4. Gently graded vegetated ramps/approaches, ideally 5H:1V. Approaches can be steeper where protection of adjacent vegetation is required, up to approximately 3:1, depending on target species. 5. Approach ramps should be hourglass or funnel-shaped to encourage wildlife to access and enter the overpass. 6. Construction method depends on topography (i.e., if road is in a cutting or at grade), the length of the span and can include pre-cast concrete arches, cut and cover tunnels, or concrete bridges. The structure must be able to support sufficient soil depth to support mature vegetation including trees (including at times of waterlogging). 7. If drainage channels are required parallel to the road and across the entrance to the bridge, the channel should be connected via a pipe beneath the bridge entrance to minimise disruption to access. If an open swale structure is unavoidable the location should not fill with water for extended periods that will restrict access to the land bridge and/or dry access should be provided across the channel.

[14] Dual-use of land bridges is highly problematic for a number reasons. Firstly, many fauna are highly sensitive to human activity and will avoid areas or change their behaviour in response to it. Secondly, many of the features that are required for other uses are incompatible with wildlife use, such as lighting requirements for pedestrian paths. Thirdly, other uses are highly likely to degrade the habitat values within the wildlife zone.

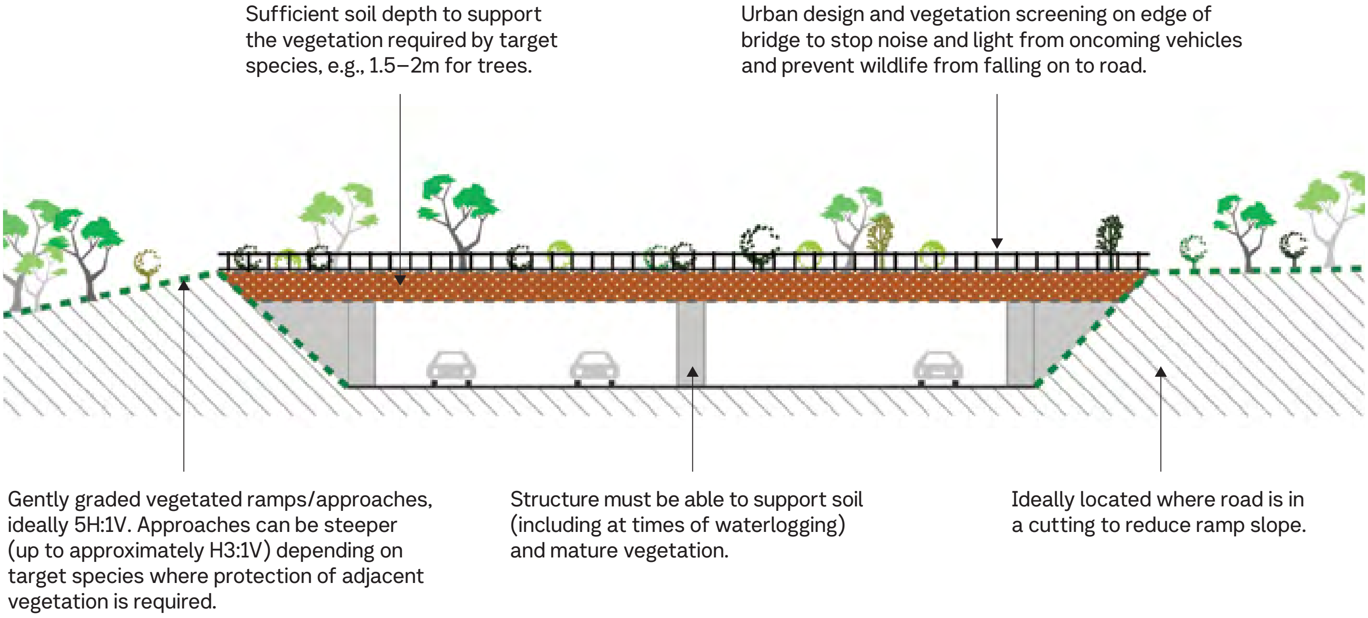
Design aspect	Specifications and considerations
Landscape position and fencing	8. Land bridges are most cost-effective at locations where the road is in a cutting. They can be built where the road is at-grade or slightly above grade, however this is more expensive and the approach ramps will extend further, requiring more land and potentially more clearing of adjacent vegetation. 9. Land bridges should be built where native vegetation/habitat for the target species occurs (or can be established) on both sides of the road. 10. The position and spacing of land bridges depends on the target species/fauna groups, extent and quality of habitat, regional connectivity needs and topography/construction constraints and opportunities. Land bridges are typically reserved for the highest priority locations to benefit high priority/multiple species, fauna groups and ecological communities and where the topography enables construction of land bridges. 11. Avoid potential barriers that may limit access to the land bridge, such as farm fences, access roads or railways. 12. Install fencing to funnel the target species to the bridge wherever there is a risk that the target species may access the road. The length of fencing is site- and species-dependent. Refer to **Section 4** for guidance. **Note**: Wildlife fencing may not be required if the land bridge offers an attractive alternative to attempting to cross a road at grade and the adjacent sections of road are on steep or tall abutments that prevent use. However, in most cases, fencing is required and should be implemented from a precautionary approach.
Landscaping and vegetation	13. Vegetation must be planted on and leading up to the bridge to encourage wildlife to use the structure, in accordance with **Section 7.2**. In addition: a. Allow vegetation adjacent to the road to grow to the land bridge, providing seamless transition from adjacent habitat to structure. b. Include different bands of habitat across the bridge (e.g. one side forested, the other more open grassland) to suit a diversity of target species. 14. Use urban design screening and/or vegetation screening on edge of bridge to stop noise and light from oncoming vehicles and prevent wildlife from falling off bridge. Soil berms are not recommended due to the additional weight and the extra space they occupy, compared to screens.
Furniture to encourage use and reduce the risk of predation	15. Strategically place artificial shelters such as wood debris piles (see **Photo 102** and **Photo 105; Section 7**), constructed shelters (e.g. Southern Brown Bandicoot hide, **Photo 104** and **Photo 108; Section 7**) or natural features such as logs, rock jumbles, piles of brush and woody debris that suit the target species on the bridge to provide natural cover/shelter from predators and improve habitat suitability. Similar materials can be used on the approach to the bridge to prevent unauthorised vehicle access. 16. Use a combination of wooden and non-biodegradable artificial shelters, in accordance with **Section 7.3**. 17. Additional structures can be installed on land bridges to facilitate movement of arboreal mammals: a. Canopy bridges (see **Section 3.7**). b. Glider poles (see **Section 3.8.1**). c. Elevated horizontal logs for arboreal mammals or koala rails (**Section 7.3.3**). d. Refuge poles with resting platforms to provide koalas refuge from dogs (see **Section 7.3.3**). e. Horizontal logs for small mammals (see **Section 7.3.3**). 18. Shallow waterbodies, wetlands or frog ponds can be installed across the land bridge and at either side of the land bridge to encourage frogs to move over the structure.

Design aspect	Specifications and considerations
Lighting	19. No artificial lighting on or within 100 m of land bridge or approach ramps. 20. Where lighting on adjacent roads is required to meet safety standards: a. Ensure lighting is the lowest intensity possible. b. Avoid use of lights within the blue, violet and ultraviolet wavelengths. c. Use light shields to prevent light spill onto the land bridge and into adjacent habitat.
Maintenance	21. Inspections to assess the structural integrity of land bridges should be conducted at the same frequency as for bridges described in *Road Structures Inspection Manual* (VicRoads 2022). 22. Inspections to assess the ecological condition of the land bridge must be conducted annually. Frequent inspections are necessary to ensure structures are performing their ecological function. Any significant failures (those that prevent use by target species) must be rectified within four weeks of inspection. Ecological failure of a structure could result in loss of ecological connectivity for potentially long periods of time, which could have severe consequences for local wildlife. 23. Inspections must be conducted by an ecologist experienced in the assessment and design of FSRD and should form part of the monitoring and evaluation program (**Section 8.5**).
Monitoring and performance evaluation	24. Develop and implement a performance evaluation plan, in accordance with **Section 10.5**.

Eltham Copper Butterfly, Dan Weller

Figure 21 Land bridge wildlife crossing design

CROSS-SECTION VIEW



AERIAL VIEW

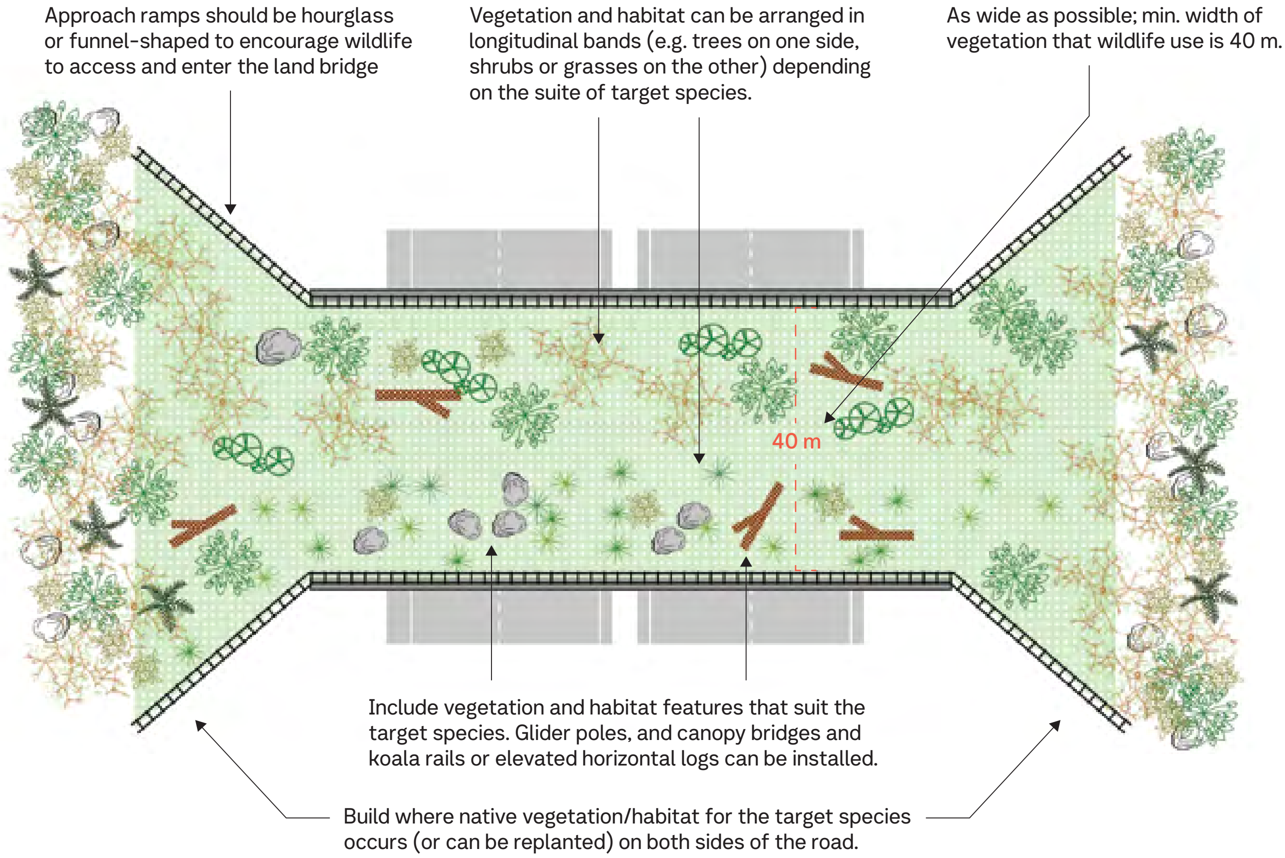


Photo 59 Yelgun Landbridge on the Pacific Hwy, NSW (Source: Rodney van der Ree, WSP)

Photo 60 Compton Road land bridge, Brisbane (Source: Rodney van der Ree, WSP)

Photo 61 Land bridge in France showing noise and light screens and different habitats for different species, i.e., a row of tree stumps, short grass down the centre and shrubs on both sides (Source: Rodney van der Ree, WSP)

Photo 62 Land bridge in Thailand. Note the approach on the right side of the land bridge is too steep, at close to 1:1 and should be closer to 5:1. (Source: Rodney van der Ree, WSP)

Photo 63 Compton Road land bridge, Brisbane, Queensland (Source: Nearmap Satellite imagery)

Photo 64 Zoomed in on Compton Road land bridge (Source: Nearmap Satellite imagery)

Figure 22 Virtual render of a land bridge wildlife crossing (super T bridge) with canopy bridge

Note in Figure 22 a canopy bridge for arboreal fauna extending across the structure facilitating movement until a tree canopy is fully established and integrated fauna exclusion fencing (top image); vegetated and treed land bridge crossing with shelter in the form of large logs, rocks, and debris piles (middle image); and canopy bridge extending to adjacent forest habitats (bottom image).

3.7. Canopy bridge

A canopy bridge is a structure, usually a rope-ladder design, that connects the canopy of trees together. While typically installed above roads, they can also be installed under road bridges or on vegetated land bridges (see **Figure 23**).

Canopy bridges are used for arboreal mammals, including the Brush-tailed Phascogale, Common Brushtail Possum, Eastern Ringtail Possum and smaller gliders (e.g. Krefft's Glider, formerly known as Sugar Glider in Victoria), the threatened Squirrel Glider, and occasional use by arboreal reptiles, such as goannas, has also been recorded (Goldingay and Taylor 2017a, Soanes *et al*. 2013, Soanes *et al*. 2018). One study on the Pacific Highway in northern NSW detected Yellow-bellied Gliders using a single canopy rope bridge (Geolink 2019).

In contrast, koalas have never been observed using canopy bridges, including a trial of different types of rope ladders (Goldingay and Taylor 2017b) and a single steel gantry structure near Brisbane (Jones *et al*., 2013). Alternative structures such as bridge underpasses and large terrestrial culverts with wooden rails are effective for this species (see **Sections 3.3 and 3.4.1**).

Design requirements to achieve ecological connectivity are detailed below in **Table 3.10** (over road) and **Table 3.11** (under road), and also illustrated in **Figure 24** (concept diagram) and **Figure 25** (virtual render).

The threatened Squirrel Glider using a canopy bridge on the Hume Fwy/Williams Lane, Violet Town, Victoria (Source: Rodney van der Ree, WSP)

Echuca-Moama Bridge Project

Table 3.10 Canopy bridge — design requirements for ecological connectivity and safe passage

Design aspect	Specifications and considerations
Target species	– Effective for arboreal and some semi-arboreal mammals, specifically small gliders (e.g. Krefft's Glider, Squirrel Glider) and possums, Antechinus, Feathertail Glider, Phascogale. – Potentially suitable for larger gliders (e.g. Yellow-bellied Glider, Greater Glider — but more research needed) and arboreal reptiles, such as goannas. – Not suitable for koalas.
Design, dimensions and construction materials	1. Canopy bridges should be a 450 mm wide rope ladder design, because it is more stable and less prone to twisting than single strands of rope. 2. Canopy bridges should be as short as possible while connecting large or hollow-bearing trees. Intermediate support posts may be required if the span exceeds 70–80 m. 3. 'Box' designs for rope bridges can be used but early monitoring showed possums and gliders walk along the top of the box, reducing the benefit of this extra cost (Bax 2006). However, current research suggests box-style bridges may be preferred by some species. Preliminary results of three months of monitoring two box-style bridges in Sydney show Eastern Ringtail Possums almost always use the inside of the box, while Common Brushtail Possums use both the inside and top of the box at similar rates (Tracey Russell, University of Sydney, unpub. data). More research is required. 4. Clearance above traffic lanes must be at least 8.5 m and ideally more, allowing a >2 m buffer above the minimum clearance on freeways (**Table 8.1** AustRoads Standard, and AS5100) and allows over-dimensional vehicles to pass. 5. **Rope ladder**: a. 12–15 mm diameter rope to be used for the ladder. Rope must be UV stabilized, such as marine-grade silver rope. b. Use two steel cables to span the gap, to which the rope ladder is attached with d-shackles. c. Steel cables should as taut as possible with minimal sag to minimise sway during wind. d. Steel cables should be attached to the cross arm with turnbuckles at both ends to enable tightening of the rope ladder if required. 6. **Support poles**: a. Support poles for canopy bridges above roads must be treated timber poles. b. Support poles for canopy bridges installed under road bridges or on land bridges can be timber poles or existing trees because there is no risk to traffic or pedestrians in case of failure. c. Use rough-sawn timber poles where possible and avoid steel poles and smooth timber poles because they are more difficult for an animal to climb. d. In most situations, poles need to be treated to prevent rot and termite damage. The cross-arm should be non-treated hardwood as this is where animals will spend most of their time. e. Support poles should not be used in medians without trees to prevent animals climbing down into the median. Support poles can be used in medians with trees. If a support pole is used in a median without trees, a cowl should be fitted to prevent animals climbing down into the median. f. Support poles can extend above the canopy bridge and be used as glider poles, providing they meet *all* the specifications for glider poles (see **Section 3.8**). g. Poles must be accessible for maintenance and/or installation of cameras or other monitoring equipment. Include hard stands at the base of poles and access behind guard rails to improve accessibility. h. If poles are at risk of vehicle collision, include protective barriers.

Design aspect	Specifications and considerations
	7. **Feeder ropes**: a. The ends of canopy bridges should be tied back with multiple feeder ropes to a minimum of two and preferably three or more large and/or hollow-bearing trees to increase access by wildlife. Single-Strand feeder ropes should never span clearings where there is a risk of mortality if wildlife fall off; in these situations, extend the rope ladder across the road or other dangerous setting. b. 40 mm diameter ropes to be used for the feeder ropes. Rope must be UV stabilized, such as marine-grade silver rope. c. Feeder ropes should not exceed 10–20 m in length. Where feeder ropes >20 m in length, move end pole of canopy bridge closer to trees, use a ladder instead of a single strand and/or plant trees to reduce the size of the gap between the end pole and existing trees. 8. Identify important access trees adjacent to the road during detailed planning and design of the project and ensure these are protected during construction.
Landscape position and fencing	9. Canopy bridges should be built wherever preferred habitat for the target species occurs or can be replanted on both sides of the road. 10. The position and spacing of canopy bridges depends on the target species. Bridges for species with a small home range may need to be every few hundred metres, while bridges for species with larger home ranges may need to be every few kilometres. 11. Install multiple canopy bridges (potentially including glider poles) because rates of use can vary significantly from structure to structure. 12. It is very difficult to build effective fences for all species of arboreal mammal. Therefore, canopy bridges should be installed in high quality habitat, along existing corridors or movement paths and at natural pinch points. 13. If there is fencing for specific arboreal mammals, the poles and stay wires should be placed behind fauna proof fencing to prevent fauna moving into the road.
Landscaping and vegetation	14. Additional poles, canopy bridge and/or tree planting may be required to connect the canopy bridge to adjacent vegetation. 15. If insufficient vegetation is present, vegetation must be planted to encourage wildlife to use the canopy bridge, in accordance with **Section 7.2**.
Furniture to encourage use and reduce the risk of predation	16. Include a metal predator shield at the top of the pole to provide protection from aerial predators. The shield must be a circular galvanised metal plate, approximately 900 mm diameter and at least 500 mm above the canopy bridge connection, ensuring it doesn't compromise function of the canopy bridge. 17. Include open-ended lengths of 100–150 mm diameter UPVC pipe (or equivalent), approximately 400 mm in length, installed horizontally on the support poles and at 7–10 m intervals along rope ladder as escape or temporary refuge sites (**Photo 69**). Further research is required to clarify effectiveness.
Lighting	18. No artificial lighting within 100 m of canopy bridges. 19. Where lighting is required to meet safety standards: a. Ensure lighting is the lowest intensity possible. b. Avoid use of lights within the blue, violet and ultraviolet wavelengths. c. Use light shields to prevent light spill onto the canopy bridge and into adjacent habitat.
Maintenance	20. Canopy bridges (particularly pole and rope components) are ideally inspected every two years. Ropes must be checked for decay and deterioration. 21. Rope tension must be maintained to ensure correct clearance above the road and reduce sway. The first two years are particularly important to deal with stretch and tightening. Canopy bridges with excessive sway are less likely to be used by wildlife. 22. Foliage from trees that grows around and through the ends of canopy bridges facilitates access by wildlife and this vegetation should be allowed to grow. However, large branches that lean on the rope bridge must be pruned to reduce stress and loading on the bridge.
Monitoring and performance evaluation	23. Develop and implement a performance evaluation plan, in accordance with **Section 8.5**.

Photo 65 A multi-pole canopy bridge span over the Hume Highway (NSW) (Source: Austin O'Malley, VIDA Roads)

Photo 66 Canopy bridge across the Hume Freeway, central Victoria, showing the flat rope ladder attached to two steel cables (Source: Rodney van der Ree, WSP)

Photo 67 Canopy bridge across Yan Yean Road, Victoria (Source: Clio Gates Foale, VIDA Roads)

Photo 68 Close up of connection of rope ladder to the supporting pole. The rope ladder should extend all the way to the pole to improve ease of access for possums, gliders and other arboreal animals (Source: Rodney van der Ree, WSP)

Photo 69 PVC pipe refuge shelters attached to a canopy bridge pole, Yan Yean Road, Victoria (Source: Rodney van der Ree, WSP)

Photo 70 Example of poor design – The rope ladder is connected to the pole via 1 m of steel cable. The ladder should connect directly to the pole to improve ease of access (Source: Rodney van der Ree, WSP)

Figure 23 Canopy bridge design

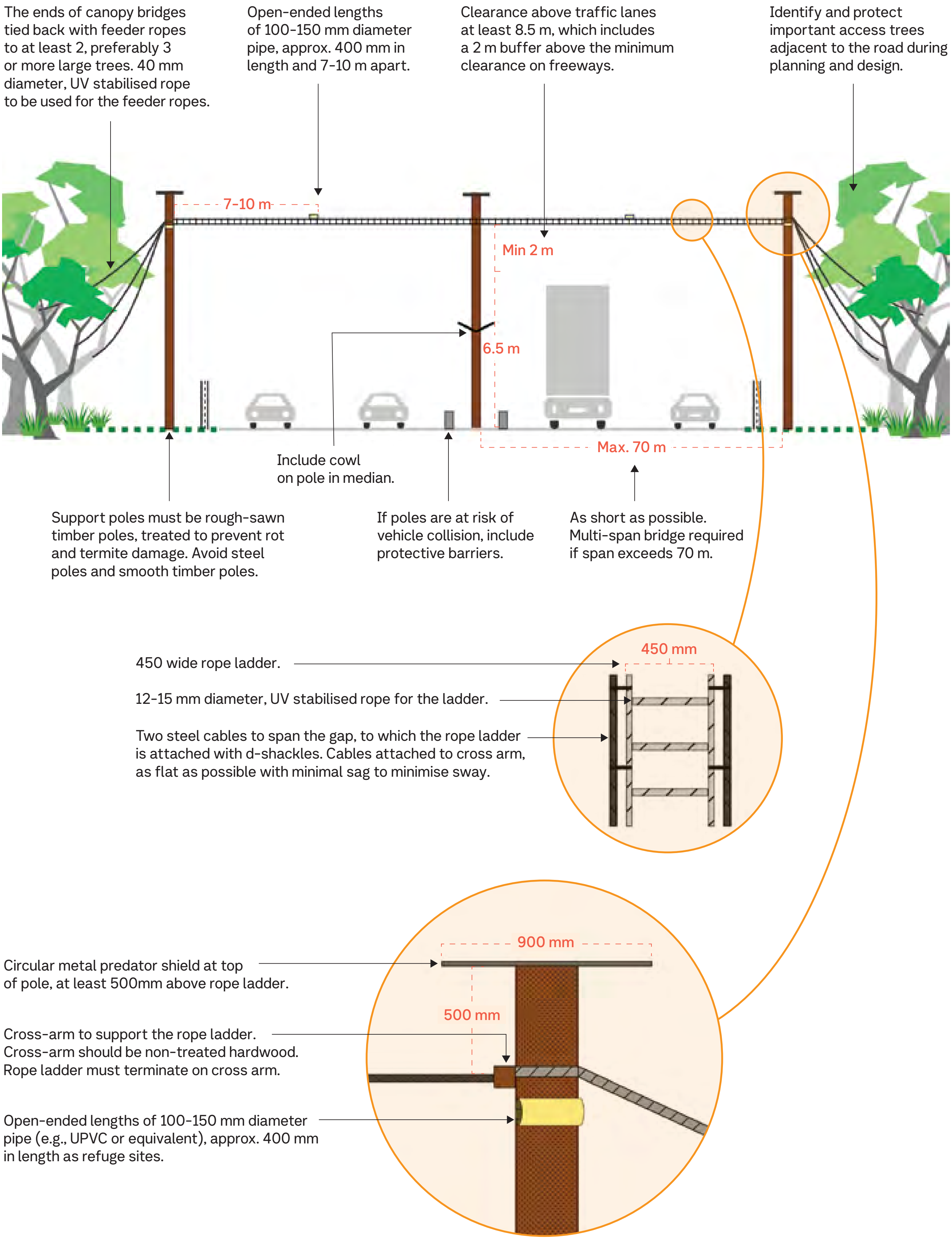
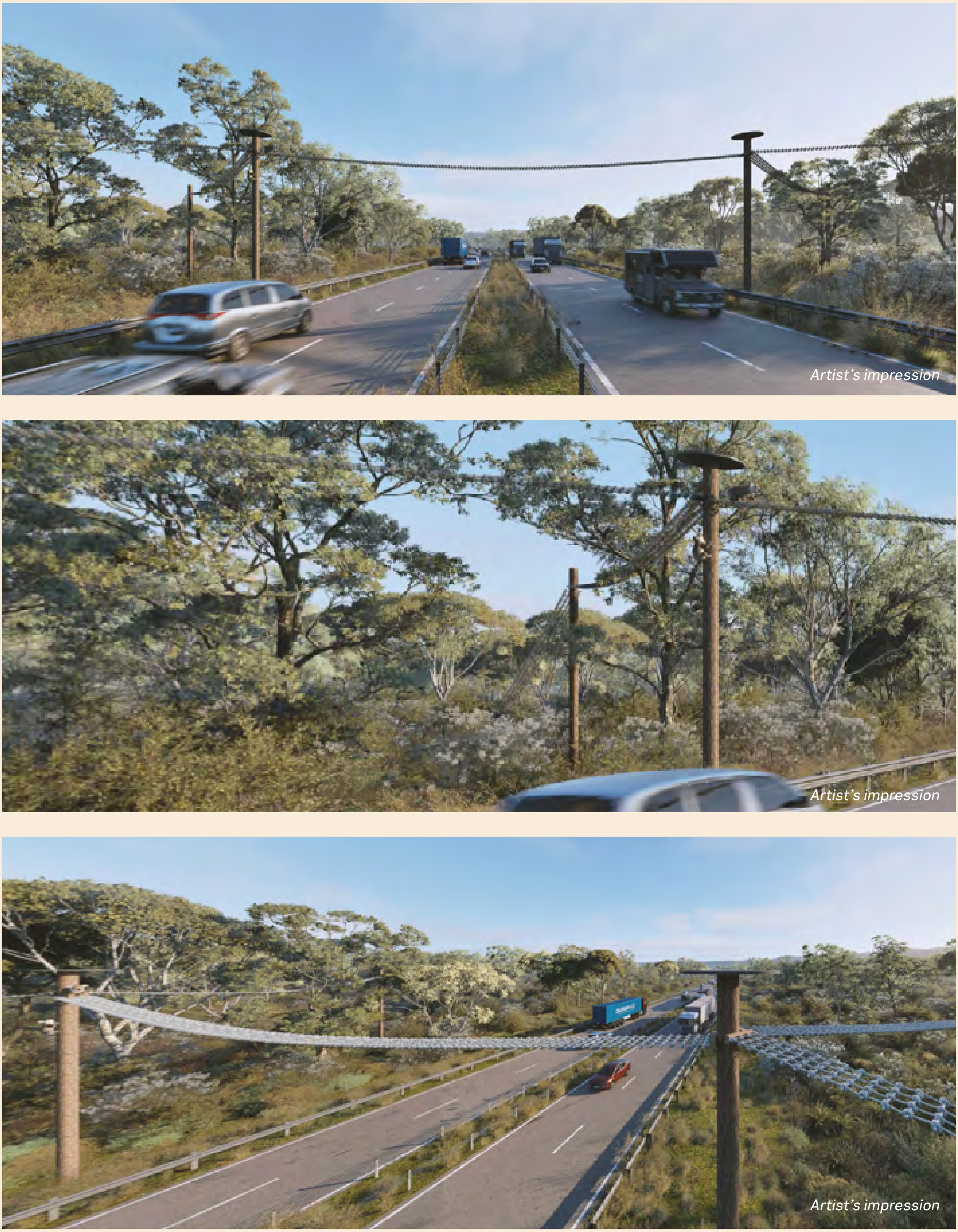


Figure 24 Virtual render of a canopy bridge for arboreal fauna (over road)



Note in Figure 24 predator shield caps on roadside pole tops (top image), rough-sawn wooden poles and canopy bridge extending into adjacent forest and tree canopy (middle image) and no gaps in rope ladder at joins (bottom image).

3.7.1. Canopy bridge — under bridge

Canopy rope bridges can be built to pass under road bridges where there is sufficient clearance underneath. This type of canopy bridge is functionally similar to above-road canopy bridges and provides safe connectivity for arboreal and semi-arboreal mammals. Under-bridge canopy bridges do not need to be engineered to the same standards as the above-road canopy bridges because the consequences of collapsing are typically lower. Nevertheless, most design features are the same as for above-road canopy bridges because the support poles are typically positioned outside the bridge underpass and exposed to UV, potential predators etc.

Recent trials and installations have shown that Squirrel Gliders and Sugar/Krefft's Gliders regularly use canopy bridges under the new Echuca-Moama bridge and under bridges along the Hume Freeway in southern NSW (Rodney van der Ree, unpublished data). These initial study results also suggest that different species utilise the 'above road' canopy bridges versus the 'below road' canopy bridges. Information on usage by other species is lacking and further research and monitoring is required.

Photo 71 Canopy bridge installed under a road, Echuca-Moama Bridge (Source: VIDA Roads)

Table 3.11 Under-bridge canopy bridge design requirements for ecological connectivity and safe passage

Design aspect	Specifications and considerations
Target species	– Proven for Squirrel Gliders and Krefft's Gliders. – Potentially other arboreal and some semi-arboreal mammals, including other gliders, possums, Antechinus, Phascogale and potentially arboreal reptiles, such as goannas, but more research required. – Not suitable for koalas.
Design, dimensions and construction materials	1. The canopy bridge to be at least ~2 m below the underside of the bridge deck and at least ~5 m above the ground. Therefore, under-bridge canopy bridges are typically not suitable for bridges with less than ~6–7 m clearance. 2. See **Table 3.10** (for Canopy bridge) for further requirements.
Furniture to encourage use and reduce the risk of predation	3. See **Table 3.10** (for Canopy bridge).
Lighting	4. See **Table 3.10** (for Canopy bridge).
Maintenance	5. See **Table 3.10** (for Canopy bridge).
Monitoring and performance evaluation	6. See **Table 3.10** (for Canopy bridge).

Photo 72 Canopy bridge under road bridge on the Hume Highway, southern NSW (Source: Josie Stokes, WSP)

Photo 73 Canopy bridge under road bridge on the Hume Highway, southern NSW (Source: Josie Stokes, WSP)

Photo 74 Canopy bridge under road bridge, Slaty Creek, Calder Freeway (Source: VicRoads)

Photo 75 Canopy bridge under road bridge, Slaty Creek, Calder Freeway (Source: VicRoads)

Photo 76 Canopy bridge under Echuca-Moama Bridge (Source: VIDA Roads)

Photo 77 Canopy bridge under Warrandyte Bridge spanning the Yarra River, Warrandyte (Source: Austin O'Malley)

3.8. Glider poles

Glider poles are timber poles installed on one or both verges of the road and/or in the median and provide a platform for gliders to launch from and/or land on when gliding across the road. Glider poles can be installed in an array of two or more poles, or they can be used in conjunction with standing trees. Glider poles have been used successfully for numerous glider species across roads in Australia and internationally (Goldingay *et al*. 2018b, Soanes *et al*. 2018, Taylor and Goldingay 2013, Taylor and Rohweder 2020). Greater Gliders have also been observed using glider poles to traverse a 30–60 m wide cleared pipeline easement in Victoria (GHD 2017).

There is recent evidence from monitoring conducted at one location on the Oxley Highway in northern NSW which showed that Squirrel Gliders and Sugar Gliders preferred to use glider poles over rope bridges, with 12–18% of detections on pole-pairs and 1% of detections on the rope bridge (Goldingay *et al*. 2018b).

Photo 78 The threatened Squirrel Glider, Echuca-Moama Bridge (Source: Manfred Zabinskas)

The study was based on data from two pairs of poles and one rope bridge and therefore cannot be generalised, because the poles may have been placed in areas of higher quality habitat or be more easily accessed by gliders than the rope bridge, thus potentially explaining the variation in rates of use. Similarly, monitoring of the rates of use of glider poles and rope bridges along the Hume Freeway in southern NSW showed variable rates of use of both types of crossing structures (Soanes *et al*. 2015). Therefore, a key factor influencing rate of use of both glider poles and canopy bridges is their placement in high quality habitat and ease of access from adjacent vegetation.

Glider pole arrays should be designed according to a conservative estimate of the gliding capability of the target species and other gliders that may occur in the area to minimise the risk of WVC. The average glide ratio (glide distance divided by height dropped) of Squirrel Gliders has been calculated at 1.84 (equivalent to a glide angle of 29°) (Goldingay and Taylor 2009) and the glide ratio for Sugar/Krefft's Gliders is 1.82 (Jackson 1999). Based on this glide ratio for Squirrel Gliders, the maximum distance between poles on flat ground that are 20 m in height is approximately 37 m. However, the calculations of glide trajectories are site-and species-specific and must be designed conservatively for each crossing location.

Design requirements to meet ecological connectivity objectives are detailed in **Table 3.12** (over road) and **Table 3.14** (under road) with supporting information on glide angles and distances in **Table 3.13**. Key considerations and concepts are illustrated in a structure diagrams (**Figure 26** and **Figure 27**) and a virtual render of an example crossing (**Figure 28**).

Photo 79 Glider poles on the Hume Highway (NSW; Source: Austin O'Malley, VIDA Roads)

Table 3.12 Glider poles — design requirements for ecological connectivity and safe passage

Design aspect	Specifications and considerations
Target species	– Proven for Squirrel Gliders and Sugar Gliders. – Potentially effective for Greater Gliders, Yellow-bellied Gliders and Feathertail Gliders, but further research required. – Not suitable for non-gliding arboreal species.
Design, dimensions and construction materials	1. Glider poles are installed as an array of two poles (or trees — see next point) on opposite sides of the road, allowing gliders to jump from pole to pole. Wide roads may also require one or more poles in the centre median. 2. Use existing large trees (living or dead) rather than poles where possible, by retaining them during construction. Large trees are likely to function better than poles because they are more natural, may contain hollows, and may support invertebrates as food. Trees retained close to the road may need to be pruned to reduce risk of failure. 3. Some trees may also last longer than poles depending on species, resistance to termite damage and decay, current condition and position in the landscape (e.g. in swampy vs drier area). 4. **Poles**: a. Always use standard length, 20 m poles as a minimum, even if this exceeds the minimum height required based on the glide capability of the target species and site conditions. This equates to a height above ground of ~17 m. Longer poles are required where necessary to achieve safe glides (Table 3.13). b. Always seek advice from an experienced ecologist. c. Longer poles (up to 26 m) are available but are more expensive to procure and require specialist transportation (i.e. escort services). It is not possible to specify a one-size fits all because road width, topography and distance from the road varies, as does the glide angle for different species. d. The glider poles must be rough-sawn and not smoothly sanded, to make it easier for gliders to climb. e. Poles should always be treated to prevent rot and termite damage. f. Protective crash barriers should be used for any poles that are within clear zones. g. For poles in the median, install two shorter poles on both sides of the tall launch pole to increase the width of the landing area and reduce the risk of gliders missing the pole and colliding with vehicles. Shorter poles should be approximately 10 m tall or a height of 2 m above where gliders are expected to land. The shorter poles should be touching the tall pole and secured with long galvanised bolts. If there are no trees in the median, include cowls on the median poles to prevent gliders descending into the traffic. If there are trees in the median, cowls won't do much as gliders can easily glide down.
	5. The distance between poles depends on numerous factors, including species-specific glide trajectory, pole height, pole placement and obstacles. The appropriate distance between poles must be calculated for individual projects, accounting for species- and site-specific factors and using the glide angles in **Table 3.13**. 6. Always seek advice from an expert in the implementation of glider poles. However, for early project planning purposes, use the maximum distance between poles in **Table 3.13** and assume poles are required in the median. 7. **Launch cross-arm**: a. The launch cross-arm must be at least 2 m in length, and preferably more, and point towards the opposite side of the road (i.e., in the direction of the glide). This will shorten the length of the glide required. b. The cross-arm should be non-treated hardwood as this is where animals will spend most of their time.

Design aspect	Specifications and considerations
Design, dimensions and construction materials	8. Glide trajectory of every glider pole array (including if standing trees are part of the array) must be drawn to scale to finalise pole height and spacing using the following parameters: 9. **Use glide angles in Table 3.13, noting**: a. When calculating glide trajectories from glider poles, use the height and position of the end of the cross-arm, which is where gliders will typically launch from. b. When calculating glide trajectories from trees, assume gliders launch from the outer canopy at approximately 75% of tree height. c. The projected glide trajectory must be at least 9 m (and preferably more) above travel lanes (4.5 m above height of tallest vehicle at 4.5 m) and 3 m above any obstructions (e.g. noise walls). d. The projected landing height on a tree or pole must be a minimum of 3 m above the ground. e. Successful glides must be achievable in both directions.
Landscape position and fencing	10. The position and spacing of glider pole arrays depend on the target species. Glider pole arrays for species with a small home range may need to be every few hundred metres, while arrays for species with larger home ranges may need to be every few kilometres. 11. Poles must be accessible for maintenance and/or installation of cameras or other monitoring. 12. Glider poles should be built where native vegetation/habitat for the target species occurs (or can be replanted) on both sides of the road. 13. It is not possible to build effective fences for arboreal mammals and glider poles. Therefore, install in high quality habitat, along existing corridors or movement paths and at natural pinch points.
Landscaping and vegetation	14. Additional poles and/or tree planting may be required to connect the array to adjacent vegetation. Trees should be planted around the base of all glider poles to provide a larger area for gliders to land on and reduce the likelihood of them missing the landing and colliding with vehicles. 15. If insufficient vegetation is present, vegetation must be planted to encourage wildlife to use the glider poles, in accordance with **Section 7.2**.
Furniture to encourage use and reduce the risk of predation	16. Include a metal predator shield at the top of the pole to provide protection from aerial predators. The shield must be a circular galvanised metal plate, approximately 900 mm diameter and at least 500 mm above the cross arm. 17. Include one open-ended length of 100 mm diameter UPVC pipe (or equivalent), approximately 400 mm in length, installed horizontally on the poles and another to the underside of the cross arm to provide protection from aerial predators.
Lighting	18. No artificial lighting within 100 m of glider poles. 19. Where lighting is required to meet safety standards: 20. Ensure lighting is the lowest intensity possible. 21. Avoid use of lights within the blue, violet and ultraviolet wavelengths. 22. Use light shields to prevent light spill onto the glider poles and into adjacent habitat
Maintenance	23. Inspections of pole integrity and condition of predator protection required every two years.
Monitoring and performance evaluation	24. Develop and implement a performance evaluation plan, in accordance with **Section 8.3**.

Table 3.13 Glide angles and horizontal glide distance for a selection of Glider species

Species [1]	Glide ratio (angle) [2]	Maximum glide distance [3]	Source
Squirrel Glider	1.84 (29°)	29.8 m	Goldingay and Taylor 2009
Sugar (Krefft's) Glider	1.82 (28.8°)	28.8 m	Jackson 1999
Greater Glider	1.19 (40°)	13.8 m	Wakefield 1970 cited in Jackson 1999. More research needed.
Yellow-bellied Glider	2.0 (27.3°)	32 m	Goldingay 2014

Table 3.13 notes: [1] No data for Feathertail Glider, but average glide length 14 m (launch and landing height not recorded) Perth Zoo fact sheet; [2] Glide ratio is horizontal distance travelled divided by the vertical drop. Glide angle is measured from horizontal surface.[3] This figure represents the maximum horizontal distance between poles that a glider species can traverse (glide between) given sufficient pole height. Glide distance assumes launch height of 16.5 m and landing height of 5 m, on flat ground. Launch height based on 20 m pole set 3 m into the ground with launch from cross beam at 0.5 m from top of pole. Landing height assumes a 3 m landing height plus a 2 m buffer. **Note that taller and/or more poles are required to achieve safer glides by animals. Detailed designs are required for each project and proposed installation site and should refer to the mots current research on glide ecology and movement behaviour.**

Photo 80 Glider pole installed in centre median of Hume Freeway, Victoria. Cross-arm should be perpendicular to the road and point towards the opposite side of the road (Source: Rodney van der Ree, WSP)

Photo 81 Squirrel glider on Hume Freeway glider pole, VIC (Source: Rodney van der Ree, WSP)

Figure 25 Glider pole design

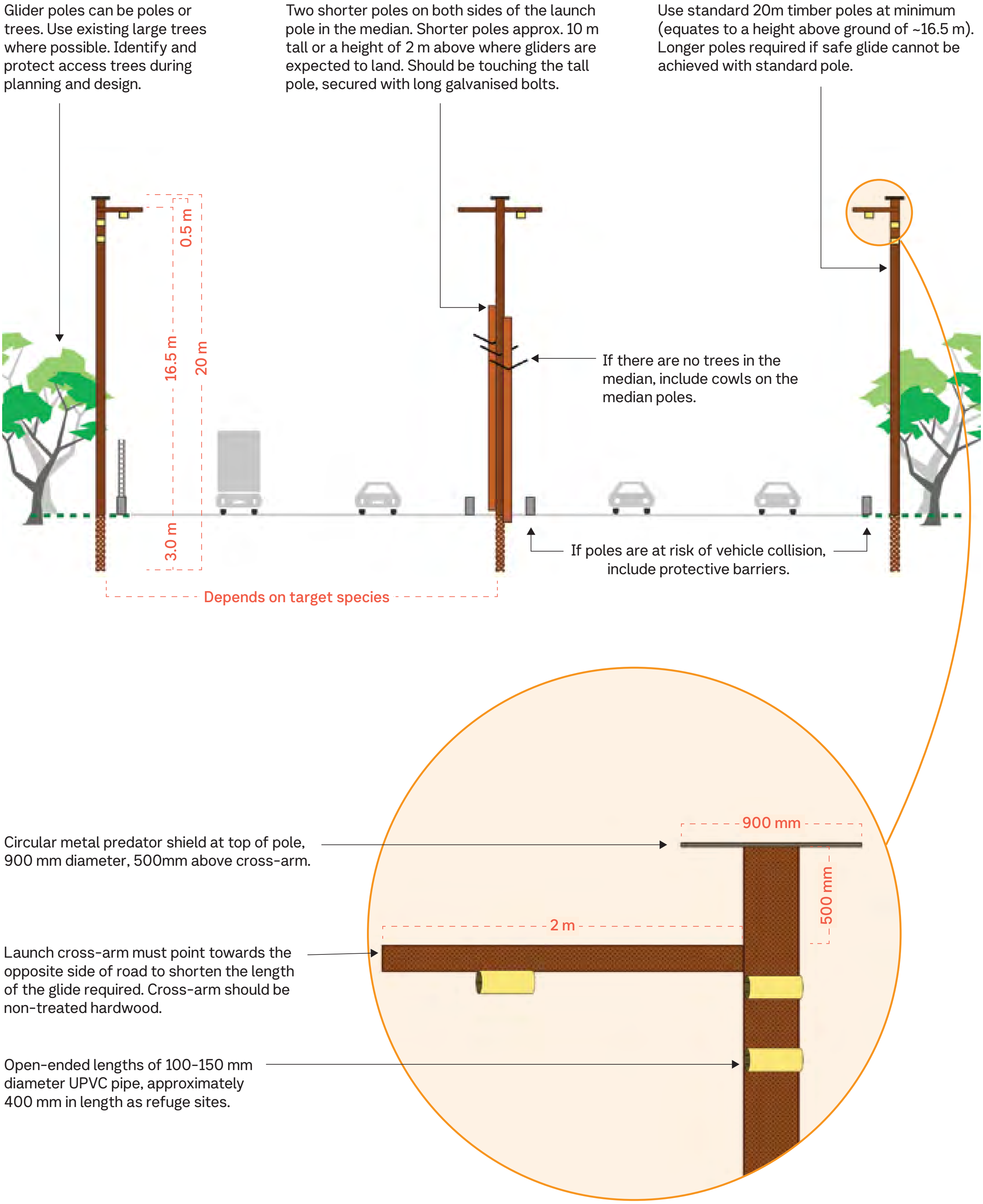
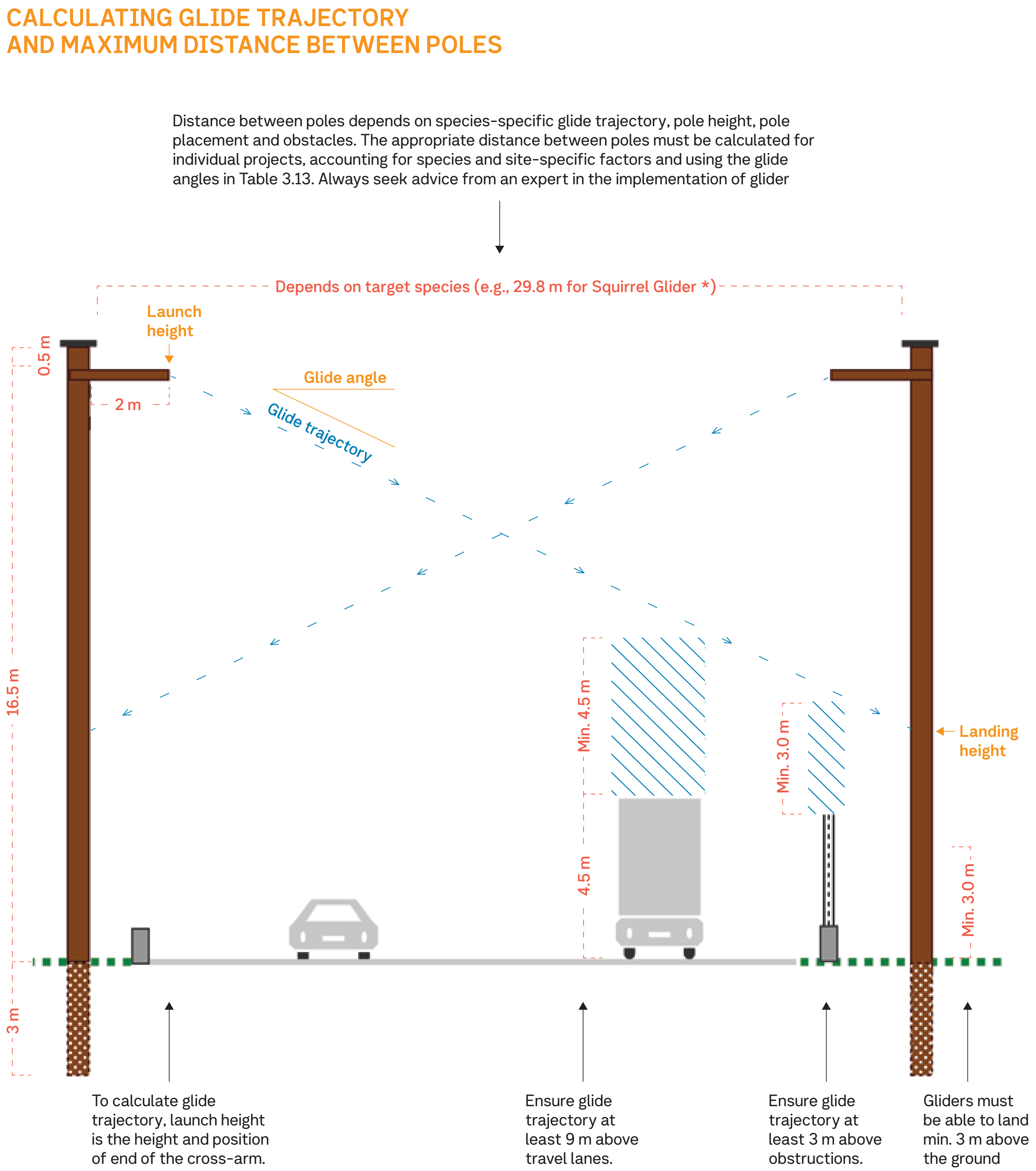


Figure 26 Calculating maximum distance between glider poles



Assumes launch height of 16.5 m (i.e. 20 m pole set 3 m into the ground with launch from cross beam at 0.5 m from top of pole) and landing height of 5 m (3 m landing height plus 2 m buffer). Detailed designs must be completed for all projects. Taller and/or more poles are required to achieve safe glides.

Figure 27 Virtual render of a glider pole crossing

Note in Figure 27 above the height of poles and gliding trajectory required for animals to clear traffic and land onto next pole (top image); adjoining poles in central median for resting (middle image); and close proximity of roadside pole to tree canopy (bottom image). Glider poles must be rough-hewn wood and the series of poles must extend to (and ideally some distance into) adjacent woodland or forest canopy.

3.8.1. Glider poles — under bridge

Under bridge glider poles are standard glider poles installed under road bridges and can include timber poles and/or retained or installed tree trunks. The intention is to achieve a single row or ideally a 10–20 m wide strip of poles and/or tree trunks under bridges which allows gliders to traverse the gap using multiple small glides. The use of under-bridge poles eliminates the risk of gliders colliding with vehicles while attempting to glide above the roadway.

The use of 'natural' glider poles (i.e., retained or re-installed tree trunks) offers a number of likely advantages over timber poles.

The effectiveness of glider poles under bridge structures is unknown but are expected to work if the bridge is at least 5–6 m above the ground, however further research is required.

Table 3.14 Glider poles under bridge — design requirements for ecological connectivity and safe passage

Design aspect	Specifications and considerations
Target species	– Likely effective for Squirrel Gliders and Krefft's Gliders, but further research required. – Potentially suitable for Feathertail Gliders, Greater Gliders and Yellow-bellied Gliders, but further research required. – Not suitable for non-gliding arboreal species.
Design, dimensions and construction materials	1. As per Table 3.12 (Glider poles). 2. If retained tree trunks are part of the array, calculate glide trajectories based on a launch-height of the top of the trunk. 3. Gliders must be able to land a minimum of 2 m above the ground. 4. The top of the poles or tree trunks should be approximately 1–2 m below the underside of the bridge structure. 5. Timber poles and retained trunks should be positioned away from bridge supports to prevent damage to the bridge structure if they collapse. 6. Where necessary, prune the tree and reduce the weight of the canopy to minimise the risk of collapse and damage to the bridge structure. 7. Each retained trunk should be inspected and pruned at construction by a qualified arborist with a minimum Level 3 Certificate in Arboriculture or equivalent plus demonstrated experience in inspecting and pruning trees for habitat. 8. Maintain as much canopy adjacent to the bridge structures where the trunks will be retained to provide connection to the trunks and provide shelter to the trunks from extreme wind to increase their standing lifespan.
Landscape position and fencing	9. As per Table 3.12 (Glider poles).
Landscaping and vegetation	10. As per Table 3.12 (Glider poles).

Design aspect	Specifications and considerations
Furniture to encourage use and reduce the risk of predation	11. Tree trunks are likely better than timber poles because they are wider and offer a larger landing surface, and provide habitat in the form of bark, hollows and potentially canopy growth. 12. Tree trunks may last longer than poles depending on species, resistance to termite activity and decay, current condition and position in the landscape (e.g. in swampy vs drier area). 13. Carved hollows can be installed into retained trunks if the stems are sufficiently large. 14. If the trees are River Red Gums, they are resistant to decay and with the root system still intact, they should remain standing for at least 30 years, if not longer (Grant Harris, Ironbark Environmental, pers. comm.; Cameron Ryder, Ryder Consulting, pers. comm.). 15. Trees that survive pruning and construction may have coppice regrowth for some years, which provides shelter and food for wildlife and increases the useful standing life of the trunk because the root system remains alive. However, retained trunks under bridges are unlikely to survive in the medium-term due to extensive pruning, reduced sunlight and soil moisture levels and compaction during construction, and hence ongoing inspection by arborists is unlikely to be required. 16. Predator shields and refuge pipes are not required on poles under bridges because the road bridge provides protection from aerial predators. Predator shields and refuge pipes are required on poles and trunks at the end of arrays that are not protected by the road bridge.
Lighting	17. As per Table 3.12 (Glider poles).
Maintenance	18. Inspections of pole integrity and condition of predator protection required every two years. 19. If the trunks, branches or coppice regrowth is within striking distance of the bridge piers, they should be inspected by a qualified arborist at least once every two years to assess health and residual risk. Coppice regrowth is poorly connected to the main stem and poses a higher incidence of failure than normal branches. A qualified arborist should advise on the required re-inspection frequency. 20. The structural root zone of each retained trunk should not be damaged during maintenance works because these are what will support the tree trunk in the long term.
Monitoring and performance evaluation	21. Develop and implement a performance evaluation plan, in accordance with **Section 8.4**.

3.9. Canopy connectivity

Canopy connectivity may be an effective approach to facilitate connectivity for arboreal mammals, birds, and bats by maintaining trees and shrubs as close to the road as possible, ideally allowing tree canopy from opposite sides of the road to remain connected above the road (**Figure 29**).

This approach minimises the size of the road gap, encouraging gap-sensitive wildlife to traverse the roadway or glide above it, or by allowing non-gliding arboreal mammals to climb between canopies. While full canopy connectivity is not feasible on wide roads, partial canopy connectivity can significantly reduce the barrier effect for many species, including birds and bats, and should be considered. Canopy connectivity can also be achieved on land bridges by planting trees (**Section 3.6**).

Wherever possible, tree clearing for road construction and maintenance should be kept to a minimum and undertaken strategically to ensure the tree canopy remains continuous, or gaps are small enough that species are willing or capable of crossing. For example, any gap in the canopy will be a barrier to possums, and gaps of 20–30 m with high traffic volume will begin to limit the movement of gliders and some species of birds and bats.

Use the glide angles and methods described for glider poles to determine if canopy connectivity is a feasible strategy for gliding species (see **Section 3.8** and **Figure 27**). Canopy bridges and glider poles will assist the movement of possums and gliders if canopy connectivity cannot be achieved.

The protection of individual trees or stands of trees in crossing zones for gap-sensitive species is particularly important and should be identified during project planning and detailed design.

Photo 82 Road with high canopy connectivity (Source: VIDA Roads)

Trees that are planned for removal during construction and maintenance activities should ideally be re-established as soon as practicable, noting that trees may take many decades to develop a canopy analogous to the one destroyed. This time delay is critical for some arboreal species that are endangered.

It is important to note that while this approach facilitates the movement of wildlife, it doesn't eliminate the risk of WVC. Therefore, this approach is more suitable when:

- Roads are narrower and/or have vegetated medians.
- Vehicle speeds are slower.
- Traffic volume is lower, and importantly at the time of day when the target species may attempt crossing the road.
- Visibility of oncoming vehicles is high, allowing animals to detect oncoming vehicles and time their movement accordingly.
- The target species has relatively low rates of WVC, is not of conservation concern and responds appropriately to oncoming vehicles.

Care must also be taken to consider potential vehicle-collision risks for birds drawn to the road by tree canopy and associated plantings. Where this is an identified risk, mitigation measures may be required to reduce this risk including:

- Limiting shrub plantings in central medium and potentially roadside and keeping these to low ground-covers native species.
- Adding shielding walls either side of a roadside to maximum vehicle height to force birds to move above traffic.
- See below examples and key concepts in virtual render of a road section with high canopy connectivity (**Figure 29** and **Figure 30**).

Figure 28 Canopy connectivity over road

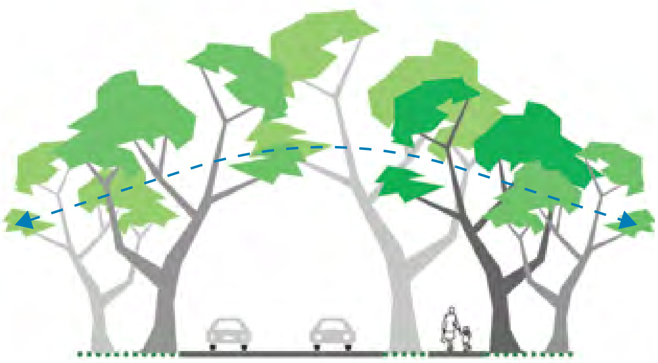


Figure 29 Conceptual example of canopy connectivity across a dual carriageway road

4. Fencing and deterrents


Healesville Koo Wee Rup Road Upgrade

Wildlife fencing and other methods to restrict or deter animal movement onto road pavements and into vehicle traffic generally have the intent of achieving either one or both of the following objectives/outcomes:

- Reducing the rate of WVC by preventing animals from accessing the road, thereby reducing injury and mortality of wildlife and increasing motorist safety.
- Funnelling wildlife to crossing structures, thereby increasing their effectiveness.

There are two forms of barrier fencing and deterrents:

- Wildlife fencing designed physically restrict wildlife moving onto a road surface and into traffic (**Section 4.1**).
- Virtual fencing which intends to modify animal behaviour to limit and deter animals from moving onto the road pavement and traffic.
- Of these two methods, only physical fencing has been proven to be effective when designed, installed and maintained correctly.

4.1. Wildlife fencing

A review of the international scientific literature showed that roadside fencing that is correctly designed, installed and maintained can reduce rates of mortality by an average of approximately 50%, and up to almost 100% in some situations (Rytwinski *et al*. 2016). While fencing alone is the most effective method to reduce WVC (Rytwinski *et al*. 2016), it necessarily increases the barrier effect and thus in almost all situations, fencing and crossing structures should be installed together. Fencing without crossing structures should only be considered under specific circumstances (see below).

> Wildlife fencing must be designed specifically for the target species to maximise its effectiveness.

Common fencing designs exist for most terrestrial species including macropods, koala, reptiles, and amphibians. General design specifications are provided in **Section 4.1.2**, with species- or taxa-specific details in **Table 4.16**.

Other types of structures, such as noise walls and safety barriers (see **Section 1**) can potentially also function as wildlife fences in some circumstances if designed appropriately.

4.1.1. Fencing without crossing structures

Fencing is rarely installed without wildlife crossing structures and requires careful consideration prior to implementation. This is because, in addition to preventing WVC, fencing without crossing structures or other modification will have a negative impact on wildlife movement and connectivity.

This should be assessed on a species- and location-specific basis and used when one or more of the following conditions apply:

a. When there is no ecological benefit in facilitating connectivity across a road, but animal mortality is likely without fencing. For example, fencing would be appropriate for ground-dwelling mammals if habitat is entirely restricted to one side and the opposite side of a road supports high-density residential developments. In this case, there is limited impact on ecological connectivity through fence installation and road mortality will be reduced.

b. When impacts of animal mortality to a wildlife population are very high and demonstrated to outweigh impacts of reduced connectivity among populations and/or habitat (either occupied or unoccupied).

c. The population of a target species in the vicinity of a road is large or occurs at high density — in concert with meeting condition a) or b).

d. There are numerous opportunities in relatively close proximity to the fencing where suitable fauna crossing structures exist, or existing structures can be modified.

4.1.2. General fence design

The majority of road projects that consider FSRD will most likely require some form of fencing to keep wildlife off the road and funnel them towards crossing structures. Situations where fencing may be difficult include locations where:

- There are many driveways or side roads that open onto the road.
- Adjacent property owners have legitimate concerns about fence design.
- There are no opportunities to install crossing structures, and thus fencing increases the barrier effect.

General fence design principles are described in **Table 4.1**. Fencing requirements for specific fauna groups are provided in **Table 4.16**. Examples of integration of exclusion fencing with crossing structures are also provided in virtual renders (**Figure 31**).

Royal Botanic Gardens, Cranbourne

Table 4.1 Fencing — General design principles

Design element	Specifications and considerations
Target species	– Proven for many target species, when designed accordingly, including most terrestrial species including macropods, koala, reptiles, and amphibians. – Not effective for gliders as they can glide above the fence from adjacent trees and many arboreal species can climb over. – Wombats will test all fencing, especially when installed across an existing pathway. Where this species is present, fencing must be strongly built and constructed. – Always consider unintended impacts of fencing and other structures (e.g. rub rails) to other species, such as entanglement, impacts on connectivity and restriction of movement where not required. Fencing should only be used where required to reduce a demonstrated risk of wildlife collision and to guide wildlife through crossing structures.
Design	1. Wildlife fencing is typically installed to both prevent wildlife from accessing the road (to reduce WVC) as well as funnel wildlife to crossing structures. 2. The height, length, design and construction materials are species- and site-specific. 3. Noise walls, light walls and safety barriers can potentially function as wildlife fencing if designed appropriately. See **Sections 4.2** and **1** for more details. 4. Avoid plastic-coated wire mesh as it will melt during bushfire. 5. Dark coloured mesh is less visually obtrusive than galvanised mesh. **6. General design principles** a. Barbed-wire should never be used near wildlife crossing structures, particularly those for arboreal species, as gliders frequently get entangled and die (van der Ree 1999). Barbed wire should also be avoided in areas of habitat for gliders, flying foxes and wetland birds. b. Wildlife fences should typically be installed on both sides of a road. Fencing on a single side may be appropriate if the source area for the target species is only on one side of the road and/or the unfenced side of the road has natural barriers (e.g. very steep cutting). See exceptions described in **Section 4.1.1**. c. Consider placement and strength of fence in areas subject to flooding. d. Design fencing for multiple species, where possible. e. Floppy-top fencing is not recommended because it has higher maintenance and clear-zone requirements compared to vertical fencing. **7. Design and placement principles** Wildlife fencing should aim to: a. maximise the area of wildlife habitat behind the fence and within the road easement (project area) — creating a habitat movement corridor which works with fence to guide animals through the intended wildlife crossing structure. b. consider and be integrated with road drainage design and other road infrastructure such as safety barriers and pedestrian access etc. c. minimise the extent of vegetation clearing. d. consider ongoing maintenance requirements including access and safety. e. consider and be (where feasible) integrated with other fencing (property, safety, amenity) to save costs and avoid unnecessary parallel fencing or conflicting outcomes.

Design element	Specifications and considerations
Design	**8. Crossing structures** Where fencing is installed to funnel fauna towards crossing structures: a. In general, fencing should be installed at every crossing structure. b. Ensure wildlife fences are attached securely to crossing structure, such as abutment walls, wing walls or pillars, thereby ensuring wildlife are funnelled directly into the crossing structure and are unable to squeeze between crossing structure and fence. c. Wildlife fencing should typically include a 'return;' an angled section of fence (a minimum of the last 10 to 20 m of fencing) to encourage wildlife to turn back towards their habitat rather than move around the fence end and onto a road. d. Where possible, fence ends should be integrated with other infrastructure, such as boundary fencing, natural barriers e.g. cliffs, cuttings, rocky areas or other geographical features that limit movement of the target species. **9. Fence length:** a. It is not possible to specify a standard minimum or maximum length of fencing that is required because it depends on various interacting factors, including the extent of habitat in the area, the occurrence and movement patterns of the target species and risk of WVC. Due to this complexity, an ecologist experienced in FSRD should be consulted and the following principles applied (b–d). b. The fence should be long enough to prevent target species from accessing the road. This typically corresponds with the occurrence of habitat and/or distribution of the target species along the road. The fence will need to extend further if the target species is willing to pass through 'non-habitat'. For example, fencing for kangaroos will likely need to be many kilometres (or continuous) in length, while fencing for a range-restricted small mammal may need to be hundreds of metres in length. c. Short fences either side of a crossing structure are less effective than continuous fencing because animals may access the road via the fence end, increasing the rate of WVC there, an effect known as the 'fence-end effect'. Nevertheless, some fencing is better than no fencing at crossing structures, as some fencing will ensure a proportion turn towards the crossing structure and safely cross the road. However, care must be taken to ensure that sufficient fencing is installed to achieve the SMART goal (e.g. no WVC vs minimise such collisions). Further research is required to elucidate minimum and optimal lengths of fencing in different scenarios and contexts. d. For preliminary planning purposes, assume a minimum 250 m of fencing to either side of each crossing structure (500 m total) length and continuous fencing where it passes through large areas of habitat. This should be further refined during detailed road design process. **Note**: Shorter lengths may be appropriate if there is no intersecting habitat and/or potential barriers at a certain distance from a crossing structure along the road alignment, with the result that animals are very unlikely to attempt crossing the road at this distance. An example could be where heavily built-up residential areas are located close (100 m) to a waterway corridor which the road traverses and target fauna groups and/or species are considered unlikely to be moving through this environment. In this case, fencing would extend along the road alignment where it intersects the waterway corridor to the edge of adjacent residential areas. Conversely, fencing may need to be longer if habitat extends > 250 m and target fauna are likely to attempt crossing at fence ends.
Design	**10. Gates and fencing breaks**: a. Access may be required through wildlife fences for vehicle or pedestrian access. In these instances, use locked or other gate designs, such as double gates, that will not allow wildlife access. b. Fencing should be continuous. Breaks (gaps) in fencing are vulnerable points in fencing systems and may allow wildlife to access the road. Where unavoidable, minimise the number and size of the break(s) as far as possible.

Design element	Specifications and considerations
Design	c. Breaks in fencing can potentially be treated with gates, wildlife grids i.e. modified cattle grids (in some instances), or wrap-around fencing. d. Gates are problematic if left open, poorly designed or not maintained. All gaps between the gate and fencing and the gate and the ground are best avoided. e. Cattle grids can be effective if the target species avoids walking on them. A small number of monitoring reports indicate they are successful for koalas (see DPIE 2020). Grid width and spacing of bars may need modifying for other species and further research is needed. f. Fencing can also be extended along the intersecting road (i.e., wrap-around fencing) in the form of a long return — see notes on fence length to inform this.
Landscape position and landscaping	11. Fencing is required wherever the target species or its habitat occurs and where the target species can access the road. 12. The fence needs to be accessible, ideally from the roadside, for inspection and maintenance. 13. Vegetation should be managed to prevent fauna from climbing over the fence. Vegetation modification requirements vary according to vegetation type, fence height, the target species and their climbing ability. Ensure any vegetation management is undertaken in compliance with regulatory requirements.
Escape mechanisms	14. Ensure appropriate escape mechanisms (e.g. one-way gates, escape ramps and drop-down poles, see **Section 4.3**) where wildlife fencing is continuous for lengths that exceed half of the typical home range of the species.
Maintenance	15. Wildlife fencing, escape mechanisms and other associated infrastructure should be inspected and repaired every 2nd year and after major flood events.

Figure 30 Example conceptual render of wildlife exclusion fencing integrated into a culvert crossing (top) and wildlife bridge underpass (bottom)

Table 4.2 Fence design and construction for specific fauna groups

Fauna group	Design, dimensions and construction materials	Escape mechanisms
Koala	1. 1.8 m in height. 2. Use non-plastic coated cyclone mesh fencing as standard because the plastic coating will melt during fires, reducing the lifespan of the mesh. Black painted mesh can blend in better than unpainted metal mesh. 3. Install a 600 mm wide strip of smooth, opaque sheeting (e.g. green or black high-density polyethylene or sheet metal) at the top of the fence to prevent koalas from gaining grip and climbing over. Recycled plastic sheets can be used, however it will melt during fires. Ensure top of strip sits above the top of the cyclone mesh to prevent entanglement by birds, bats, flying foxes and gliders. 4. Sheet metal strips can be added to other types of fencing (e.g. controlled access/boundary fencing) or structures (e.g. noise walls). 5. May also be effective for possums, Antechinus and Brush-tailed Phascogale if the mesh is fine.	– Provide escape mechanisms when fencing > 500 m in length. – Escape mechanisms include drop-down poles, (see **Section 4.3**).
Kangaroos and wallabies	6. 2.1 m in height. 7. Use non-plastic-coated cyclone mesh fencing or sheet fencing (e.g. high-density polyethylene or sheet metal). 8. Kangaroos frequently attempt to jump fences and the top 300 mm of fence must not have single wires or large open mesh that could entrap their feet.	– Provide escape mechanisms when fencing > 500 m in length. – Escape mechanisms include jump outs, one-way gates (see **Section 4.3**).
Small mammals	9. 0.6 m in height. 10. Ideally use opaque sheeting (e.g. high-density polyethylene or sheet metal) that prevents them from seeing through. Recycled plastic sheets can be used, however it will melt during fires. Where drainage needs to be achieved through the fence it can have small perforations, as small as possible with a maximum perforation diameter of 10 mm or a diameter that prevents the movement of the target species. 11. If using a mesh fence, the mesh size depends on target species: 35 mm for rabbits down to less than 4 mm for juvenile amphibians. 12. Can be stand-alone or affixed to another fence.	– Provide escape mechanisms when fencing > 500 m in length. – Escape mechanisms include one-way gates, escape ramps (see **Section 4.3**).
Digging mammals — wombats	13. At least 0.6 m in height. 14. Wombats will test all fencing, especially when installed across an existing pathway. As such, fencing material, design, and construction must be strong and durable and have a deep curtain underground to discourage digging/burrowing. 15. Use opaque sheeting (e.g. high-density polyethylene or sheet metal) that prevents them seeing through, which discourages them from trying to get through. Where drainage needs to be achieved through the fence it can have small perforations.	– Provide escape mechanisms when fencing > 500 m in length. – Escape mechanisms include one-way gates, escape ramps, wombat pipes (see **Section 4.3**).

Fauna group	Design, dimensions and construction materials	Escape mechanisms
Digging mammals — wombats	16. The base of fence must be buried or include a skirt to discourage digging. Opaque sheeting should be buried to 300 mm, and mesh or steel fencing should have a 600 mm skirt on the habitat side of the fence (i.e., the side away from the road) secured using jute pins (or equivalent) in a zigzag pattern. Fence can also have a concrete base to which the fence is attached. 17. Can be stand-alone or affixed to another fence.	– Provide escape mechanisms when fencing > 500 m in length. – Escape mechanisms include one-way gates, escape ramps, wombat pipes (see **Section 4.3**).
Arboreal fauna	18. There are no standard designs for fencing for arboreal species, except koalas (see above). 19. Likely effective designs will consist of smooth and opaque sheet metal or plastic that they are unable to climb, to a height of 1.8 m. Careful attention to detail to exclude features they may use to climb (e.g. joins, posts) is required. 20. If mesh, it must be small enough to prevent egress by juveniles of the target species. 21. All fencing must be securely buried or concreted to prevent animals from passing underneath. 22. There is currently no fencing that effectively excludes gliders as they can glide from adjacent trees over the fence. 23. Overhanging trees will be used by arboreal species to breach the fence	– Provide escape mechanisms when fencing > 500 m in length. – Escape mechanisms include drop-down poles (see **Section 4.3**).
Amphibians	24. At least 0.5 m high, have an overhanging lip (between horizontal to 45° downwards) of at least 100 mm on the side opposite the road, and be buried into the soil at least 100 mm. The fence should consist of a single piece of material from the top of the lip to the bottom of the buried section. 25. Use opaque sheeting (e.g. high-density polyethylene or sheet metal). Where drainage needs to be achieved through the fence it can have small perforations, as small as possible with a maximum perforation diameter of 10 mm or a diameter that prevents the movement of juvenile frogs. 26. Standard sediment fencing (i.e. geotextile/silt fence) is only recommended for temporary structures due to the high level of maintenance required and the potential for barrier permeability. 27. Frogs will use adjacent vegetation to climb up and over the fence. Vegetation that may overhang the fence should not be planted or allowed to grow. 28. Can be stand-alone or affixed to another fence.	– Breaks in fencing on both side of the roadway at driveways, intersections (see **Section 4.3**).

4.2. Safety barriers

Some types of road safety barriers (e.g. rub rails installed on w-beam safety barriers and concrete jersey barriers) can prevent the movement of some wildlife. If installed on both sides of the road they may be as effective as barrier fencing for some species (**Section 4.1.2**) however they are often installed only in the median or one side of the road. In these situations, they can potentially trap animals in the roadway and increase WVC.

Use of these barriers should be avoided in areas with high wildlife populations, unless necessary for human or vehicle safety reasons. If these barriers are unavoidable, the following guidelines should be followed to reduce negative impacts on wildlife:

- Install on both sides of the road to prevent animals from accessing the road from either side. Crossing structures should be installed if wildlife movement is important.
- Rub rails installed on one side of the road: Rub rails should not exceed 500 m without a break or escape mechanism installed.
- Concrete jersey barriers installed in the median or on one side of the road only: Concrete jersey barriers should not exceed 500 m in length without a break or escape mechanism installed. Jersey barriers should also include drainage slots that allow small animals to pass underneath.

Wire rope and other 'permeable' barriers are less problematic than solid barriers because smaller animals can pass underneath, and kangaroos and wallabies can jump over. However, there are anecdotal reports of increased rates of WVC after installation and further research is urgently required to determine the extent to which 'permeable' and other types of safety barriers impact wildlife movement.

4.3. Escape mechanisms

Wildlife inevitably breach fencing and escape mechanisms are required to allow them to leave the fenced road corridor. Escape mechanisms are one-way structures that allow animals to leave the fenced corridor, but not enter it. Escape mechanisms without moving parts (e.g. jump outs, escape ramps or drop-down poles) are preferred over those with moving parts (e.g. one-way gates) because they require less maintenance.

Escape mechanisms are required along roads with long lengths of continuous wildlife fencing. They are not required for short lengths where wildlife can move to the ends of fencing to leave the road reserve. The length of wildlife fencing where escape mechanisms are required is species-specific and dependent on their typical movement parameters. As a guide, escape mechanisms are likely required where the length of fencing exceeds a target species maximum home range length.

4.3.1. Gaps in fencing

Gaps in fencing are required for access roads and property access. Ideally, these will include gates or grids to prevent wildlife from accessing the fenced road (see below). If grids and gates are not feasible, consideration should be given to include a break in the fence on the opposite side of the road. This will enable animals that do enter the roadway to exit it on the other side and reduce the likelihood of them getting trapped between fencing.

However, road mortality will likely increase at these locations and expert input from an ecologist is required to weigh up the pros and cons of this approach.

4.3.2. Jump-outs or escape ramps

Jump-outs or escape ramps are designed to allow animals to exit the roadway but not enter it. Escape ramps are used where the road is at grade and are ramps on the roadway-side of the fence that allows animals to walk up to the height of the fence and then jump down to escape the roadway. Jump-outs are installed where the road is on fill and animals jump down a retaining wall. Jump-outs can also be installed at the wing-walls of culverts or potentially bridge abutments.

The height of the vertical drop is critical to prevent wildlife from climbing up into the road reserve, and there are currently no standard designs available yet in Australia. However, early trials on the Pacific Highway (Goldingay *et al*., 2018) show that vertical heights should probably be at least 1.1 m high to prevent use in the reverse direction (i.e., towards the road), and further research is urgently required.

4.3.3. One-way gate

A gate that allows wildlife to exit the roadway, but not access the roadway. One-way gates are rarely recommended because they have jammed open or closed in installations overseas and require additional maintenance to ensure they operate effectively. One-way gates may be effective for wombats (see below), but further research is required.

4.3.4. Escape poles

A U-shaped pole installed on the roadway-side of a fence for trapped koalas and other arboreal fauna to climb up and over the fence. The pole terminates above the ground on the habitat side of the fence, requiring animals to jump the final metre to ground level. While deployed extensively in NSW and Queensland, there has been no monitoring of the use or effectiveness of escape poles.

4.3.5. Wombat pipe or gate

Generally used where wombat digging is causing damage to a fence. A pipe or heavy one-way gate is installed at the bottom of a fence, allowing wombats to pass through without damaging the fence.

Photo 83 Fence for kangaroos and koalas, Calder Freeway (Source: VicRoads)

Photo 84 (Left) Fence for burrowing wildlife (Source: Rodney van der Ree, WSP)

Photo 85 (Right) Koala escape pole (Source: Carla Meers, WSP)

Photo 86 Temporary fencing for Growling Grass Frog (Source: Aidan Cresser, VIDA Roads)

Photo 87 Low fauna fence for small mammals, reptiles, and amphibians at Royal Botanic Gardens Cranbourne, VIC (Source: Austin O'Malley)

Photo 88 Escape ramp for Koalas on W2B Pacific Hwy Upgrade, NSW (Source: Rodney van der Ree, WSP)

Photo 89 Example of one-way gate from the USA (left) and jump out from the Pacific Highway NSW (right) (Source: Rodney van der Ree, WSP)

Figure 31 Fencing — General design principles

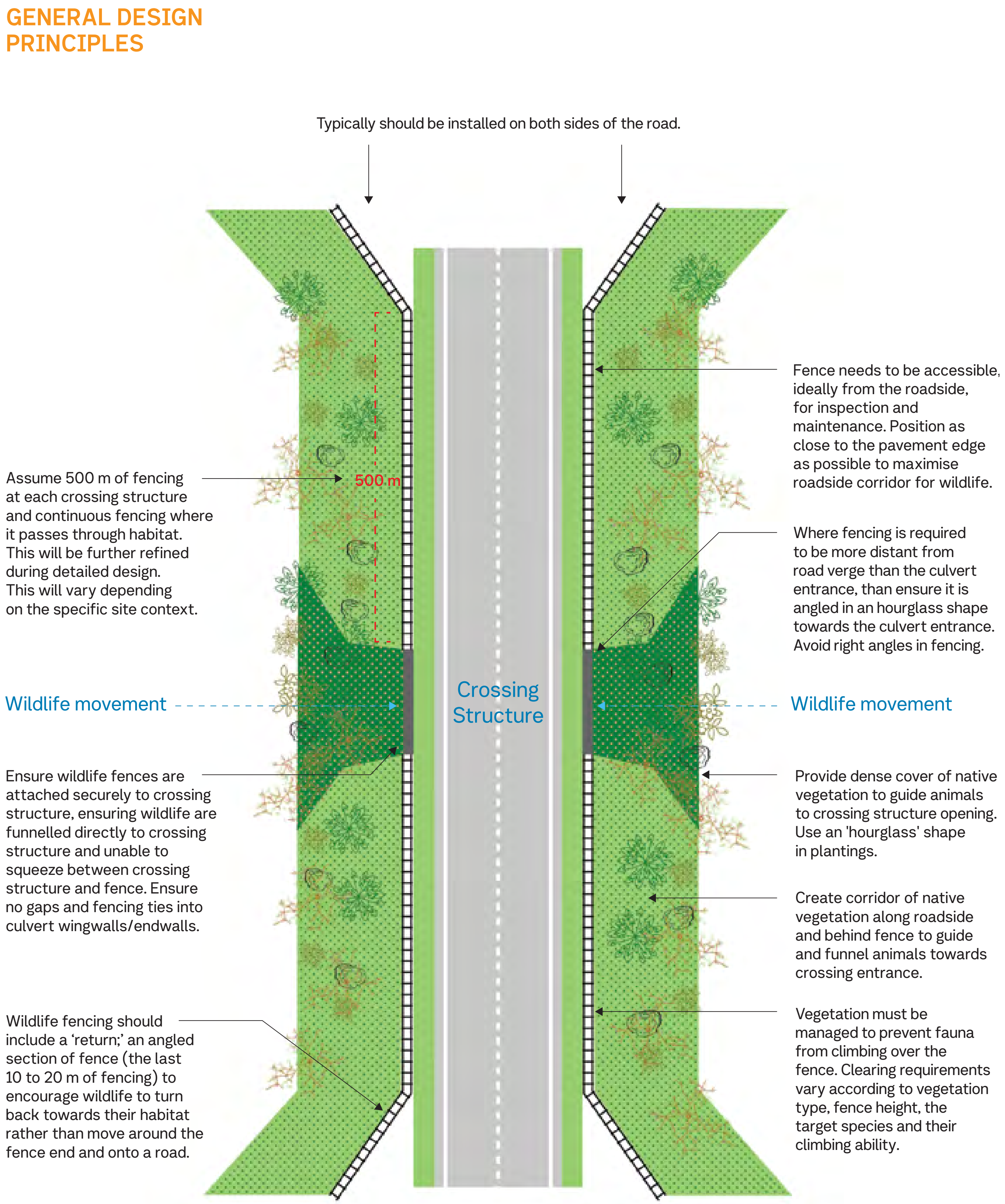


Figure 32 Fencing — Koala, kangaroo, wallaby, and small mammal fencing

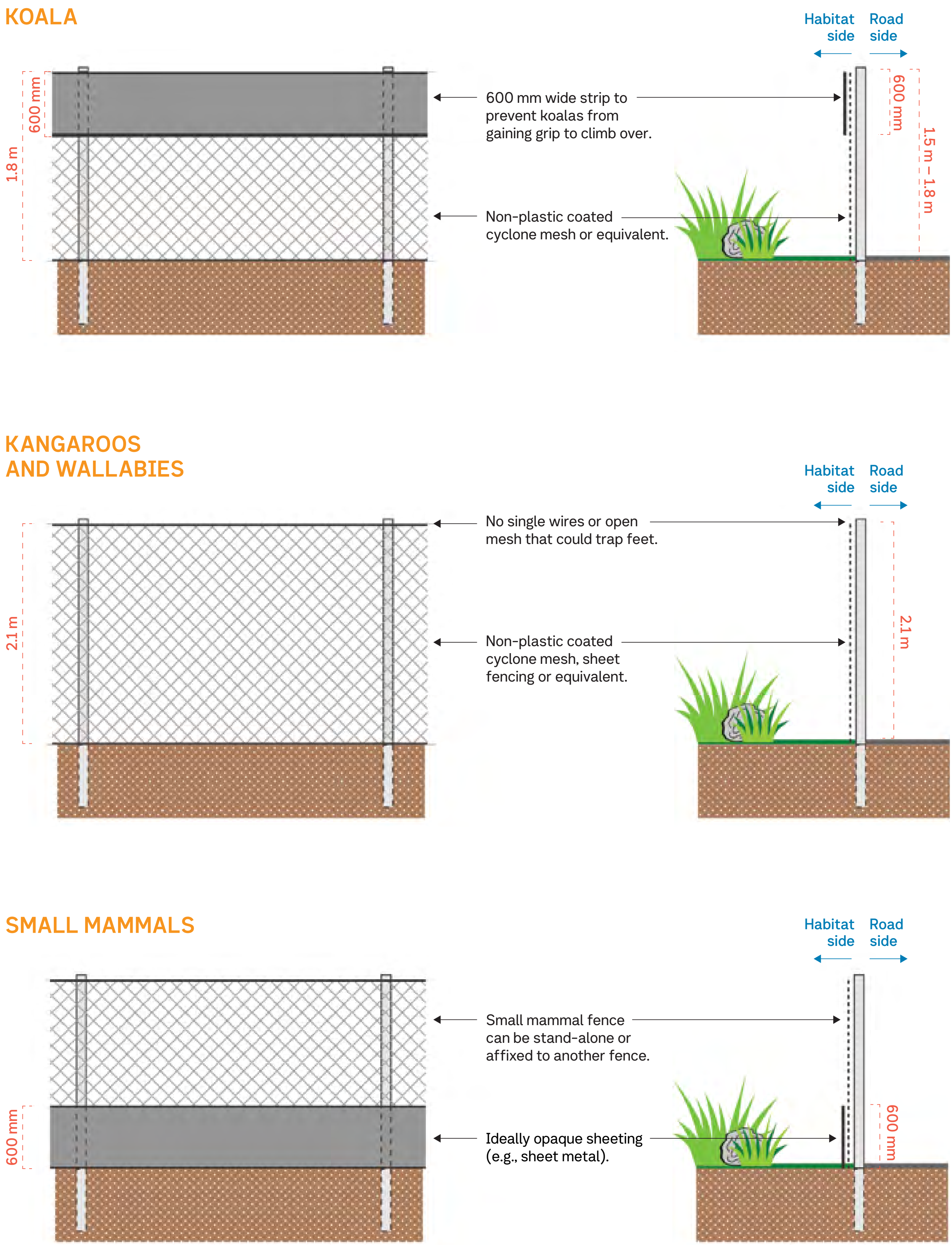
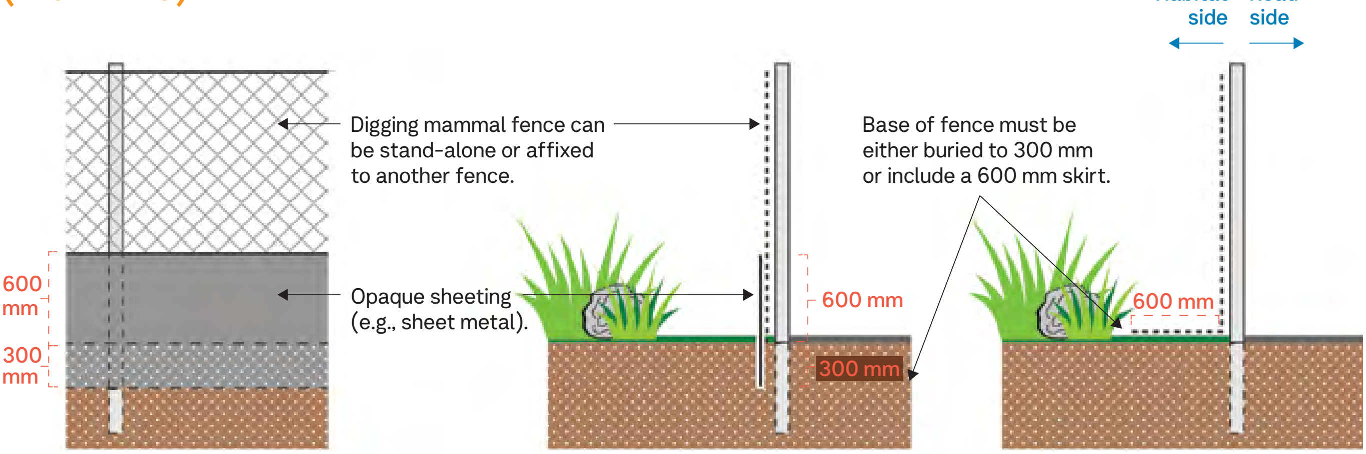


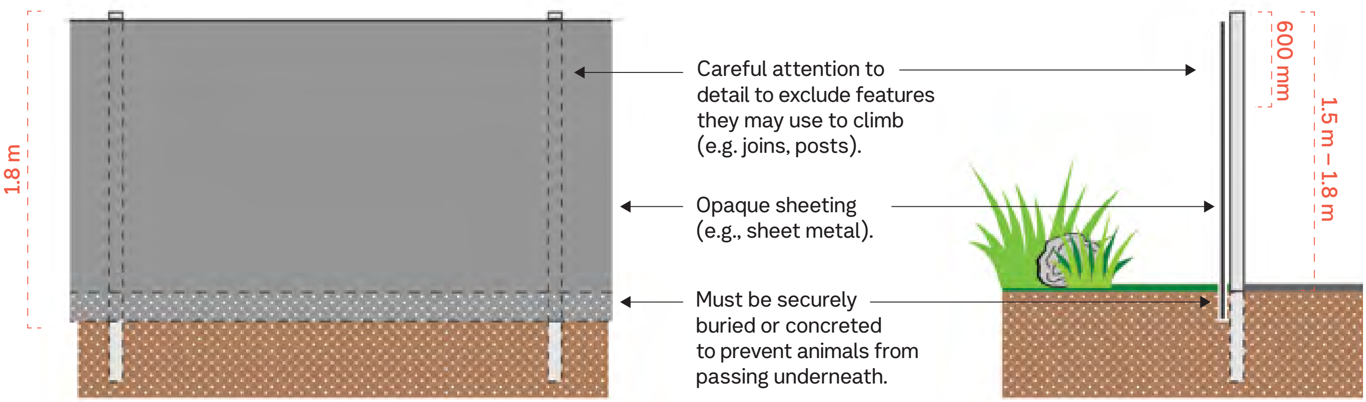
Figure 33 Digging mammals (wombat), arboreal fauna, and amphibian fencing

DIGGING MAMMALS (WOMBATS)

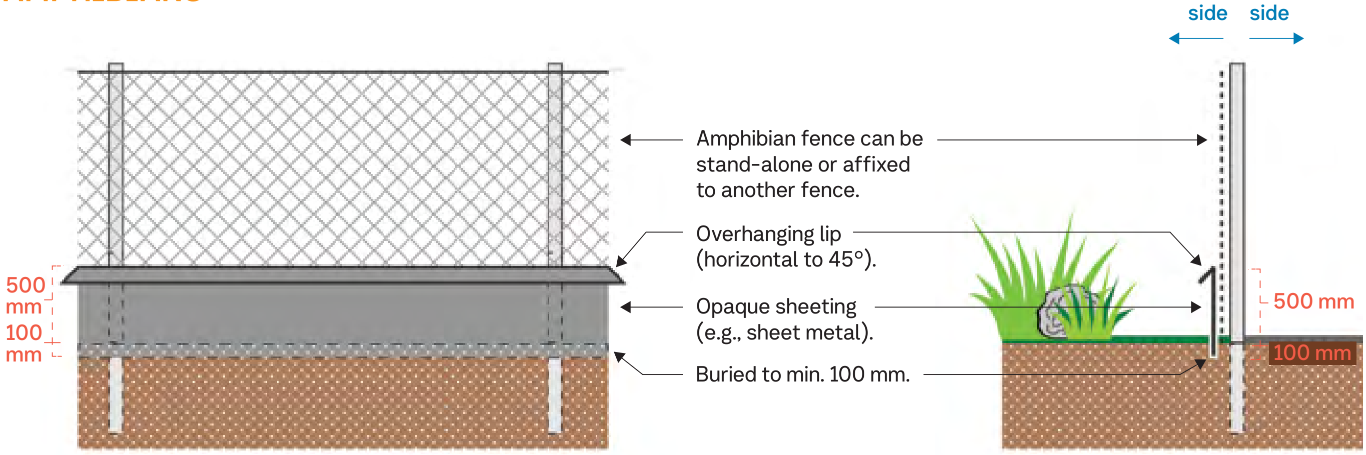


ARBOREAL FAUNA

No standard design for arboreal species (except Koalas). Likely effective design shown below.



AMPHIBIANS



4.4. Virtual fencing

4.4.1. Odour and chemical repellents

Odour and chemical repellents, such as predator scents, have been trialled overseas with limited success (Kušta *et al*. 2015). The use of odour and chemical repellents is attractive as a mitigation strategy because it may be relatively cheap, however, effective application is difficult because:

- The scent must trigger animals to leave the roadside.
- The sensitivity of the same species may vary regionally, as well as amongst individuals.
- Animals may habituate to the scent, causing it to become less effective over time.
- The effects on non-target species, including people, is unknown.
- There are logistical challenges to deployment, including frequent re-application and difficult to apply over large distances.

> Currently, there is limited evidence to support the effectiveness of odour or chemical repellents and there may be unintended negative side-effects. At present, their use as a mitigation measure is not recommended. Further research is required to demonstrate effectiveness and methods of safe application.

4.4.2. Acoustic and visual deterrents

Acoustic and visual deterrents use sounds, flashing lights, reflectors and/or natural wildlife warning signals to scare wildlife from the road corridor as vehicles approach (D'Angelo and van der Ree 2015).

These deterrents theoretically provide additional time for animals to react to an approaching vehicle and reduce the probability of WVC (Backs *et al*. 2020) and may be most beneficial where vehicles are obscured by vegetation or topography, or masked by other competing noises (Backs *et al*. 2017). They are also potentially useful on roads where continuous fencing is not feasible, such as those with lots of driveways or other access points. They are sometimes to referred to a '**virtual fences**' for their objective of keeping wildlife off roads.

Acoustic and visual deterrents are intuitively appealing because they are relatively low cost and simple to install, and because they only operate when vehicles approach, they do not form a permanent continuous barrier. The most common visual and acoustic deterrents in Australia are roadside reflectors and 'virtual fencing'. Virtual fencing for wildlife comes in many forms but usually incorporates an active system using one or more visual and/or acoustic deterrents like high-frequency noise and flashing lights. These are usually contained in poles/bollards placed at regular intervals along the roadside and are activated by approaching vehicle headlights.

Unfortunately, there are few scientific trials of such systems in Australia and those that have been conducted report variable results (Englefield *et al*. 2019, Fox *et al*. 2018, Stannard *et al*. 2021). Importantly, many of these studies have also been criticised for their lack of scientific rigour, casting further doubt on their effectiveness at this point in time (Coulson and Bender 2019, Coulson and Bender 2022).

Limitations

Like all mitigation measures, there are limitations with acoustic and visual deterrent systems:

- Animals must hear or see the stimuli amongst all the other noise and disturbance of the road corridor.
- Animals must associate the stimuli with the danger of an oncoming vehicle and respond appropriately (i.e., leave the road via the most direct route).
- If the stimuli are not associated with danger, it must cause sufficient pain or distress to cause the animal to move away.
- Animals must not habituate to the stimuli over time.
- There is limited study and understanding of the most effective visual and acoustic stimuli for different species of Australian wildlife. Most systems available in Australia were developed for European species, such as ungulates.

More research is urgently needed to explore the effects of different variables such as flashing versus steady lights, light frequency and light brightness, especially on night-vision of nocturnal wildlife (Backs *et al*. 2017).

Trials of visual deterrents are currently underway on a section of Wellington Road in Melbourne and on a section of Cowes-Rhyll Road on Phillip Island, Victoria, which may provide further useful insights into their effectiveness.

Photo 90 Virtual fence using sound and flashing lights (Source: Rodney van der Ree, WSP)

At present, the use of acoustic deterrents or 'virtual fencing' as a primary mitigation measure for WVC is not recommended. Further evidence in the form of rigorous peer-reviewed experimental trials is required to evaluate their effectiveness.

Flight diverters

'Flight diverters' are potentially effective strategies to force birds and bats to fly above vehicles and if solid structures they can also double as noise and/or light walls. Poles and flags have also been trialled and some studies indicate they are effective at raising the flight height of certain species.

Both solid walls and rows of poles may be effective adjacent to waterbodies and coastal areas where birds may fly low on take-off or landing (Hu *et al*. 2020, Zuberogoitia *et al*. 2015). Additional advantages of pole barriers include their relatively cheap price, ability to be retro-fitted to existing roadways and in areas where standard fences are more difficult to install and maintain, such as in areas prone to flooding or in steep terrain (Zuberogoitia *et al*. 2015).

4.5. Light and noise walls

Noise and light walls can also function as wildlife fencing, which can have positive or negative effects on wildlife populations, depending on placement and design. For example, noise or light walls on one side of the road may increase wildlife mortality if animals get trapped on the roadway. Similarly, tall noise walls may decrease mortality for some birds that fly up and over the road and above vehicles, and simultaneously create a more severe barrier for low-flying birds. Calculations of glide trajectories for gliders need to account for the height and placement of noise and light walls (see **Figure 27**).

Recommendations

It is beyond the scope of these Guidelines to specify design parameters for structures to mitigate noise and light impacts, however the following should be considered when used as wildlife fencing:

- Noise mitigation for wildlife should aim to reduce noise levels to ~55–60 dB(A) (Dooling and Popper 2007).
- Wall design and materials should aim for high visibility at all angles to reduce bird collisions and avoid injury. Clear glass or plastics should never be used on walls as birds can fly into them and be injured or die.
- Noise and light walls should be installed on both sides of the road and extend to ground level to prevent animals from passing underneath. If noise and light walls are only required on one side of the road, standard wildlife fencing may be required on the opposite side.
- Designs that allow wildlife to escape should be considered for long installations.
- The wall should be designed according to the needs of the target species.

For further details on noise and light impacts on wildlife and how to mitigate them, see **Section 1**.

Photo 91 Flight diverters and other measures can reduce bird-vehicle collisions (Source: VIDA Roads)

5. Light and noise

5.1. Light

5.1.1. Light impacts

Artificial light at night can adversely affect wildlife and ecological communities in many different ways including:

- Changing behaviour and life cycle events including breeding.
- Disrupting migration and movements.
- Increasing risks of predation and pest attack.
- Acting as a barrier to movement or excluding animals from foraging habitat.

With the rapid proliferation of lighting in recent times, including energy efficient LED lighting, light pollution is becoming an increasingly greater threat to wildlife populations and ecosystem processes. Many species are also particularly sensitive to light in the UV-blue spectrum, of which many LED lights have greater content when compared to older incandescent lights. Consequently, along with there being more light pollution overall, it is also more disruptive to wildlife than previously.

5.1.2. Light mitigation

Streetlighting and any other lighting for road delivery should only be installed wherever absolutely necessary for motorist and pedestrian safety and to meet required lighting standards.

Lighting should be designed with reference to the National Light Pollution Guidelines for Wildlife (DCCEEW 2023; **Figure 35**).

Some ways to minimise light impacts include:

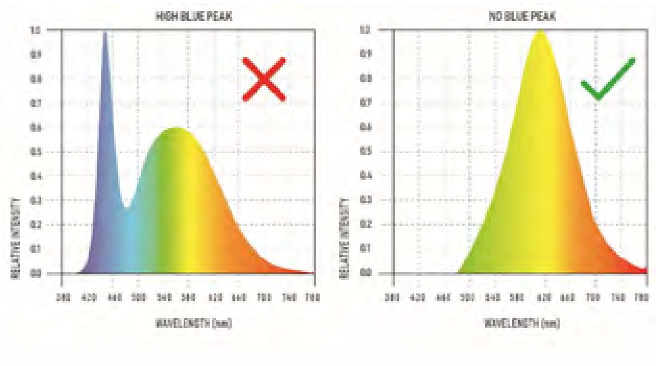
- Avoid use of lights and light spill into adjacent roadside habitats and at wildlife crossing structures, habitat corridors, or waterways where possible – only add lighting for specific purpose.
- Consider spacing and location of lighting to illuminate only the intended area (e.g. roadway) and minimise light spill.
- Using the lowest intensity lighting possible appropriate for the purpose.
- Do not over-illuminate roads and attempt to keep to within 20% excess light.

- Use sensors or timers to only illuminate when required or manage intensity and colour.
- Implement temporal limits to lighting, e.g. automated deactivation of decorative or unessential lighting at a set time each night when no longer required. This will allow some periods of darkness for wildlife.
- Use presence-controlled lighting for pedestrian and bicycle paths activated by movement.
- Keep lights close to the ground, directed to areas that require illumination, and shielding to reduce light spill beyond them, particularly any areas supporting fauna habitat, at wildlife crossing structure locations, or at waterway corridors.
- Use red wavelength LED lights where possible and avoid short wavelength light (400–500 nm blue light spectrum) which causes greater scatter into the atmosphere and affects wildlife more than lighting with longer wavelengths. This includes lights with higher blue content and wide emission spectrum (**Figure 34**). Alternatives which are safer for wildlife include HPS or filtered LED and metal halide lights with LED filters including commercially available:
  - High and low-pressure sodium vapour
  - Filtered LED a
  - Filtered metal halide a
  - Filtered white LED a
  - Amber LED
  - PC amber
- Use luminaires with flat glass to reduce light spill.
- Do not exceed a maximum correlated colour temperature of 3000k (i.e. yellow, warm light) where possible.
- Use physical barriers such as wall (noise) barriers or soil berms to reduce street light spill and/or vehicle lights into habitats, waterways, wetlands, or crossing structures.
- Use non-reflective and darker coloured surfaces.

Light mitigation is generally required where roads pass through habitat that support species of wildlife that are sensitive to light or within proximity of wildlife crossing structures. Barrier walls are also required on land bridges and the approach to them to minimise noise and light extending onto the structure.

To a lesser degree, dense plantings of vegetation can also reduce light penetration, but do not have the additional benefit of reducing noise. Lighting of wildlife bridge underpasses (e.g. for pedestrian safety) can reduce rates of use by insectivorous bats and should be avoided (Bhardwaj *et al*. 2020). Lighting on and around other crossing structures should also be avoided (see **Section 3** for specific lighting requirements).

Figure 34 Avoid blue light spectrum (400–500 nm) in lighting (Source: DCCEEW 2023)



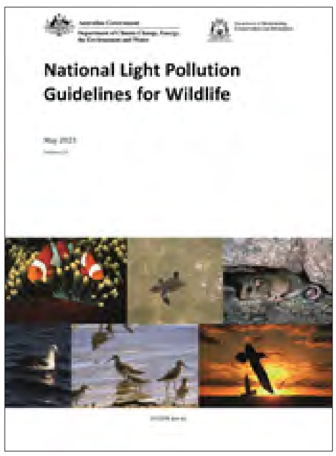
Assessment and management

An important step to avoiding and minimising impacts from a particular activity is to first understand baseline conditions of the environment to appreciate how particular designs could impact wildlife populations. Photometers are devices that be used to measure night sky illumination and could be used to build a map of existing conditions along with measuring changes over time. In combination with an understanding of sensitive wildlife habitat locations, an analysis of various lighting design approaches can then be implemented for informed decision-making to minimise lighting impacts on wildlife populations and their habitats. Before and after field assessment can then be used to measure the performance of design decisions, management actions, and specific mitigation measures.

Other resources:

- DCCEEW (2023) National Light Pollution Guidelines for Wildlife. Department of Climate Change, Energy, the Environment, and Water.
- Science for Environment Policy (2023) Light Pollution: Mitigation measures for environmental protection. Future Brief 28. Available at ec.europa.eu
- Lockett, M. (2022) Wildlife Sensitive Lighting – Tools for local and state government. University of Melbourne.

Figure 35 National Light Pollution Guidelines for Wildlife (Source: DCCEEW 2023)



5.2. Noise

5.2.1. Noise impacts

Noise pollution occurs primarily during the construction and operation of roads. Construction noise is typically high intensity but of relatively short duration, while traffic noise is ongoing, with peaks in the morning and evening and typically lower intensity than construction. These peaks correspond with the dawn and afternoon chorus of bird song and amphibian calling, limiting their ability to communicate effectively.

Anthropogenic noise can have significant direct and indirect impacts on fauna:

- Reduced ability of species to hear prey, predators and mates.
- Reduced breeding success.
- Increased stress levels.
- Alterations in the timing, volume, and/or frequency of calling or activity, with potential energy costs associated with these changes.
- Modified development, physiology, and behaviour of species in aquatic systems.
- Temporary or permanent hearing damage.
- Lower survival rates.
- Reduced density, richness, and/or activity of affected fauna species in noisy habitats.

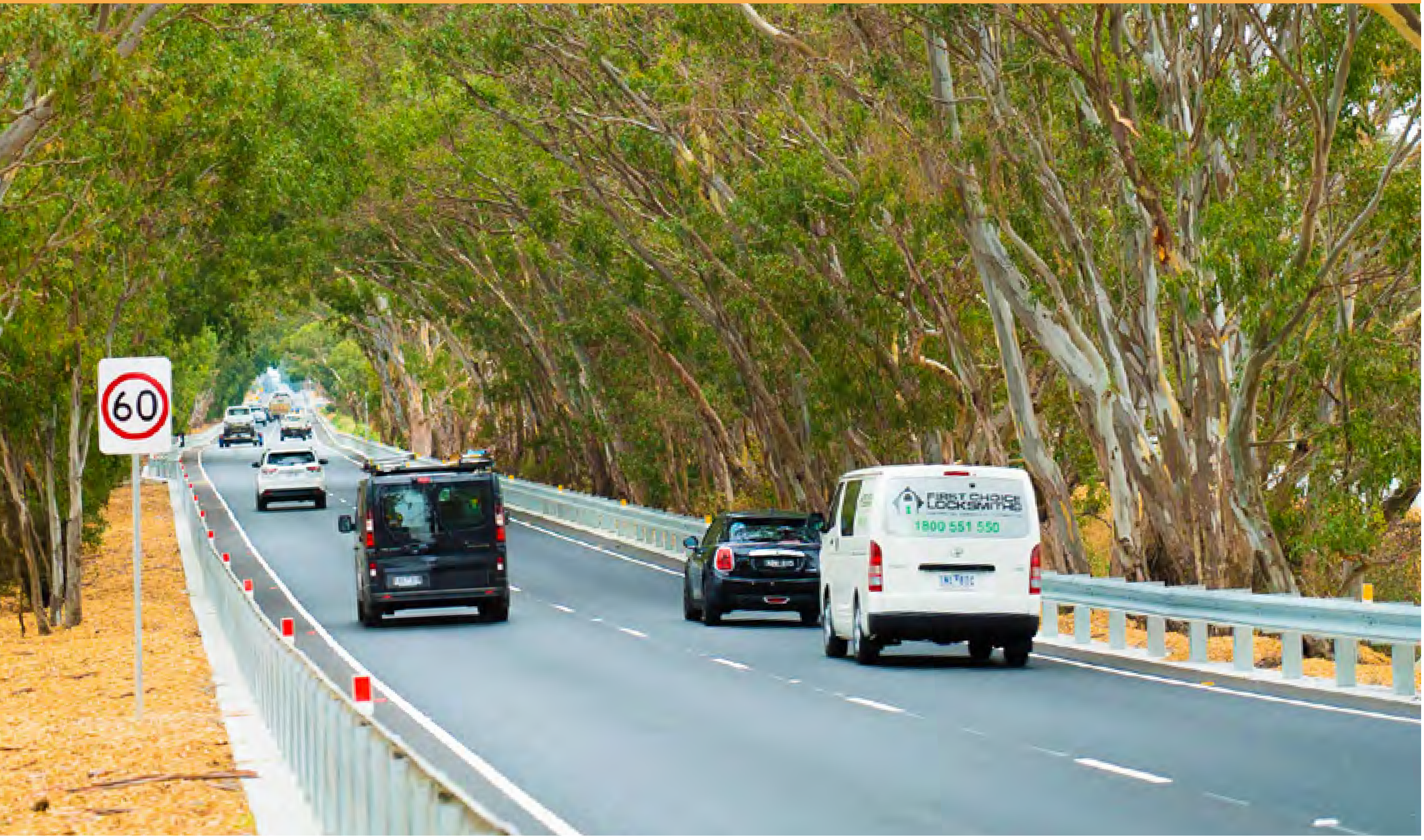
5.2.2. Noise mitigation

Traffic noise can be mitigated using similar methods to those used to mitigate noise on people, including:

- Minimise noise levels during construction where practicable.
- Avoid high-noise activities (e.g. pile driving) during critical life cycle periods such as breeding and dispersal.
- Use noise walls or soil berms to deflect noise away from wildlife habitats and crossings.
- The type of pavement used, however, wear and re-sealing of the road surface over time may reduce the effectiveness of this approach.
- Reducing vehicle speed and decreasing vehicle braking and acceleration, however this is limited on high-speed roads.
- Vegetation plantings are not effective at mitigating traffic noise.

Common Ringtail Possum (Dean Ingwersen)

6. Other mitigation measures



6.1. Traffic calming

Traffic dynamics play a major role in WVC. Vehicle speed directly impacts driver reaction times and stopping distance with some recent studies showing a link between vehicle speeds and increased wildlife collisions (Jones 2000). Reduced vehicle speeds can therefore reduce the rate of collisions and wildlife mortality, as well as the severity of outcomes for motorists.

Traffic calming relates to managing the speed, timing and/or volume of traffic on a road in order to reduce the rate and/or severity of WVC. However, motorists typically drive at the design speed of the road and forcing drivers to drive slower without changing the design of the road is very difficult.

The implications (and impact) of higher traffic speed and volume should be considered at the time of road development and design and efforts made to reduce these as much as feasible, particularly at locations where fauna are more likely to attempt to move across a road, such as intersections with waterways, habitat corridors, or where roads pass through or beside patches of habitat.

Some measures to reduce speed or keep drivers to set limits include speed bumps and surface treatments. Higher speed limits are generally applied to sealed roads versus unsealed roads, with resulting lower vehicle speeds on unsealed roads. An increase in WVC involving eastern quolls and Tasmanian Devils in one Tasmanian study was attributed to a road upgrade and increased speed limit and associated vehicle modal speed increase of 20 km/hr (Jones 2000). Within 17 months of the road upgrade the eastern quoll population had gone extinct, and the Tasmanian Devil population had halved. Reinstated reduction in vehicle speed by 20 km/hr led to the recovery of both populations. Other studies have also found a correlation between wildlife roadkill and higher vehicle speeds (Hobday and Minstrell 2008).

Speed reductions may be spatially targeted at high incident areas or timed to coincide with biological events such as time of day (e.g. dawn and dusk) and breeding or migration events when wildlife are likely to access the road. However, these measures are more difficult to implement and complex to manage long-term when compared to a reduced set speed limit. If variable speed limits are the only option, then this is best considered early in the business case phase and factored into additional costs for permanent electronic signalling systems.

Current practice

All measures will be required to meet DTP Traffic Engineering Manual requirements. Speed limits and speed reduction structures are determined through the application of standards set out in the VicRoads Traffic Engineering Manual and the Department Speed Zoning Policy and supporting Speed Zoning Technical Guidelines.

6.2. Wildlife signage

Signs are intended to modify driver behaviour by warning them of an increased risk of collision or advising of enforced or recommended reductions in speed. The intended effect is to reduce driver speed and/or increase alertness to potential wildlife on the road.

There are three types of wildlife warning signs used on roadsides: standard, enhanced and temporal (Huijser *et al*. 2015).

6.2.1. Standard signs

Standard signs are typically the same style and dimensions as other roadside warning signs, and in Victoria are often a stylised black animal on a yellow background. While standard signs are commonly used around the world, they have **little to no effect** on vehicle speed (Huijser *et al*. 2015).

The vast majority of drivers do not modify their behaviour in response to standard signs because they rarely see wildlife and therefore do not trust or believe the sign. In addition, the widespread deployment of standard signs in areas with few animals reinforces this perception, thereby minimising effectiveness everywhere, including in high-risk areas.

DTP (Transport) and VIDA Roads do not recommend standard signage alone as an effective, long-term solution, for reducing wildlife collisions and mortality. They may be, however, used for the purpose of increasing general awareness of wildlife or threatened species.

Photo 92 Roadside signage

6.2.2. Enhanced and temporal signs

Enhanced signs may be larger than standard signs and include flashing lights, and/or disturbing images or text designed to grab the driver's attention, such as real-time data on the number of WVC in the area. Temporal signs operate at certain times of the day (dawn or dusk) or year (migration season) and warn motorists of a heightened risk of collision.

Enhanced signs and temporal signs may reduce vehicle speed slightly because the information is targeted to a species, specific to an area and only operate when the risk of WVC is high. For example, enhanced signs with real-time data on the rate of WVC on a stretch of road would explicitly inform drivers of the actual number of collisions and reinforce the high risk of collision.

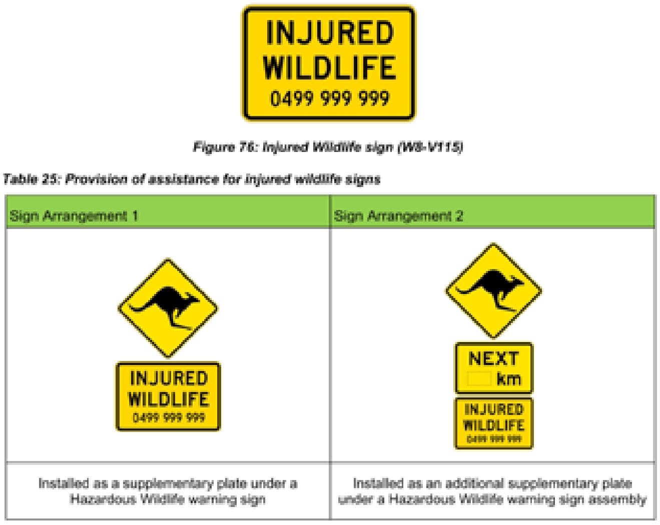
Enhanced or temporal signs could be trialled subject to monitoring to demonstrate effectiveness. They should only be used in instances where reductions in driver speed are feasible and safe. They are not a replacement for fauna crossings integrated with wildlife fencing where the primary objective is to provide safe passage across a road barrier.

Current practice

The main references for road signs in Victoria are contained in AS1742:2 (including designs) and AS1743. Guidance on sign design and requirements for wildlife awareness (injury) are included in Appendix H of AS1742:2. In DTP's Traffic Engineering Manual (Clause 4.11.2.7 Hazardous wildlife) the need for hazardous wildlife signs to warn road users is determined through consultation with the state Department of Energy, Environment and Climate Action (DEECA) to ascertain wildlife numbers and movement patterns and frequency; and reputable sources of recorded wildlife incidents (police, council rangers, maintenance supervisors, wildlife protection groups, etc.).

Photo 93 Example of wildlife hazard sign for kangaroos (Source: Rodney van der Ree, WSP)

Figure 36 DTP Guidance on signs for injured wildlife (Source: VicRoads 2021)



Importantly, approved Victorian DTP standards for wildlife signage only apply to situations in which wildlife are a hazard to vehicles and motorists (and not the other way around) or where there may be injured wildlife. Although they could be used for this purpose, there are only a small number of native animals in approved DTP signage with bright warning colours e.g. kangaroos, koalas, wombats.

A different class of approved wildlife signage may be required that could be used for smaller animals e.g. bandicoots. There are also many requirements around signage content and location that must be considered in determining the appropriate type and location of signage.

Figure 37 Warning signs for (larger) hazardous animals (Source: VicRoads 2021)

Figure 38 Information signs for smaller wildlife (Source: State of Queensland (Department of Transport and Main Roads)

6.3. Animal detection systems

Animal detection systems are vehicle- or roadside-based devices that detect the presence of wildlife and alert motorists and/or wildlife, thereby reducing the risk of WVC (Huijser *et al*. 2015). Animals are detected using a range of technology, including 'break the beam' and other sensor types, and motorists are alerted via enhanced warning signs or in-car GPS messaging. Roadside detection systems targeting ungulates and large carnivores continue to be tested in North America and Europe, however they have not been trialled in Australia. A promising approach is in areas where wildlife is funnelled by fencing to a specific location where they can cross the road 'at grade', and thus the warning to motorists is applied to a specific area.

Animal detection systems are only suitable in certain situations, including (Huijser *et al*. 2015):

- Where sudden reductions in vehicle speed in response to detected wildlife do not result in increased risk of collision with other vehicles.
- Relatively low traffic volume.
- Areas with the necessary power supplies and topographical conditions for the method to detect wildlife and alert motorists.
- Where the target species is large enough to be detected by sensor.
- Where the roadside vegetation and topography enable the deployment of a reliable detection system.

6.4. Predator control

The disturbance associated with road construction activities may result in increased activity and predation from feral predators, such as the European red fox and feral cats. Co-ordinated and integrated predator control programs may be required in situations where road projects increase the risk of threatened fauna species being predated by cats and foxes.

This may be required until protective cover and shelter is available until replacement habitat plantings become established.

Predator control should be established during the pre-construction phase, aiming to reduce predation pressure in habitats within and adjacent to the project area. The broad objective is to mitigate potential impacts of the road and enhance the viability of target species populations. Predator control could cease after the revegetation has matured and the risk of predation has declined or continued by DTP and/or adjacent land managers.

A predator control program should include:

1. Baseline monitoring prior to predator control. This includes monitoring of populations of the target predator and focal native species, and predation rates.
2. Predator reduction targets informed by baseline monitoring.
3. Integrated and stratified method consistent with current best-practice and local laws (e.g. some methods cannot be implemented in urban areas due to domestic dog and cat presence).
4. MER (see **Section 8.4**) to assess the success of the program.
5. Annual review of targets, success and monitoring to determine whether the program should be modified to improve outcomes.

Photo 94 The European Fox (*Vulpes vulpes*) and domestic cat (*Felis catus*) have had a devastating impact on native wildlife populations, particularly small mammals (Source: VIDA Roads)

6.4.1. Risk of predation in wildlife crossing structures

It has been theorised that wildlife crossing structures could be prey-traps for wildlife because predators learn that they can get an 'easy feed' at those locations, termed the 'prey-trap' hypothesis.

However, as discussed in **Section 3.2.4** above, there is little evidence that predators systematically use crossing structures in this way (Little *et al*. 2002, Mata *et al*. 2015, Soanes *et al*. 2017). In addition, numerous studies, including some on canopy bridges over the Hume Freeway in Victoria and NSW, found the same individuals using the bridges over multiple years, demonstrating successful long-term use without substantial predation by owls (Soanes *et al*. 2015).

Some more recent Australian research has further demonstrated that installation of fauna crossing structures does not inherently increase predator activity and predation risk for wildlife at crossing locations (Goldingay *et al*. 2022).

Nevertheless, predation and attempted predation can occur at crossing structures because they can be used by both predators and prey, potentially at the same time. As such, wildlife crossing structures should contain furniture (**Section 7.3**) and be coupled with a monitoring and evaluation program (**Section 8.4**) and a predator control program to ensure the structure is functioning as intended.

Improved outcomes will be achieved by combining measures to reduce predator populations with other complimentary measures to reduce predation risk, including:

- **Retaining native vegetation, fauna habitats, and natural shelter** wherever possible within the road project area. Native local wildlife populations are innately adapted to them and have persisted with continued and sustained predation pressure by cats and foxes. During removal and until establishment of any habitat re-instatement (e.g. revegetation or landscaping), wildlife populations will be at increased risk of predation. For both these reasons, retention of existing habitats and shelter is preferred over restoration.
- **Increasing continuous protective cover** from predators in the form of dense vegetation within (for bridges), on (land bridges), and up to entrances (of all types of crossing structures).
- **Adding appropriate shelter such as hollow-logs, roof tiles, rocks, tree-hollows** and specifically constructed shelters that provide shelter and protection to specific target species or fauna generally from predators. An example of a shelter for the Southern Brown Bandicoot is shown in **Photo 104**. These must be informed by the types of shelters used by the target species or attempt to replicate these using artificial equivalents e.g. tiles instead of rocks for reptiles.

- **Reducing gaps in habitat** (revegetation and landscaping) which provides protective cover where animals would be exposed to predators.
- **Including native plants species** in landscaping or revegetation which provide wildlife a dense protective cover to hide from predators. This includes creating dense clumps of grasses/sedges or shrubs, along with incorporating species with thorns and spikes such as Hedge Wattle and Prickly Moses (particularly effective for small birds). Suitable plant species selection must be appropriate for and guided by the focal fauna groups or species being targeted by the FSRD measures.
- **Increasing the width of crossing structures** (land bridges, underpasses, and culverts) to reduce the chance of predator-prey interactions.
- **Implementing predator control programs** using baits and/or soft jaw traps.

In some cases, it may even be important to consider **retention of exotic vegetation** where it affords important protection from predation. An example for this is with the nationally threatened Southern Brown Bandicoot, for which dense stands of exotic Blackberry provide critical protection from foxes and cats. For this reason, the removal of Blackberry stands is recognised as a potential significant impact to the species under federal *Environment Protection and Biodiversity Conservation Act 1998* under draft referral guidelines for the species (DSEWPC 2011).

Monitoring of predator populations is also important to assess the level of risk to wildlife, effectiveness of management measures, and adaptive management, particularly predator control programs, to ensure the right level of population reduction and predation risk is attained.

These complimentary measures become more important where predator control programs are not feasible, such as more heavily urbanised areas.

Photo 95 Domestic cat (*Felis catus*) with native mammal prey item

Common Wombat, Dean Ingwersen

7. Biodiversity enhancement

Biodiversity enhancement includes the reinstatement of native vegetation along with the creation of habitat for wildlife and is a critical element to ensuring the effective functioning of wildlife crossing structures and achieving FSRD objectives.

Restoration objectives may be focused on a specific community — such as the threatened Victorian Volcanic Plains Grasslands (and the faunal community it supports), a faunal group (woodland birds), a specific threatened species, or a wider landscape function like habitat connectivity. Biodiversity enhancement and restoration objectives and treatments are context-specific, and advice should be sought from a qualified ecologist to determine those most appropriate.

7.1. Restoring habitats and ecological connectivity

Restoration of vegetation along roadsides provides habitat and resources for a wide range of flora and fauna species and supports functioning and healthy ecosystems. It increases the amount of available habitat and resources within the landscape for fauna to utilise while also serving as habitat corridors or stepping-stones to facilitate movement of animals across a landscape, either for daily movements or dispersal, and supporting ecosystem services like seed dispersal and pollination.

Remnant roadside vegetation often forms the only remaining habitat connectivity in modified landscapes, connecting populations and larger areas of extant habitat. Maintaining and enhancing this connectivity is recognised as a key measure to combat the impacts of future climate change on wildlife populations.

Restoration of wildlife habitats may be required as a mitigation measure to meet environmental regulations of approval conditions. These are often required to be tailored to specific threatened species habitat requirements but can also serve to provide habitat and connectivity for a wide range of native fauna species (**Photo 96**). Opportunities to protect and enhance habitat connectivity through roadside restoration should be explored on all VIDA Roads projects early in the project lifecycle.

Photo 96 Revegetation of pond to create habitat for the threatened Growling Grass Frog, Princess Highway (Source: Austin O'Malley, VIDA Roads)

7.2. Revegetation and landscaping

Revegetation is the re-establishment of native vegetation in areas where it has been removed or disturbed. Revegetation can create habitat for native plants and animals, assist wildlife movement and reduce soil erosion.

Revegetation can be informed by standards outlined under DEECA's *Native vegetation gain scoring manual – version 2* (Appendix 1) and *Native Vegetation Revegetation Planting Standards* (DELWP 2006), with the former taking precedence. Higher planting densities than those defined in these documents may be needed to meet approval requirements or specific ecological or landscaping objectives. Indigenous plants of local provenance should be used to ensure plants are adapted to the local conditions (see **Photo 97**).

The recommended range of species should be appropriate to the pre-European bioregional Ecological Vegetation Classes (EVC) relevant to the site and local conditions (e.g. soil, topography, aspect), and be informed by site floristic surveys and biodiversity database (flora) records.

A list of native remnant flora occurring in the project area can be collected as part of a **VIDA Roads Detailed Ecology Assessment** and used to inform a revegetation list for the project. Seed collection is best undertaken well before vegetation removal and used to propagate indigenous species for landscaping, native revegetation, and habitat restoration across the project area. Revegetation can either re-establish native vegetation and fauna habitats or enhance them through supplementary plantings, such as adding trees to provide canopy habitat or restore specific species within a natural ecological community, including threatened species (see **Photo 98**).

In order to develop an appropriate revegetation species list for the site, consideration should also be given to the relevant floristic community, local environmental and site conditions, ease of propagation, and likely availability from nurseries.

Photo 97 Revegetation should use species appropriate to the bioregional EVC of the site, and locally indigenous stock where possible (Source: VIDA Roads)

Photo 98 Supplementary planting of a threatened species, Matted Flax-lily, into remnant bushland (Source: VIDA Roads)

In some situations, specific revegetation plans that do not adhere with these standards may be developed to benefit a specific species of threatened fauna. For example, additional prickly shrubs may be added to the species mix to benefit small woodland birds or threatened small mammals (**Photo 99**). These modifications should be informed by fauna ecologists and endorsed by the relevant regulator.

Photo 99 Revegetation to restore habitat for the threatened Southern Brown Bandicoot, Healesville-Koo Wee Rup Bypass (Source: Clio Gates Foale, VIDA Roads)

Other steps that can be taken to improve outcomes in revegetation or landscaping include:

- **Early planning and implementation is critical to success.** Allow sufficient lead time to develop an appropriate planting list (schedule), acquire relevant approvals, collect seed, and order and grow plants. Generally, this should commence at project commencement or earlier allowing for two or more planting seasons.
- Obtain advice early from revegetation and landscaping contractors, restoration ecologists, native plant nurseries, and landscape architects to develop an appropriate list of local provenance species that will meet the correct structural and habitat requirements of the target species.
- Collect and store topsoil for use in landscaping according to best practice techniques.
- Collect and store topsoil from higher quality remnant native vegetation areas approved from removal. This will contain a seedbank that can assist in natural regeneration of habitats.
- Ensure only healthy plant tube stock is used (**Photo 100**).
- Collect seed from vegetation prior to clearing (**Photo 101**), ensuring the timing and method of seed collection is appropriate to the species.
- Collect and store large rocks. Place bush rock on surface in revegetation areas or existing vegetation to provide shelter to wildlife.
- Retain and store timber, logs, and course woody debris for addition to landscaping or habitat creation areas.

Photo 100 Healthy tube stock of a diverse range of indigenous flora species (Source: VIDA Roads)

Photo 101 Collection of seed of local provenance from remnant trees on-site conserves local genetic diversity (Source: VIDA Roads)

7.2.1. Revegetation for crossing structures

Vegetation should be planted right up to the entrance of bridge underpasses, culverts and land bridges to encourage wildlife to use the structures. Vegetation plantings should:

- follow the locally indigenous EVC and use indigenous stock wherever possible.
- match the adjacent vegetation (species and compositional structure) and provide a continuation of the natural landscape unless there is a species-specific requirement to rehabilitate habitat (e.g. more trees to provide shade for threatened fish vs. less trees to provide basking opportunities for threatened frogs).
- be shaped to funnel wildlife towards the underpass.
- consist of the preferred habitat of the target species.
- not be so dense as to obscure sightlines through the underpass.

7.3. Habitat creation

Habitat creation is the protection, enhancement, and restoration of habitats for native flora and fauna. This can involve the complete restoration of habitats or ecosystems where none existed previously or the addition of specific habitat elements (e.g. litter, hollow logs, tree hollows, waterbodies) or niches to support more species or to improve ecological connectivity.

7.3.1. Fauna furniture for crossing structures

The provision of 'fauna furniture' within and at the entrance to crossing structures is essential to maximise the rate of use by wildlife and minimise the risk of predation, particularly for species of conservation concern, species vulnerable to predation and those that avoid open areas.

Examples of fauna furniture and other habitat enhancements to reduce the likelihood of predation, include installing refuge pipes, placement of rocks, logs, branch piles, and the use of above-ground ledges, shelves and rails. Fauna furniture should be a combination of artificial shelters and natural features that are specific to the target species. Furniture can be installed on the ground, attached to walls, or built into the structure itself (e.g. bat roosts built into culverts).

The inclusion of fauna furniture in wildlife crossing structures that are also used for drainage should ideally be identified in early reference designs to ensure that it is accounted for in flood modelling. The size of bridges and culverts may need to be increased to take into account any hydraulic restrictions imposed by the furniture. Fauna furniture should be secured in place to ensure it is not washed away during flood events.

7.3.2. Shelters

Various forms of natural and artificial shelters encourage wildlife use of crossing structures and can be essential in ensuring they achieve their intended function of facilitating movement of animals. They provide animals with shelter for resting and protection from predators, and may also be important for breeding e.g. tree hollows. They aid in helping animals use an area near or along a crossing structure (**Photo 102** and **Photo 103**) or provide critical habitat features that enable them to make use of an area e.g. for breeding or shelter such as tree hollows.

Natural shelters include:

- hollow or large logs (**Photo 103**)
- tree hollows (**Photo 121**)
- retained dead standing trees (stag trees)
- dense vegetation (**Photo 99**)
- course woody debris (**Photo 102**)
- rocks.

> Shelters also afford animals with important protection from predators, both the perceived and actual threat.

Consequently, a species will be more likely to make use of an area that contains appropriate shelter, along with reducing risks of predation. This is particularly important when guiding animals towards and through fauna crossing structures (see **Sections 3.2.4** and **7.4.1** for further discussion).

Artificial shelters are those that replicate these natural shelters in wildlife habitats, or provide functional alternatives, that animals would otherwise use for shelter. Both artificial and natural shelters provide protection from predators and provide a type of 'structural connectivity' which helps animals in moving between areas of habitat.

The type of shelter should be informed by the ecology of the target species and fauna groups which is being targeted and what is known of their behaviour from research. For example, bandicoots will use low hide-type structures (see **Photo 104**, **Photo 108**, **Figure 40**) or debris piles (**Photo 105**) but do not use hollow-logs or artificial equivalents.

Photo 102 Tree stumps and timber piles retained on a land bridge for small animals (Source: Rodney van der Ree, WSP)

Photo 103 Example fauna furniture and natural shelters — large logs laid on the ground beneath the Calder Freeway (Source: VicRoads)

Photo 104 Bandicoot hide shelter from side showing entrance door (A) and placed in-situ (B) (Healesville-Koo Wee Rup Road Upgrade; Source: Eddy Hou, VIDA Roads)

Photo 105 Bandicoot timber shelter pile (Healesville-Koo Wee Rup Road Upgrade; Source: Austin O'Malley, VIDA Roads)

Various shelters can be made from either natural or artificial non-biodegradable materials. Those made from natural materials include:

- Hollow log shelters created form naturally hollow tree trunks and limbs from felled trees (on-site).
- Logs (trunks or large branches) mechanically hollowed out for either placement on ground or in trees or poles (see **Section 7.4.1**).
- Shelter (debris) piles of tree and shrubs trunks and branches >10cm diameter (see **Photo 102** and **Photo 105**).
- Constructed wooden nest boxes (see **Photo 115**).
- Constructed wooden hide-type shelters (see **Photo 104** and **Figure 40**).

Examples of artificial non-biodegradable shelters include:

- Lengths of concrete, terracotta or plastic pipe (approximately 15 cm diameter and 0.4 to 1 m in length) stacked to mimic a log pile (see **Photo 106**).
- Terracotta or concrete tiles for reptiles.
- PVC pipes on glider poles, canopy bridges, or along elevated rails in large terrestrial for arboreal marsupials (possums and gliders).
- Alternatives using recycled plastic materials could also be investigated.

Artificial shelters are best placed within (or along the length) crossing structures and near entrances. Shelters within box culverts or arch structures, may be required for the life of the structure as vegetation or natural counterparts cannot establish within the crossing structure. Artificial shelters near culvert entrances, on land bridges, and (potentially) under bridges, may be temporary in nature until vegetation establishes and natural shelters (and habitat) becomes established.

Artificial shelters:

- Install within and at entrances to all box culverts and arch structures, under bridge underpasses, and on land bridges.
- Design to have numerous options for small animals to enter and exit.
- Construct from natural biodegradable materials if intended as temporary shelter until establishment of vegetated cover (i.e. landscaping or habitat creation).
- Construct from long-lasting non-biodegradable materials if intended to be permanent structures and ensure securely fixed (e.g. terracotta pipes fixed to crossing structure with concrete; see **Photo 106**).
- Construct wooden artificial shelters using hardwood or marine ply for greater longevity.
- Construct non-biodegradable shelters from materials such as concrete, terracotta, or recycled plastic. Care must be taken to ensure materials will not break down in the environment and introduce pollutants.
- Artificial shelters should be secured safely to crossing structures or otherwise fixed so that they cannot be moved — **see example in Photo 106 showing pipe shelters cemented together and to the culvert floor**.
- Care must be taken to ensure artificial shelters are not accidentally driven or mown over, particularly once vegetation is established. Star picket posts or similar should be used to identify their location.

If future access and maintenance of fauna furniture within the crossing structure is unlikely, furniture should be constructed from non-biodegradable material. In contrast, wooden shelters near culvert entrances may be appropriate if surrounded by planted or existing vegetation that will eventually establish a protective shelter for animals, as these wooden structures are will eventually break down over time.

Photo 106 Terracotta pipe pile shelter and natural floor treatment (Healesville-Koo Wee Rup Road Upgrade; Source: Austin O'Malley, VIDA Roads)

7.3.3. Elevated logs and refuge poles

With sufficient clearance from the structure ceiling, crossing structures can include elevated logs and refuge poles to provide alternative pathways and allow wildlife to avoid predators:

- Elevated horizontal logs for arboreal mammals or koala rails (**Photo 107**). Should be at least 1.5 m above the ground with a minimum 0.5 m clearance from the ceiling (0.75 m from the ceiling if for koalas). Should connect with trees at the entrances, and access ramps to logs should be no steeper than 1:5.
- Refuge poles with resting platforms to provide koalas refuge from dogs.
  - *Within crossing structure*: Should be at least 2 m tall, extend to the ceiling of the culvert and include a 'v' shaped resting point for koalas to sit on that is at least 1.5 m from the ground and 0.5 m from the ceiling.
  - *Outside crossing structure*: Should be approximately 4 m tall and include a 'v' shaped resting point that is at least 2.5 m from the ground for koalas to sit on to escape dogs and other predators at ground level.
- Horizontal logs for small mammals. Should be ~0.5 m above the ground with a minimum of 0.75 m clearance from the ceiling. Access ramps to logs should be no steeper than 1:5.

Figure 39 Suggested design for a Southern Brown Bandicoot hide (Source: Masters *et al*., 2019)

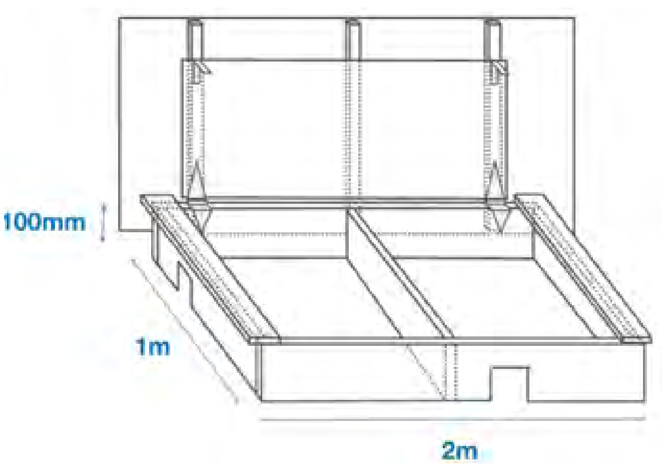


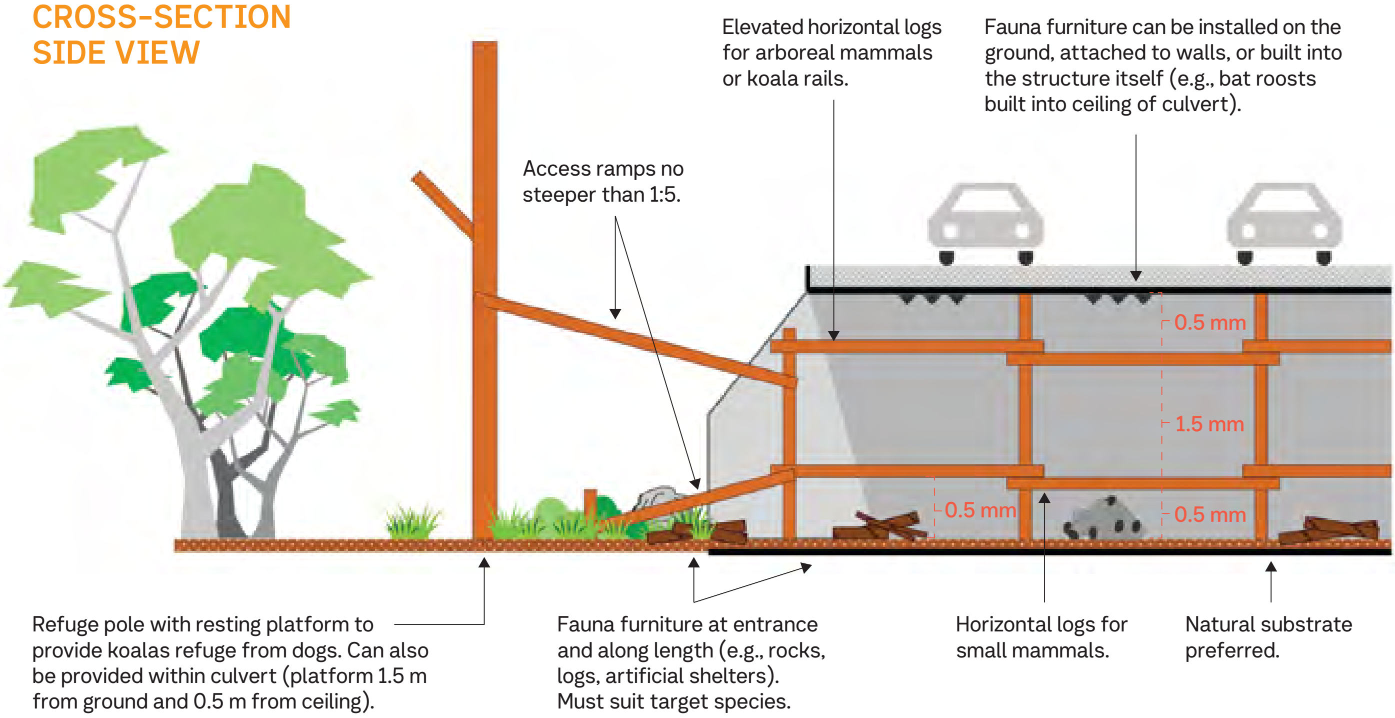
Photo 107 Example of fauna furniture – koala rail installed through culvert on Pacific Hwy, NSW (Source: Rodney van der Ree, WSP)

Photo 108 Bandicoot hide, Healesville-Koo Wee Rup Road Upgrade (Source: Austin O'Malley)

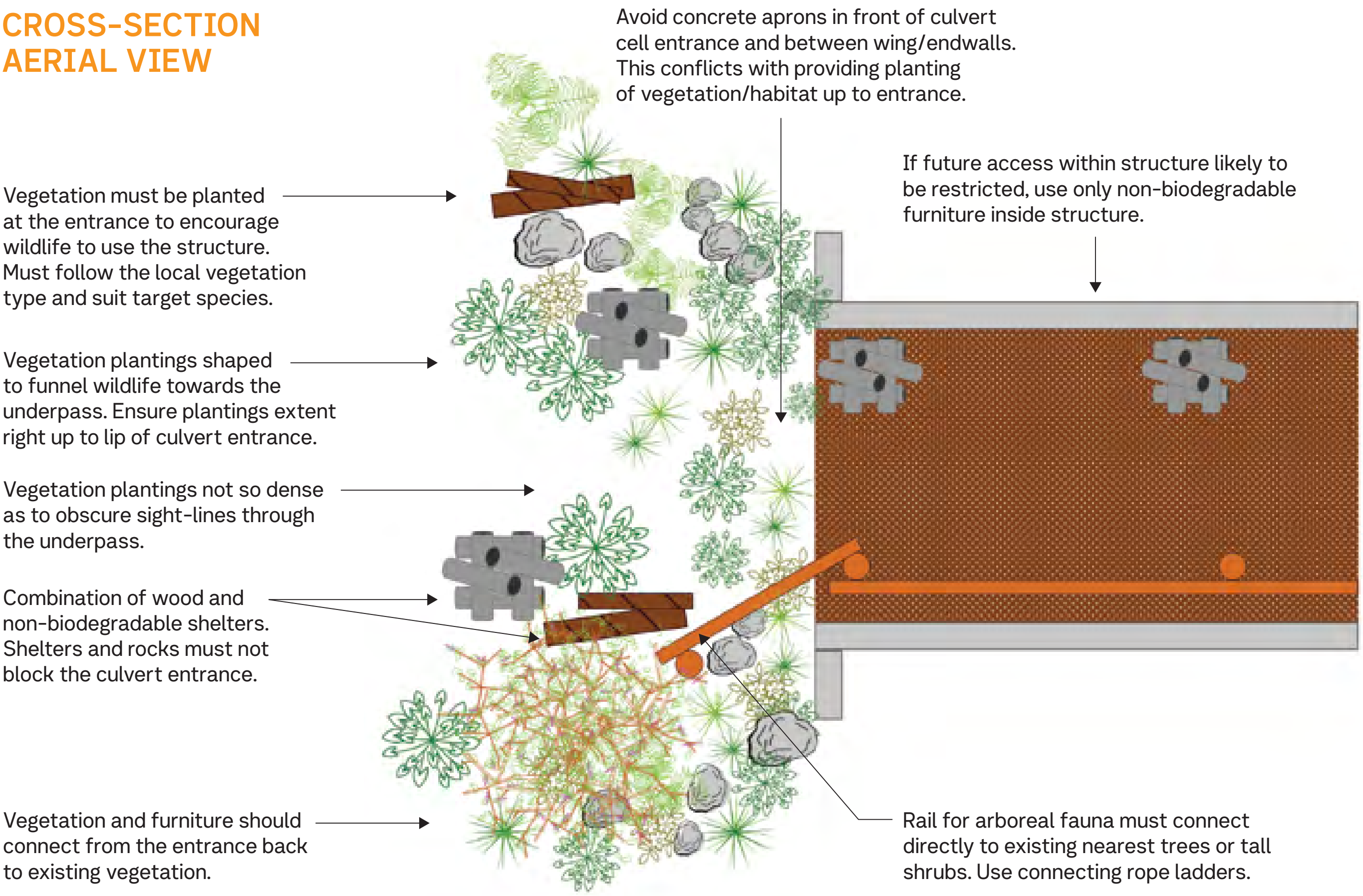
Figure 40 Fauna furniture and vegetation

Diagrams show the variety of fauna furniture that could be implemented in a culvert, bridge underpass or land bridge. Fauna furniture must be selected to suit the target species. All features shown below may not be necessary in a single crossing structure.

CROSS-SECTION SIDE VIEW



CROSS-SECTION AERIAL VIEW



7.3.4. Habitat creation in a waterway

For waterways that require significant modification, such as where a diversion and or a new channel is required, principles as described in the *Constructed Waterways in Urban Developments Guidelines* (2009) by Melbourne Water should be considered and where applicable applied. Each situation will be specific and require a range of considerations of what is required on site.

Basic principles include:

- Maintaining the natural aspect/characteristics where possible.
- Establishing waterway form based on existing conditions and habitats present including alignment, size and slope.
- Creating instream structures riffles, pools, meanders.
- Considering scour protection requirements.
- Restoring riparian and instream vegetation.

Significant modification to waterways that become hardscaped and 'unnatural' can become barriers to fish passage, through behavioural changes caused by conditions including temperatures, depth, flow rates, lack of shading and instream structure. These channels should be designed with habitat and ecosystem functionality in mind to maintain connectivity of the waterway.

7.4. Replacement tree hollows

The historical and ongoing loss of tree hollows is recognised as a significant threatening process for Australian wildlife populations, many of which rely on them for shelter and breeding. This includes marsupial gliders, possums, many bird species, owls, and even some reptiles such as the lace monitor (**Photo 109**). While preserving hollow bearing trees is paramount, it is not always possible. To replace habitat lost from the removal of habitat trees, replacement hollows should be provided.

Replacement hollows come in three different forms:

- Carved hollows (**Photo 110**).
- Suspended log hollows (**Photo 112**).
- Nest boxes (**Photo 115**).

These can be created with various sized cavities and entrance sizes, which are specific to (target) different fauna species.

> Advice from a zoologist is required to determine the appropriate hollow and entrance dimension to suit the target species.

Photo 109 The threatened Powerful Owl is dependent on large tree hollows for breeding (Source: Dan Weller)

7.4.1. Carved hollows

Carved hollows are excavated in standing trees (trunks or branches) using chainsaws or other tools and aim to mimic natural hollows. These hollows have been shown to exhibit thermal properties similar to natural hollows. Carved hollows can be created in living or dead standing trees or in a felled tree that can be re-stood. Various techniques and designs have been developed including a 'narrow door' method combining a chainsaw carved hollow and an inserted narrow timber faceplate with an entrance hole (**Photo 110**). One variation on this is a large natural 'face-plate' carved from the tree itself and then re-attached after a hollow has been carved out (**Photo 111**). Another different technique being developed is the use of specialised tools (like the 'Hollowhog') that can carve out a hollow through a narrow entrance, either directly into a tree limb or trunk or in a suspended hollow log (**Photo 113**).

Carved hollows should only be created by suitably qualified arborists (level 5 or above) to ensure the continued health of the trees with hollows installed.

Photo 110 Carved 'narrow door' hollow (Echuca-Moama Bridge Project; Source: Rodney van der Ree, WSP)

Photo 111 Carved hollow 'face-plate' method (left) and salvaged log artificial hollow (Echuca-Moama Bridge Project; Source: Rodney van der Ree, WSP)

Photo 112 Carved log hollow (Hall Road Upgrade Project; Source: VIDA Roads)

Photo 113 Carved log hollow being installed in a native tree (Hall Road Upgrade Project; Source: VIDA Roads)

7.4.2. Suspended log hollows

Suspended log hollows are sections of large branches or tree trunks that have been hollowed out and are capped at either end, then suspended in a tree to mimic a natural tree hollow (**Photo 112**). Logs can be obtained with naturally occurring hollows in fallen or felled timber and are salvaged for use as replacement hollows. They can also be made from solid sections of timber and hollows manually carved out.

The log hollows are prepared by an arborist by capping either end, installing an entrance hole (if required) and then anchoring it into a standing host tree (**Photo 113**). Salvage of natural log hollows should form part of a project's tree removal strategy, so that natural logs from the project can be reused as log hollows on the same project. Materials used to anchor natural log hollows into trees need to be carefully selected to not affect the future health of the host tree.

7.4.3. Nest boxes

Nest boxes have been used extensively in the past as replacement hollows (**Photo 115**), however they are no longer accepted as a long-term mitigation measure for tree hollow loss by state environmental regulators (DEECA). Nest boxes may be useful as temporary mitigation measures for wildlife during/after habitat removal. Nest boxes are considered sub-optimal because they can be prone to collapse and decay, often require ongoing maintenance, and provide inferior thermal conditions. Therefore, nest boxes are no longer recommended as a long-term habitat enhancement technique, except in specific circumstances.

Further information about nest boxes can found in *Use of nest boxes – general guide* (DELWP 2018).

Photo 114 Nest box installed in a tree (Echuca-Moama Bridge Project; Source: Rodney van der Ree, WSP)

Photo 115 Duck nest box in wetland (Source: VIDA Roads)

7.4.4. New hollow types

There is currently extensive research and trialling of new types of artificial hollows, including 3D-printed versions and other variations to traditional nest boxes. These recommendations should be updated as reliable evidence demonstrating effectiveness becomes available.

7.5. Waterbodies and frog ponds

The inclusion of wetlands and frog ponds associated with crossing structures encourages and facilitates the use of underpasses by frogs as well as increasing the local frog population. For many frog species (and potentially other aquatic taxa such as freshwater turtles), wetlands associated with crossing structures are likely to play an important role in facilitating use of the underpass (e.g. the Growling Grass Frog) along with providing important stepping stones and valuable habitat for a diverse number of fauna species (**Photo 117**).

Where aquatic (i.e., wetland-associated) amphibians are the target group for a crossing structure, frog ponds should be constructed at both ends of a culvert system wherever feasible. Wetlands and frog ponds should align as far as feasible with the best practice design standards, as derived from the following sources:

- *Design, construction and establishment of constructed wetlands: design manual* (Melbourne Water, 2017).
- DELWP (2017) *Growling Grass Frog Habitat Design Standards: Melbourne Strategic Assessment*. Department of Environment, Land, Water and Planning, 2017).
- Heard et al. (2010). *Guidelines for managing the endangered Growling Grass Frog in urbanising landscapes*. Department of Sustainability and Environment.
- Koehler, S., Gilmore, D., & Newell, D. (2015). *Translocation of the threatened growling grass frog Litoria raniformis*: a case study. Australian Zoologist, 37(3), 321–336.

Photo 116 Waterbodies provide habitat and movement stepping-stones for a diversity of fauna species including frogs, waterbirds, and reptiles (Source: VIDA Roads)

It is important to note that culvert frog ponds are not designed to provide large breeding wetlands per se. Rather, they are designed to facilitate use (potentially including breeding) by target amphibian species, with the primary objective of facilitating successful crossing of the culvert. For this reason, it is not essential for culvert frog ponds for the Growling Grass Frog to meet the DELWP (2017) habitat creation guidelines.

Frog ponds need to be designed to accommodate the particular target amphibian species. An appropriately experienced ecologist/zoologist should be consulted to confirm the best practice design standards for the target species.

For the Growling Grass Frog and many other wetland-associated amphibians in Victoria, key design parameters for frog ponds at culverts include:

- Pond depth of 1.5 m (excavated depth may need to be 2 to 3 m or more to ensure a water depth of 1.5 m is maintained over time, to address sedimentation, evaporation etc).
- The minimum size of each pond should be approximately 240 m^2.
- Include rock jumbles covering approximately 20 to 30% of the pond edge, extending into the water at the normal water level.
- Vegetated with suitable aquatic vegetation (DELWP 2017), including floating, submergent and emergent vegetation (**Photo 118**).
- A supply of suitable water (e.g. treated stormwater, directed overland flows from vegetated areas) must be identified as part of the design. Water supply options should consider options for exotic fish exclusion, to prevent the introduction of predatory exotic fish (such as Eastern Gambusia) entering frog ponds.

Photo 117 Constructed frog pond with emergent and floating vegetation (Princess Highway Duplication; Source: Austin O'Malley, VIDA Roads)

7.6. Highest value reuse

Most transportation projects result in the removal of living and non-living habitat elements of potentially high value to biodiversity and wildlife. These include:

- Native vegetation.
- Trees and timber (fallen or felled).
- Tree hollows (**Photo 121**).
- Dead standing trees (**Photo 119**).
- Large logs and hollow logs.
- Course woody debris (CWD).
- Rocks.

The highest priority for all VIDA Roads projects is to avoid clearing and removal of these important habitat elements wherever possible. When clearing is unavoidable, all habitat elements should be re-used to its highest-value-reuse. It is not possible to specify the highest value use of all materials for all projects and ecological expertise should be sought.

In addition, the local community, including First Nations groups, should be engaged to assist in identifying and implementing the highest value re-use program. However, some general principles should be applied in determining the best reuse of these valuable materials, as outlined below.

Photo 118 Dead trees retained for habitat (tree hollows), Napier Park, Melbourne (Source: Austin O'Malley, VIDA Roads)

7.6.1. Aims and principles

The primary aim of highest-value re-use programs is to improve biodiversity outcomes for all projects. These outcomes will ideally be at the project site; however, they can also occur off site if opportunities exist elsewhere.

The principles to determine highest value re-use include should:

f. Be as close to the original (road development) impact site — biodiversity or connectivity loss — as possible.
g. Prioritise the mitigation of the most severe long-term impacts to biodiversity as a result of road development (e.g. loss of tree hollows).
h. Prioritise actions that enhance conservation outcomes for biodiversity, wildlife populations, and threatened species.
i. Prioritise long-term outcomes rather than short-term use.
j. Target the needs and conditions of the ecological system and health ecosystem function.
k. Be aligned with local community needs and biodiversity and social programs.

7.6.2. Timber reuse

Felled timber and other elements can be used in a wide variety of ways to enhance terrestrial habitats, including:

- Placing logs and woody debris (litter and branches) on the ground amongst revegetation or existing woodland to provide shelter to wildlife, invertebrates, and fungi. Ensure the larger timber is protected from firewood collectors.
- Re-standing felled tree trunks or whole trees (**Photo 120**).
- Retaining dead trees with existing hollow-bearing tree sections (**Photo 119** and **Photo 121**), or carving/installing hollows into them (**Section 7.4**).
- Repurposing dead or felled trees as glider poles (see **Section 4.6**).
- Use of hollow logs as replacement hollows (see **Section 7.4**; **Photo 114**).
- Use of felled timber — greater than 10cm diameter — as course woody debris (CWD) in landscaping, revegetation, and restoration (habitat creation) to enhance ground habitats for fauna (**Photo 103**).
- Mulch for revegetation areas.
- High quality timber suitable for milling and high-value products should also be prioritised for 'higher-value' reuses such as furniture, structures, fencing, retaining walls, garden beds, and community initiatives.

Photo 119 Salvaged tree trunk reinstalled on the Calder Freeway as part of the Ravenswood interchange project. Note habitat value would be improved with surrounding native revegetation (Source: Rodney van der Ree, WSP)

Timber for Fish MOU

In 2019, VIDA Roads (previously MRPV) and 13 other parties signed on to a *Memorandum of Understand (MOU) for repurposing timber felled during road projects for waterway rehabilitation*. The purpose is to allow timber removed as part of infrastructure works to be reused for waterway rehabilitation, namely re-establishing woody debris in waterways for native fish. Guidelines have also been prepared to support the implementation of the MOU (DELWP 2021).

Communication among parties follow procedures set out under MOU which aims to connect the various parties and ensure the timber is allocated for beneficial reuse to locations where it is needed.

Photo 120 Large habitat logs installed from felled timber (Source: VIDA Roads)

Photo 121 Felled timber installed as large habitat logs in a nature reserve (Source: Stuart Boardman, City of Casey)

Community engagement on timber reuse

Local communities should be engaged to identify high value reuses that are locally relevant, such as:

- Re-standing Aboriginal scar trees in appropriate locations to celebrate indigenous culture.
- Provision of milled timber to local community groups for a wide variety of uses. Use should be determined prior to felling and milling to ensure the material is in a format suitable for the intended use.
- In general, re-use for firewood is a low-value use.

7.6.3 Aquatic habitat enhancement

Instream Woody Habitat (IWH), known as snags and Large Woody Debris, consist of branches, logs and whole trees that fall into waterways and create essential habitat for aquatic fauna and help maintain the health of waterways (DEPI, 2013; **Photo 122**). Over many decades IWH has been removed from waterways to improve boat access, flow, and property protection. With historical clearing on riparian habitats in these regions IWH has not been reinstated through natural processes. It is currently estimated that over 53% of Victorian river reaches have severely or highly depleted IWH density (DEPI, 2013).

Timber felled as part of road works can be reused for waterway rehabilitation. The timber is ideal as it is often large, with complex shapes and structures that provide high quality habitat to many native fish species. An example of this are tree root balls which are ideal for creating complex habitats for native fish to shelter and breed (**Photo 123**).

Photo 122 Example of natural 'instream woody habitat', section of a root ball protruding from the water surface (Source: Andrea McPherson, ARUP)

Photo 123 Tree root balls from Yan Yean Road — Stage 1 Upgrade being installed in Barwon River to create fish habitat (Source: Austin O'Malley, VIDA Roads)

7.6.3. Implementation

General guidance on implementation of FSRD timber reuse is detailed in Table 7.17 below.

Table 7.1 Implementation of timber re-use

Design aspect	Specifications and considerations
Target species	– Instream woody habitat proven for most fish species, macroinvertebrates and other aquatic species (platypus, turtles) – Terrestrial uses proven for many terrestrial species
Implementation	1. Develop a project-level Timber Reuse Strategy well in advance that details: a. summary of timber resources available – drawn from an arboriculture assessment and specialist timber milling advice. b. partner and stakeholder engagement plan. c. schedule of identified reuse for each tree. d. secure storage locations for timber. e. arrangements for cleaning and milling of timber. f. planned timber re-use activities including volumes for each outcome. Developing an effective timber re-use strategy can take time and should commence as soon as feasible, ideally 6 to 12 months prior to tree removal, to ensure that all opportunities with partners are explored. Partners organisations, like Catchment Management Authorities, may need to see seek separate funding for fish habitat restoration projects under the MOU with VIDA Roads. 2. Explore and identify timber reuse opportunities (on-site and offsite) including: a. Retention of sections of branches and trunks for use in fauna habitat creation and enhancement (see **Section 7.3**); b. Identifying and repurposing hollow-bearing branches and trunks as ground habitat or artificial tree hollows (see **Section 7.4**) suspended in retained trees or in offsite location in coordination with other land managers; c. Use as ground habitat logs in landscaping, revegetation, or restoration sites; d. Use as course woody debris (timber greater than 10 cm diameter) to enhance ground habitat values; and e. Use in creating in-stream habitat such as Timber for Waterway Resue projects. 3. Communication with relevant bodies and stakeholders should be undertaken to determine timber reuse opportunities and logistics. This includes, but is not limited to, DEECA, Victoria Fisheries Authority (VFA), Catchment Management Authorities, local councils and landowners, and community groups relevant to the project area. This is best undertaken well in advance (6 to 12 months) and can enable funding applications by partner organisations. 4. Explore opportunities for enhancements with local Landcare groups and farmers or other landholders (e.g. Parks Victoria) whose land is adjacent to the road project area. 5. Trees and suitable timber should be identified prior to felling to ensure the timber is appropriately removed and priority features (e.g. hollow limbs, root balls) are not damaged and can be reused. 6. Other cleared vegetation should be checked prior to it being disposed of and or mulched, to further identify suitable timber or other features that may be used on site to enhance project-specific fauna structures and/or surrounding habitat. 7. Wood acquired from site should be appropriately and securely stored for its allocated purpose, must not be contaminated by spills and/or exposures that may deem the timber unusable. For example, furniture grade or structural timber needs to be felled and stored in a certain way to maximise its use.

Implementation	8. Local materials should be used where available (e.g. do not use wood with high tannin content that could leach into waterways with low/no tannin concentrations). 9. Ensure timber is stored safely and appropriately to its intended reuse.
Landscaping and vegetation	10. Branches, logs and root balls can be used as part of the landscaping enhancements.
Enhancements and fauna furniture to encourage use of crossing structures	**11. Aquatic habitat**: a. Large complex root balls, trunks and whole trees (~>0.4 m diameter) can be utilised as IWH in larger waterways. Smaller diameter timber can be used in smaller waterways. b. Complex log 'jams' and instream structures can reduce instream flow velocities providing erosion control in addition to habitat (Brooks, et al., 2006). c. Logs placed at margins of wetland, waterbodies, and ponds provide resting, basking, and calling platforms for frogs, birds and aquatic mammals. **12. Terrestrial habitat**: a. Hollow logs can be used as nesting locations in trees and on the ground. b. Trunks and large branches can provide habitat and cover for smaller animals to safely access wildlife crossing structures. Consider placement, attachment techniques and risk of woody debris becoming an obstruction in culverts and under bridges during high flow events.
Maintenance	13. Visual inspection of timber used on wildlife crossing structures should occur during standard assessment of the structure to identify decayed timber that should be replaced. 14. Inspections of habitat installations within project areas, such as suspended tree log hollows, timber shelter piles, in-stream timber, should occur during project implementation. Monitoring of fauna use should occur to establish effectiveness of treatments.
Further references	15. The following resources are available to guide timber re-use opportunities: a. UFCA (2019) *Urban Forest Tree Repurposing Guidelines*. Report prepared by Urban Forest Consulting and Agroforestry Insight (Bambra Agroforestry Farm) for City of Greater Dandenong. *Available here online*.

Yellow-bellied Glider, Dean Ingwersen

8. Fauna Management Plan

A Fauna Management Plan (FMP) details the mitigation and enhancement measures that will be implemented for a project.

An FMP may form part of project approvals and be placed as a condition of a state planning and approval process (e.g. Planning Scheme Amendment) or an EPBC Act approval. It may also be a recommendation of an Environmental Effects Statement or other Environment Impact Assessment (EIA) process.

An FMP provides an opportunity for VIDA Roads to clearly define actions that demonstrate FSRD. Many of these actions or activities may be relatively novel and require clear commitments and instruction (guidance) both for VIDA Roads employees, industry partners, and construction contractors to ensure they are delivered effectively.

An FMP should aim to provide the road construction contractor with sufficient level of detail to be able to design and construct the identified FSRD measures, implement any necessary control or monitoring programs and report on progress.

An FMP includes:

- FSRD measures to be implemented for the project (**Section 8.2**).
- Fauna management measures pre-, during, and (possibly) after construction (**Section 8.3**).
- Any specific design standards or requirements that must be met.
- Associated environment management measures relevant to FSRD e.g. weed management, pest control (**Section 8.3**).
- Timeframes, accountabilities, reporting, and notification requirements for all actions.
- Statutory reporting requirements.
- (Ideally) Monitoring and evaluation program (**Section 8.5**).

8.1. Objectives for VIDA Roads FMPs

The first critical step is defining the objectives for an FMP which will be a combination of the requirements set by any environment approvals along with mitigation and enhancement opportunities for the project. A key source of information for FMP development is the VIDA Roads Detailed Ecology Assessment Report for the project.

A project FMP may consider one or more of the following in defining appropriate objectives and actions:

- Mitigating impacts on threatened fauna species and their habitat.
- Reducing wildlife road mortality.
- Retaining and enhancing wildlife movement, habitat corridors and connectivity.
- Enhancing existing fauna habitat within the project area.
- Creating new fauna habitat and vegetation communities.
- Providing critical habitat resources (e.g. tree hollows) and shelter for wildlife.

The FMP objectives and actions should reflect current biodiversity issues as defined by Victoria's biodiversity strategy *Biodiversity 2037*, EPBC species recovery plans, FFG Act Action Statements, and other relevant state and national policy. It should also consider the impacts of climate change on faunal populations and appropriate climate adaptation and mitigation measures.

Project FMPs should aim to compliment and contribute to VIDA Roads strategic initiatives in biodiversity, sustainability and best practice in transport delivery.

All FMPs should have some level of monitoring and reporting to a) ensure objectives are being, b) assess the effectiveness of (often) novel FSRD treatments (like crossing structures, tree hollow creation etc.), and finally, c) contribute to FSRD knowledge and best practice for continual improvement (see **Section 8.5**).

Project-level FMP monitoring should consider alignment with any VIDA Roads-wide monitoring programs including any data or collection standards.

8.2. Specification of FSRD structures

The FMP provides specific design requirements for wildlife crossing structures and other mitigation measures to meet the ecological connectivity objective of facilitating passage for different target species and fauna groups. Specifications detailed in an FMP should not be inconsistent with those contained in the FSRD Guidelines wherever possible, only deviating where necessary due to project- or site- specific limitations or particular needs of the target species or fauna group to facilitate safe movement.

The FMP will specify:

- The type, location and dimensions of wildlife crossing structures, along with any other details necessary to inform design and construction.
- The type, location and dimensions of other mitigation measures (e.g. frog ponds, revegetation, fencing), along with any other details necessary to inform design and construction.

An FMP requires sufficient technical detail for FSRD measures to be delivered effectively and efficiently. It must consider all other requirements of road delivery and be informed and integrated with other interacting components, such as drainage, lighting, utility relocation and installation.

8.3. Fauna management measures during construction

The necessity and frequency of site inspections to assess adequacy of fauna protection measures during construction should be identified during the planning stage. The Site Manager and project Environmental Manager should work together during construction to ensure that fauna protection measures are adequate and adhered to at all times. Any changes to site condition or impact to fauna which may arise should immediately be updated in approved plans. If a non-compliance with fauna safety measures occurs, a timeframe for compliance and remedial works should be specified by the Contractor and signed off by VIDA Roads. With follow up inspections scheduled to ensure compliance with the new protection measures.

To minimise impacts on fauna during construction, the following actions should be considered:

- Remove fauna habitat in stages, including the gradual removal of trees, from within construction footprints to encourage fauna dispersal.
- Manage waste streams (particularly organic waste) to minimise fauna incursion.
- Avoiding the incidental creation of temporary habitat that is likely to be removed or destroyed at completion of construction e.g. aquatic habitats such as dams, waterbodies. In unavoidable, implement measures to limit colonisation by native fauna.
- Management of disease vectors, particularly chytrid fungus (for frogs) and phytophthora (native vegetation).
- Arrange wildlife handlers to be present during habitat removal activities.
- Consider the timing and duration of activities and the breeding cycles of species known to be present — where possible avoid activities during breeding periods.
- Any waterway modifications should be cognisant of flow requirements and aim to maintain natural flow and fauna passage.

8.4. Compliance monitoring

Compliance monitoring assesses whether the various avoidance, minimisation, mitigation, and compensation/offset programs were implemented as planned and designed. There largely arise as conditions of environmental approvals for VIDA Roads projects, particularly federal EPBC Act approvals. Monitoring may form part of the management plans, such as regulator approved threatened species or fauna management plans.

Some questions that may need to be addressed through monitoring or regular audits during construction and during completion include:

- Was the mitigation measure built as planned and designed?
- How have wildlife populations or threatened fauna species responded to planned mitigation or management measures?
- Does the mitigation measure meet the objective intended?
- Are there any conflicts or poor integration between FSRD measures and other road design elements and structures such as drainage, lighting, landscape plantings, or safety barriers?
- Has all clearing been within approved clearing limits?
- Is sediment fencing and temporary construction fencing intact and functioning?
- Are tree protection zones being complied with?

Outcomes of monitoring and audits feed into adaptive management and corrective actions to meet relevant environmental approval conditions and any specific project objective for wildlife populations.

Photo 124 Image from Southern Brown Bandicoot monitoring using infra-red wildlife camera traps

Wildlife monitoring is most often associated with nationally (EPBC Act) threatened fauna species and the implementation of management actions, either those related to mitigation measures on projects or for EPBC Act offset sites. For example, monitoring the response of southern brown bandicoot populations to mitigation measures on VIDA Roads' Healesville-Koo Wee Rup Road Upgrade project as part of implementing a Fauna Management Plan required under an EPBC Act approval (**Photo 124**). This monitoring can inform adaptive management at the project level, an understanding of the effectiveness of mitigation measures, along with incidental and unique insights into the wildlife populations present within or adjacent to VIDA Roads road projects (**Photo 125**).

Learnings from monitoring and auditing results across projects can provide more in-depth insights into the effectiveness of mitigation and enhancement measures, and ways to improve practices for improved outcomes for both wildlife and VIDA Roads projects.

Photo 125 Rare observation of an albino native swamp rat (*Rattus lutreolus*)

Maintenance

Maintenance of structures and FSRD features should be informed by guidance contained in this document until handover of the asset to DTP. Maintenance requirements and records of any rectification should also be provided to DTP at asset handover.

8.5. Ecological monitoring, evaluation and reporting (MER)

8.5.1. When is MER required?

Evaluation of the effectiveness of the various measures employed to achieve a fauna-sensitive road is a critical step in the project lifecycle to ensure the goals of the project have been met and lessons to improve future projects are identified and shared.

Monitoring is particularly important for wildlife crossing structures and other mitigation measures which are relatively new and novel. In addition, the strength of the evidence on effectiveness can vary greatly among studies and can be highly dependent on a number of factors including the type of structure, landscape context, and fauna species being targeted (Goldingay *et al*. 2022; van der Ree *et al*. 2013; Young *et al*. 2023). Of the FSRD crossing structures described in these Guidelines, peer-reviewed research quantifying their effectiveness in different Victorian landscape contexts is extremely limited and further evidence would be highly beneficial.

Well-conducted monitoring, evaluation and reporting (MER) is increasingly a condition of approval of projects and is the fundamental basis for evidence-based decision-making. The evaluation of road projects should:

1. Assess whether the SMART goals outlined for the project were achieved, such as:
   a. Maintenance or improvement of ecological connectivity.
   b. Prevention of WVC and roadkill.
   c. Limiting the severity of traffic noise or artificial light at night on adjacent wildlife populations.
2. Ensure the results, and lessons learned, are adequately reported and shared with relevant stakeholders.
3. Inform whether adaptive management or further works are required to meet the aims of the project.

All VIDA Roads projects require some form of ecological MER, although the necessary complexity and scale of MER on each project will vary according to:

- The biodiversity and fauna values present and enhancement opportunities.
- The scale, severity and consequences of potential impacts.
- The complexity and scale of FSRD measures implemented.
- The degree of uncertainty surrounding the effectiveness of mitigation or achieving SMART goals.
- The consequences of mitigation failure.
- Whether thresholds have been set to trigger routine management or adaptive management.
- When there is a specific goal or intention to compare the effectiveness of a suite of different mitigation options (i.e., experimental mitigation/intentional learning while doing).
- How novel the mitigation is and the degree of evidence demonstrating effectiveness.

8.5.2. Aims of MER

Despite being a relatively straightforward requirement of many projects, most ecological monitoring and evaluation programs fail to deliver reliable or useful information. It is critical that expert ecological and evaluation expertise is obtained when developing and implementing an MER program. Consider getting a peer-review of a proposed MER program to ensure it is likely to achieve its objectives. There are also numerous resources that should be consulted to inform the design of ecological monitoring (e.g. Lindenmayer and Likens 2010) and specifically road mitigation projects (Rytwinski *et al*. 2015, Van der Grift *et al*. 2015, Van der Grift and van der Ree 2015a, van der Ree *et al*. 2015a, van der Ree *et al*. 2015b).

The first step is to understand how the ecological system operates and identify any uncertainties. This step includes careful consideration and articulation of the question(s) being asked. In some situations, the question may be trivial and not transferable to other projects and thus MER may not be required. Alternatively, trivial questions can be reframed to address important questions that can be applied to future projects. For example, long-term surveys that measure the rate of use of an underpass by a well-studied species and structure type to simply confirm that the species will use it may be a waste of resources. However, an evaluation of the rate of use of different structure types in relation to local population size, habitat conditions or structure design is valuable because it can inform future projects.

8.5.3. Designing an effective MER program

Effective MER programs typically have scientifically rigorous study designs that maximise inferential strength. Inferential strength is the ability to identify an impact or response from the collected data if such an effect exists.

Good study designs will measure each ecological variable of interest (e.g. population size, crossing rate, mortality rate) both before (B) and after (A) an intervention (e.g. road construction) at both control (C) and impact (I) sites.

This is termed a Before–After, Control–Impact (BACI) design which is the standard for monitoring programs aimed at assessing the effectiveness of mitigation measures for wildlife. Measurements may also be taken during (D) an intervention. This design variant is often referred to as B(D)ACI study designs.

A critical step in all before and after studies is to gather enough data using identical methods before and after the management action has occurred.

Control sites are locations that remain unimpacted by the treatment or intervention and help identify changes that occur as a result of the intervention (e.g. road construction, installation of crossing structures, etc.) compared to changes that occur due to background environmental factors.

Replication (i.e., number of sites) is also critical in improving the reliability and transferability of the results and insights. For example, if only one culvert was studied and no animals were found to use it, it is not possible to determine if the problem is associated with the design of that single culvert, its location or something else. However, conclusions can be drawn about the suitability of the failed culvert if multiple culverts were studied and the occurrence of the target species in adjacent habitat was also investigated.

8.5.4. Monitoring methods

A large and diverse range of methods, with varying cost and accuracy, can be used to answer the questions posed in 8.3.1, such as:

- Camera traps to measure the rate of use of crossing structures by the target species of wildlife.
- Genetic sampling to assess gene flow, wildlife diversity, dispersal and/or migration across the road.
- Various sampling methods to assess population size in the vicinity of the road or mitigation measure.
- Roadkill surveys to assess rate of WVC and mortality.

An important consideration prior to embarking on a multi-year project is to determine whether enough data can be collected to reliably answer the questions posed. If necessary, additional surveys may be required each year, or the duration of the survey program extended.

8.5.5. Reporting, dissemination and data sharing

All MER programs should include data evaluation and reporting to ensure conclusions are accurately drawn and disseminated to relevant stakeholders. Data evaluation should use appropriate statistical analysis and modelling approaches to ensure the findings reflect the data.

Deep insights and understanding are possible if a project has a scientifically robust study design, adequate replication and reliable analytical techniques.

Further value can be obtained where MER programs, monitoring, or research initiatives are replicated and coordinated across multiple projects.

Reporting and data provision should include:

- Submission of a report, analysis results, and both raw and summarised data to VIDA Roads in agreed format.
- Submission of data points to the Victorian Biodiversity Atlas.
- The results of MER programs, even those that are ineffective, should be reported and analysed to ensure the same mistakes are not repeated and to continually improve FSRD practice.
- Sharing results so they can be combined with other projects and larger data sets analysed.

The results of project-level MERs, any program-wide monitoring, and research partnership outcomes should inform a **regular review of these FSRD Guidelines**.

8.5.6. Short and long-term monitoring

Implementation of FSRD measures and realisation of their intended benefits for wildlife can take considerable time. Revegetation, habitat, and wetland creation can take many years to fully establish, fauna may take some time to start using wildlife crossings, while some measures may reduce in their effectiveness over time e.g. virtual fencing as animals become habituated to deterrents. Effectiveness can also vary over time due to climate variation, urban development, and stochastic events that influence wildlife populations and their habitat (fire, flood).

For these reasons, longer-term monitoring and research will produce more valuable and meaningful results to inform FSRD evaluation and continual improvement. As VIDA Roads is not the long-term asset maintainer of road and related FSRD infrastructure – 'handing over' these assets to the Department of Transport and Planning (DTP) – any MER or simple monitoring should be divided into short- and long-term components and ideally be coordinated among parties to achieve the optimal program. Shorter-term monitoring incorporating only the post-construction liability period (generally 12 to 24 months) could be useful but would be unlikely to produce peer-reviewed research or as meaningful or definitive results as longer-term monitoring.

As DTP are the long-term maintainers of the road asset, optimal design wildlife outcomes, both for any FSRD measure and MER program, are likely to be achieved through effective VIDA Roads-DTP communication and coordination throughout the development, delivery (construction), and handover phases of the project lifecycle.

Further Monitoring Guidance

The following resources can be referred to in developing monitoring and reporting plan:

- O'Connor, J., Stuart, I. and Jones, M. (2017) Guidelines for the design, approval and construction of fishways. (PDF, 3.0 MB) Arthur Rylah Institute for Environmental Research. Technical Report Series No. 274. Department of Environment, Land, Water and Planning, Heidelberg, Victoria
- van der Grift, E. A., & van der Ree, R. (2015). Guidelines for evaluating use of wildlife crossing structures. Handbook of road ecology, 119-128
- O'Connor, J., Stuart, I. and Jones, M. (2017) Guidelines for the design, approval and construction of fishways. (PDF, 3.0 MB) Arthur Rylah Institute for Environmental Research. Technical Report Series No. 274. Department of Environment, Land, Water and Planning, Heidelberg, Victoria

9. Material reuse

VIDA Roads is committed to implementing the use of recycled and repurposed products wherever possible, in accordance with the Victorian government Recycled First Policy.

A selection of potential opportunities to use these materials is listed below. The use of recycled and repurposed materials is an evolving space, and there are likely to be many additional products, opportunities and uses.

Any proposal to replace a feature that is used directly by wildlife (e.g. dry passage ledges, artificial shelters) with an innovative recycled product should include consultation with an ecologist. A review of research studies could be undertaken into the effectiveness and suitability of the replacement material prior to substation of a standard material.

For a number of features and structures (identified below), a natural repurposed material is generally preferred to a plastic one, without further research and evidence regarding effectiveness and benefit.

Trials of recycled plastic products should be undertaken and compared to traditional (and natural materials) applicable) approaches.

Plastic nest boxes and artificial tree hollows could feasibly be created from recycled product but are relatively new products that require further testing. Although there are several reasons why plastic could be equivalent to (or even outperform) traditional wood construction in certain areas (such as thermal insulation and longevity), with some promising early research on the topic (Berris *et al*. 2020; Callan *et al*. 2023), further research is required prior to adopting as an acceptable substitution. In addition, regulator endorsement may be required for any non-standard material substitution related to a mitigation commitment under an environmental approval.

Photo 126 Recycled plastic for a fauna culvert ledge (Healesville-Koo Wee Rup Road Upgrade project; Source: Austin O'Malley)

Table 9.1 Opportunities to use recycled and repurposed materials

Product	Feature	Applicable structure
Recycled plastic	Noise walls or visual screening	Land bridge
	Fence sheeting, fence posts	Fencing (permanent)
	Star pickets	Fencing (temporary)
	Dry passage ledges	Culverts, bridge
	Nest boxes and artificial tree hollows [15]	Tree hollow loss mitigation and replacement
	Fauna furniture (e.g. artificial animal shelters)	Bridge, culverts, land bridge
Recycled timber	Various fauna furniture (e.g. log piles)	Bridge, culverts, fish ladders, land bridge
	Posts for fences	Fencing
Trees/logs salvaged from site	Fauna furniture (e.g. koala poles, elevated log rails, habitat logs)	Bridge, culverts, fish ladders, land bridge, frog ponds
	Nest boxes and artificial tree hollows [8]	Tree hollow loss mitigation and replacement
Rocks salvaged/ excavated from site	Fauna furniture (e.g. rock piles)	Bridge, culverts, fish ladders, land bridge, frog ponds
	Frog pond rock shelters	Frog ponds
	Gabion walls, rock platforms	Amphibian culvert
Recycled steel	Wiring, fencing, netting	Fencing
Recycled shade cloth	Fencing, screening	Fencing (temporary)
Recycled power poles	Wooden poles	Canopy bridges and glider poles under road bridges. Not recommended for above-road installation unless poles in excellent condition due to risk of collapse.
Supplementary Cementitious Materials in Concrete (fly ash, slag)	Concrete components	All structures
Concrete Aggregate Replacement – recycled crushed rock/brick/concrete and manufactured sand/ glass fines	Dry passage ledges	Culverts, bridge
Recycled aggregates, Geopolymer Concrete i.e., high SCM content	Fauna furniture (e.g. artificial shelters)	Bridge, culverts, land bridge

[15] Natural repurposed material generally preferred until substitution demonstrated to be equivalent through trials.

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