Maroondah Habitat Connectivity Plan

Maroondah City Council

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Glossary

Term	Description
Barrier	A landcover type that's resistance is so high as to be considered impassable to fauna.
Biodiversity	The diversity of all forms of life, including species, the genetic diversity within each species and the diversity of communities that species form. Biodiversity spans organisms from the smallest virus to the largest trees. Biodiversity cannot be measured simply by the number of distinct species, communities and genetic variants; it takes into account how diverse these things are in size, ecological function, evolutionary origins and other respects.
Biolink	A spatial grouping of habitat and pathways which are considered to be critical to the maintenance of connectivity for a range of dispersal guilds at a landscape scale.
Component	A group of patches that are linked to each other but isolated from other components (also made of groups of patches).
Connectivity network	A network of interconnecting habitat patches and linkages.
Connectivity study	An analysis of the ecological connectivity across a landscape for terrestrial fauna species.
Core habitat	A relatively homogeneous area differing from its surroundings and consistent in its broad habitat values. The minimum size of core habitat is defined as an area of habitat of sufficient size and structure so as to support populations of one or more fauna species of interest, referred to in the singular as a 'patch'. Interchangeable with the term 'node' in graph theory.
Dispersal guild	A group of animals that share similar habitat and dispersal behaviour. Dispersal includes the concepts of gap-crossing and inter-patch distance thresholds (Lechner et al. 2015).
Ecosystem	The combination of a community of living things and the physical features that support it, such as climate, soil and water.
Engagement species	Fauna species identified for the purpose of informing broader conservation planning and management initiatives.
Fauna	Animals.
Flora	Plants.
Functional connectivity	The degree to which flora and fauna successfully disperse through the landscape, taking into consideration both the structural configuration of habitat (i.e. the physical nature of vegetation and landcovers) and the physiological attributes of the species in question.
Gap-crossing distance threshold	Maximum (average) distance an individual will move between two structural connectivity elements.
Habitat connectivity	The degree to which the landscape facilitates or impedes the movement of individuals between habitats. Maximising connectivity is often an objective of conservation planning.
Indigenous	A species of flora or fauna is 'indigenous' to an area if it occurred there prior to European colonisation. A species may be indigenous to one part of Maroondah and not to another.
Interpatch-crossing distance threshold	The maximum distance that individuals will move between patches provided there are sufficient structural connectivity elements present to meet the gap-crossing threshold.
Linkage (least-cost path)	The shortest route between two patches as a function of land cover resistance. Can indicate movement passages or corridors for fauna (current or future) facilitated by structural connectivity elements and environments through which animals can move more easily (e.g. fewer barriers).

Term	Description
Modelled species	A species of relevance to the study area that is considered to be representative of a dispersal guild and has therefore been used as the basis for parameterisation of the model.
Nationally significant	A Matter of National Environmental Significance (MNES) listed as critically endangered, endangered or vulnerable under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999.*
Patch	A single, contiguous area of core habitat.
Resistance	A value assigned to each land cover type in a landscape that reflects the ecological costs for individuals to move through it. Also, sometimes referred to as dispersal-cost. High resistance means high dispersal costs.
State significant	Listed as critically endangered, endangered or vulnerable under the Victorian *Flora and Fauna Guarantee Act 1988*.
Structural Connectivity Elements	Fine-scale landscape features facilitating movement and dispersal (e.g. trees, shrub cover, dense grass cover, rocks etc) and act as 'stepping stones' for species to move between habitat patches across areas of non-habitat.
Study Area	The area used for the connectivity study i.e. the Maroondah local government area.
Taxon (plural taxa)	Any grouping of organisms in the classification system of living things, particularly a species, subspecies, variety or form. Hybrids can be regarded as taxa even though they combine genes of multiple species.
Wildlife passage	A linear corridor identified as currently, or potentially, suitable for facilitating movement between areas of core habitat. Used in this context to identify areas designated for management and further investment. Differentiated from a modelled 'linkage' or 'least-cost path', in that additional considerations associated with the practical implementation and long-term management of the pathway are taken into account.

Acronyms

Abbreviation	Description
DAWE	The Australian Government Department of Agriculture, Water and the Environment.
DELWP	The Victorian Government Department of Environment, Land Water and Planning.
dIIC	delta Integral Index of Connectivity (dIIC), a measurement of the contribution to network connectivity under the GAP CLoSR framework.
ELA	Eco Logical Australia Pty Ltd.
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*. Key piece of national legislation to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places.
EVC	Ecological Vegetation Class.
FFG Act	*Flora and Fauna Guarantee Act 1988*. Key piece of Victorian legislation for the conservation of threatened species and communities and for the management of potentially threatening processes.
GAP CLoSR	General approach to planning connectivity from local scales to regional framework.
MNES	Matter of National Environmental Significance as defined under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.
NDVI	Normalized difference vegetation index.
NIR	Near infrared.
NVIM	Native Vegetation Information Management system.
OBIA	Object-based image analysis.
VBA	Victorian Biodiversity Atlas.

Executive Summary

Background

Maroondah City Council is working towards improving indigenous flora and fauna habitat connectivity and function in Maroondah as part of its strategic vision. Namely more vegetation, in the form of a well-connected network of indigenous trees and understorey plants, and aquatic habitats, providing resources such as food and shelter that allow fauna to move through the landscape and flourish. This will simultaneously create more opportunities for people to encounter and connect with nature close to where they live, work and play. More vegetation also helps with other strategic goals such as cooler neighbourhoods, increased liveability, water sensitive urban design and improved resilience to climate changes.

In this context, the Maroondah Vegetation Strategy 2020-2030 identified *"More nature throughout Maroondah"* as a strategic outcome for the municipality. To achieve this outcome one of the Strategy's actions seeks to identify strategic, priority locations and measures to improve biodiversity connectivity. This connectivity study has been commissioned to inform this mapping and provide guidance to achieve "more nature" in a strategic and sustainable manner. It builds on the recently completed Biodiversity in Maroondah report (Volumes 1 and 2; Lorimer 2020) which aims to provide a clear, contemporary understanding of Maroondah's biodiversity.

Maroondah's biodiversity

The City of Maroondah is located on the fringe of metropolitan Melbourne, approximately 30 km to the east of the central business district and situated at the base of the Dandenong Ranges and Warrandyte State Park within the Gippsland Plain and Highlands Southern Fall bioregions. It is comprised of 6,138 hectares of primarily urban residential land with scattered parks and reserves and two main creeks, the Dandenong and Mullum Mullum running through the local government area. Prior to 1945, most of Maroondah's native vegetation had already been cleared with the few currently remaining patches of native vegetation containing a higher density of eucalypts due to resulting regrowth. Drainage works and urbanisation have also contributed to changes in the movement of water through soil and waterways; and increased fragmentation of habitat for fauna including plant pollinators (Lorimer, 2020).

Nowadays, habitats within the LGA can be roughly grouped into dry eucalypt woodlands along ridgelines, particularly in the north of the municipality, modified riparian and flood plain vegetation associated with creek lines and waterbodies, such as lakes, dams and constructed wetlands. Other prominent habitat features include managed parklands and residential gardens.

Connectivity analysis

Approach

Eco Logical Australia, in collaboration with Alex Lechner and Darrel Tiang Chin Fung from University of Nottingham, were engaged to undertake a connectivity study using the GAP-CLoSR framework and Circuitscape modelling tools and prepare the associated connectivity plan for Maroondah. This included:

- Modelling the existing habitat connectivity in Maroondah

- Identifying where best and how to improve connectivity between existing habitat areas
- Identifying where best and how to improve habitat function of existing habitat areas

Eco Logical Australia was also tasked with developing a prioritisation matrix to allow the prioritisation of conservation management actions within the municipality over the short, medium and long-term.

Whilst separate tasks, each of the above have been incorporated into this connectivity plan and underpin the associated priorities and specifications presented.

Also incorporated into this project was the development of a list of faunal 'engagement species' that can provide a focus and profile for efforts to protect, restore and create new habitat in Maroondah.

Species connectivity

Existing and potential habitat connectivity modelling was completed for three dispersal guilds, using Superb Fairy-wren, Rakali, and two Marsh Frog species as the target species (Table A). All exhibited significant differences in their responses to the Maroondah landscape as discussed below.

Table A. Species selection and rationale

Habitat type	Forest and woodlands	Riparian	Wetlands
Species	Superb Fairy-wren *Malurus cyaneus*	Rakali *Hydromys chrysogaster*	Marsh Frogs *Limnodynastes tasmaniensis* and *L. peroni*
Rationale	• Representative of large fauna guild of significance to Maroondah (e.g. woodland birds). • Lower dispersal ability than larger birds (e.g. raptors). • Sensitive to urban environments due to reliance on dense vegetation to facilitate dispersal. • Requires understory structure for foraging and nesting, limiting use of open parklands and other 'semi-natural' areas.	• Utilises both aquatic and terrestrial habitats for movement allowing for connectivity between waterbodies to be examined. • Moderate dispersal ability through modified urban environments using a diversity of natural and artificial covers. • Requires permanent waterbodies. • Sensitive to cover and structure of riparian vegetation.	• Lower dispersal ability compared with other aquatic faunal groups (e.g. waterbirds) however still able to utilise terrestrial environments to disperse. • Requires standing or slow-moving water as core habitat however can utilise waterways as corridors. • Can utilise both permanent and ephemeral waterbodies. • Requires fringing vegetation with limited woody cover.

Despite the abundance of connectivity elements for **Superb Fairy Wren** throughout Maroondah, including small woodland pockets, gardens and street trees, core habitats remain isolated due primarily to the distance between each and dispersal resistance associated with the heavily urbanised landscape. Whilst limited, significant areas supporting multiple, interconnected patches of core habitat include:

- Croydon Hills reserves (Warranwood Reserve, Yarrunga Reserve and Narr-Maen Reserve) and the interconnecting bushlands associated with Jumping Creek
- Hochkins Ridge Flora Reserve and smaller parks and reserves to the south within Croydon North
- Dandenong Creek and surrounding reserves west of the confluence with Bungalook Creek

- Bungalook Conservation Reserve and Eastwood Golf Course, including woodlands on private property along Tereddan Drive.

Potential connectivity for Superb Fairy Wren has been modelled based on two scenarios. Model 1.2 shows the potential to dramatically improve the connectivity for this species in both the north of the municipality through Warranwood, Croydon and Croydon Hills and in the south along Bungalook Creek, and the Wicklow ridgeline through Ringwood East. When targeted management actions are applied in Scenario 1.3, connectivity along the ridgeline and Mullum Mullum Creek is also considered viable, noting that the former will require significant improvement of habitat on private land to realise this goal. Both potential connectivity models still show a lack of connectivity along the upper reaches of Dandenong Creek, indicating significant investment is required through this corridor to see benefits for this faunal group.

Given the association with permanent water, patches of core habitat are limited for **Rakali** within the municipality. This can be attributed in part to the removal and modification of waterways due to urbanisation. As a result, interconnected patches of core habitat were restricted to 'natural' creek lines supporting mature woodlands with dense or unmanaged understories. This includes:

- Jumping Creek and associated tributaries in Croydon Hills
- Mullum Mullum Creek between Plymouth Road and the Ringwood Bypass
- Brushy Creek in Croydon North
- Dandenong Creek and Bungalook Creek west of Bayswater Road

Despite Rakali's higher dispersal ability, connectivity between waterways and associated core habitat is not shown to be present in Maroondah.

Potential connectivity for Rakali has been modelled based on two scenarios. Scenario 2.2 shows the potential to improve the connectivity for this species between core habitats in the north of the municipality and those along Mullum Mullum Creek. When targeted management actions are applied in Scenario 2.3, without modifying movement parameters, an improvement in connectivity is only apparent along existing creeklines, with Tarralla Creek showing the greatest potential for improvement. Given the reliance on aquatic environs for this species, the feasibility of establishing additional core habitats to facilitate movement between existing patches, along with reducing movement barriers within heavily urbanised landscapes, may be difficult. Scenario 2.3 is therefore considered a more realistic representation of potential improvements to connectivity within the Maroondah context.

Like Superb Fairy Wren, potential connectivity models for Rakali show a lack of connectivity along the upper reaches of Dandenong Creek due to a lack of high-quality riparian vegetation and lack of permanent water (piped sections).

Core habitat for **Marsh Frogs** were primarily identified along riparian corridors, with the modelling identifying multiple interconnected ponds and wetlands in these locations. Like Rakali, connectivity between core habitat was strongly correlated to catchment boundaries, with waterbodies away from streams and creeks frequently showing as isolated in the modelling. Significant clusters of core habitat were associated with:

- Jumping Creek and associated tributaries in Croydon Hills

- Andersons Creek East Branch south to Monterey Bush Park
- Brushy Creek in Croydon North
- Middle reach of Mullum Mullum Creek between Plymouth Road and the Ringwood Bypass
- Lower reach of Mullum Mullum Creek along the Ringwood Bypass
- Waterbodies associated with Dorset Golf Course
- The eastern reach of Bungalook Creek and waterbodies associated with Eastwood Golf Course
- Dandenong Creek, the western reach of Bungalook Creek and Little Bungalook Creek

Potential connectivity for Marsh Frogs has been modelled based on a single scenario. This scenario shows an improvement in connectivity along existing waterways and low-lying areas supporting complex remnant vegetation. This was notable along Tarralla Creek, Bungalook Creek and Mullum Mullum Creek, and the southern extent of the Hochkins Ridge and Stringybark Rise/Exeter Ridge woodlands.

Landscape connectivity

To provide an overview of connectivity across the landscape for all terrestrial species, data from the various connectivity scenarios was compiled into a single, weighted map. Given the combination of different models, this map is considered valuable for consideration of landscape-scale priorities only. Based on this analysis, seven biolink corridors have been identified within Maroondah (Table B).

Table B. Proposed Biolinks and associated management objectives for Maroondah

Biolink	Description	Management objectives
Northern hills biolink	This biolink is centred on the foothills in the north of Maroondah and represents the most significant area of interconnected habitat within the municipality.	• Improve east-west connectivity between core habitat clusters.
Mullum Mullum Creek biolink	The Mullum Mullum Creek biolink extends from Narr Maen Reserve in the north to Ringwood Lake Park in the south and Ringwood Bypass in the west.	• Improve quality and function of aquatic and terrestrial habitats along entire creek corridor • Establish connectivity with Northern Hills biolink to the north.
Wicklow Ridgeline biolink	This biolink extends from Warrien Reserve in the north to Wombolano Park and Bungalook Creek in the south, via small pocket parks, large established gardens and street reserves along the existing ridgeline where vegetation cover is highest.	• Establish second north-south corridor • Connect core habitats present through corridor
Tarralla Creek biolink	This biolink runs along the Tarralla Creek corridor from Fred Geale Oval in the north to the confluence with Bungalook Creek and Dandenong Creek in the south.	• Improve habitat function along Tarralla Creek
Bungalook Creek biolink	This biolink connects the eastern and western reaches of Bungalook Creek to the lower reach of Dandenong Creek, including significant habitat areas associated with Bungalook Conservation Reserve in the east.	• Utilise freeway reserve to establish extensive, diverse core habitats • Connect to Dorset Golf Course and eastern reaches of Creek
Belgrave Rail biolink	The Belgrave Rail Biolink represents a potentially valuable corridor connecting the northern Mullum Mullum Creek Biolink at Ringwood Lake Park, with the Dandenong Creek and Bungalook Creek Biolinks in the south.	• Connect Mullum Mullum Creek with Dandenong Creek and Bungalook Creek

Biolink	Description	Management objectives
Dandenong Creek biolink	The Dandenong Creek biolink is well recognised as a significant regional corridor linking the high-quality habitats of the Dandenong Ranges to the east with extensive aquatic and floodplain habitats, and major reserves such as Churchill National Park, to the south.	• Protect habitat in lower reaches of Dandenong Creek • Improve habitat and connectivity in upper reaches through daylighting of creek corridor

Connectivity priorities

Protect, improve and connect priorities were identified by location within Maroondah to inform targeted management actions. Drawing on the outputs of the prioritisation analysis, these priorities were ranked based on the associated biodiversity conservation values across each biolink corridor.

Management priorities to 'protect and improve' focus on existing areas of vegetation which may or may not currently be considered core habitat for one or more target species.

Areas identified for 'protection' recognise the significant role they currently play in supporting biodiversity and facilitating connectivity within the landscape. The focus is therefore on securing their future and continued management to minimise threatening processes and promote further enhancement of existing biodiversity.

In contrast, areas identified for 'improvement' are those which, based on the modelling, do not currently act as core habitat due to being either too small or fragmented, or lacking function (e.g. structurally diverse understoreys). The priority for these areas is therefore to improve the extent and/or function of existing habitats with the aim to create core habitats or allow a broader range of species to effectively use as a stepping-stone.

Key management themes to protect or improve habitat connectivity include:

- Prevent the loss of habitat and connectivity elements associated with existing core habitats, prioritising management of key threats.
- Consolidate and expand areas of potential core habitat, focusing on improving the structural complexity and diversity of habitats.
- Implement appropriate planning measures or management incentives to prevent the loss of existing or potential core habitat, focusing on vegetation structure and habitat features.

Opportunities to 'connect' focus on establishing or improving connectivity between existing or potential areas of core habitat, for a range of faunal groups, along designated 'wildlife passages'.

Key management priorities to connect habitats include:

- Create new core habitats along wildlife passages to reduce interpatch distances between existing core habitats. Focus on vacant private land or unused public land, irrespective of future land use or development.
- Improve functional connectivity between existing or potential core habitats along wildlife passages through the addition or enhancement of vegetation structure and habitat resources

(e.g. shrubs, tree canopy, grass, litter, and logs) for multiple faunal groups with the aim to create a mosaic of habitat types across the landscape.

- Reduce the resistance associated with barriers (e.g. roads) through implementation of crossings or other mitigation measures along wildlife passages.
- Implement appropriate planning measures to promote the improvement of habitats and structural connectivity on private land with a particular focus on wildlife passages.

The on-ground implementation of management objectives will be influenced by a range of factors, including land tenure and use, ownership arrangements, the nature and extent of vegetation and the target species requirements. This report provides connectivity specifications for major land use types and barriers present within Maroondah based on key habitats and fauna groups applicable to each (Table C).

Table C. Specifications developed for the improvement of connectivity by land use and barrier

Land use specifications		Barrier mitigation specifications	
1.1	Conservation reserves	2.1	Fences
1.2	Parklands	2.2	Roads and rail
1.3	Residential gardens	2.3	In-stream barriers
1.4	Wetlands and waterbodies	2.4	Human-activity
1.5	Creek corridors	2.5	Predation
1.6	Streetscapes	2.6	Aggressive species
1.7	Rail reserves	2.7	Light
1.8	Industrial and commercial precincts	2.8	Sound
1.9	Vacant or unused land and utility easements	2.9	Buildings

1. Introduction

Maroondah City Council (Council) is working towards improving indigenous flora and fauna habitat connectivity and function in Maroondah as part of its strategic vision. Namely more vegetation, in the form of a well-connected network of indigenous trees and understorey plants, and aquatic habitats, providing resources such as food and shelter that allow fauna to move through the landscape and flourish. This will simultaneously create more opportunities for people to encounter and connect with nature close to where they live, work and play. More vegetation also helps with other strategic goals such as cooler neighbourhoods, increased liveability, water sensitive urban design and improved resilience to climate changes.

Vegetation management is a shared responsibility with many stakeholders playing vital roles. Council has embarked on this study to provide a strategic, city-wide overview. This may be used by all stakeholders to inform local action with amplified outcomes.

1.1 Background

Council has a legal, ethical and social responsibility for the management and protection of biodiversity within the Shire. This is reflected in the community vision statement in Maroondah 2040: Our Future Together developed via extensive community consultation.

> *"In 2040, Maroondah will be a vibrant and diverse city with a healthy and active community living in green leafy neighbourhoods which are connected to thriving and accessible activity centres contributing to a prosperous economy within a safe, inclusive and sustainable environment."*

There is also strong community support for protecting biodiversity in Maroondah with Café Consult in 2017 identifying *"Native plants and animals"* as the top ranked response for why the community values vegetation (34% of all respondents).

In this context, the Maroondah Vegetation Strategy 2020-2030 identified *"More nature throughout Maroondah"* as a strategic outcome for the municipality. To achieve this outcome one of the Strategy's actions seeks to identify strategic, priority locations and measures to improve biodiversity connectivity. This connectivity study has been commissioned to inform this mapping and provide guidance to achieve "more nature" in a strategic and sustainable manner. It builds on the recently completed Biodiversity in Maroondah report (Volumes 1 and 2; Lorimer 2020) which aims to provide a clear, contemporary understanding of Maroondah's biodiversity.

1.2 Objectives

Eco Logical Australia (ELA), in collaboration with Alex Lechner and Darrel Tiang Chin Fung from University of Nottingham, were engaged to undertake a connectivity study using the GAP-CLoSR framework and Circuitscape modelling tools and prepare the associated connectivity plan for Maroondah. This included:

- Modelling the existing habitat connectivity in Maroondah.
- Identifying where best and how to improve connectivity between existing corridors and habitat areas
- Identifying where best and how to improve habitat function of existing habitat areas

Eco Logical Australia was also tasked with developing a prioritisation matrix to allow the prioritisation of conservation management actions within the municipality over the short, medium and long-term.

Whilst separate tasks, each of the above have been incorporated into this connectivity plan and underpin the associated priorities and specifications presented.

Also incorporated into this project was the development of a list of fauna 'engagement species' that can provide a focus and profile for efforts to protect, restore and create new habitat in Maroondah.

The project outputs will guide and enable Council to:

- inform stakeholder engagement (e.g. 'wildlife gardening').
- inform conservation works (e.g. bushland management, landscaping in public green spaces and streetscapes).
- inform land use planning (e.g. development of environmental significance overlays).
- inform regional connectivity planning and management and future potential collaborations.

Finally, the Maroondah Habitat Connectivity Plan (the 'Plan') is intended to complement the Biodiversity in Maroondah report (Lorimer 2020) by providing scientifically robust advice on the existing and potential linkages between sites identified as being of biological significance.

1.3 Strategic context

This Plan has been developed within a matrix of related local, regional, state and national plans. Importantly, the Plan shares the two foundation principles of the Protecting Victoria's Environment - Biodiversity 2037 through cost efficiency and complementarity. Cost efficiency is important to provide maximum returns to Maroondah community and the environmental outcomes sought. Complementarity is important to provide benefits to as many species as possible and support as many of the local ecosystem services as possible for Maroondah.

This Plan updates the former Maroondah Habitat Corridors Strategy 2005. It is informed by the Biodiversity in Maroondah 2020 report that identifies 109 contemporary sites as having biological significance under the state government 'Standard Criteria for Sites of Biological Significance in Victoria' (Amos 2004). The Plan recognises retention of, and improvements to, viable pathways between these sites of biological significance across the LGA, and into adjacent municipalities, will improve the overall functional capacity of habitat within the network.

1.4 Connectivity modelling

As human populations continue to grow, so too do the urban centres and agricultural systems required to support them. This changing land-use inevitably leads to habitat loss and fragmentation, reducing connectivity of animal and plant populations and impairing essential ecological processes such as pollination, dispersal, recolonisation, and gene flow (Fischer and Lindenmayer 2007, Saunders et al. 1991). The result is that biodiversity is often limited to small, isolated habitat elements which are vulnerable to a range of environmental threats such as pests, diseases, fire and climate change, and unable to support viable, long-term populations.

Despite the challenges, many modified landscapes contain critical populations of threatened species or communities. The restoration, preservation, and enhancement of biodiversity within modified landscapes therefore becomes increasingly important, and in turn poses a significant challenge to conservation management (Seto et al. 2012).

One method of mitigating the threat to remaining populations is through the protection and restoration of ecological connectivity - enabling species to move through the landscape and utilise as many of the remaining habitat elements as possible (Noss 1987, Doerr et al 2010, Mackey and Hugh 2010). These 'biolinks' are recognised as critical for addressing the impacts of habitat fragmentation and more intensive land use (Bierwagen 2007, Minor and Urban 2008). Identifying, protecting and improving biolinks in Maroondah is likewise critical to the preservation of its local and regional biodiversity.

1.4.1 GAP-CLoSR Decision Framework

Spatially explicit models which incorporate ecological traits of species and fine-scale landscape elements can help to provide insights and predictions into ecological connectivity at multiple spatial scales (Doerr et al 2010, Drielsma and Ferrier 2009). The most common approach to model connectivity internationally and in Australia is based on least-cost path analysis (Adriaensen et al 2003; Foltête et al 2012). Least-cost path analysis characterises non-habitat areas based on the cost of dispersal to or through these landcover types. These dispersal costs represent the difficulty, energetic costs or mortality risk of movement (Adriaensen et al 2003; Sawyer et al 2011). The costs of dispersal through each landcover type are combined with species-specific dispersal probabilities over a range of distances. The importance of a patch or linkage within a network can be quantified using the graph theoretic approach (Urban and Keitt 2001, Minor and Urban 2008, Rayfield et al. 2011). Modelling tools such as Circuitscape (McRae and Kavanagh 2011), Linkage Mapper, and Graphab can be used to calculate these least-cost paths and provide the graph-metric analysis to assign the relative importance.

The GAP CLoSR decision-support tool provides both a processing framework to develop key spatial layers and parameters for these models, and a conceptual framework for incorporating specific ecological thresholds for species such as minimum viable patch size and movement capabilities (Lechner and Lefroy 2014, Lechner et al. 2015, 2017). The tool is based on concepts of fine-scale animal movement and ecological connectivity developed in previous Australian studies on dispersal ecology and habitat connectivity. The tool can be used by conservation planners in managing habitat connectivity at the regional scale while taking account of implications for fine-scale landscape features. Comparisons of connectivity implications can also be made at different spatial scales (regional or local) and under different scenarios (Lechner et al. 2015). Spatially explicit models of ecological connectivity using the GAP CLoSR framework were developed and applied to Maroondah.

1.4.2 Conceptualising the landscape

Patches and linkages

The ecological connectivity network concept, which the GAP CLoSR framework models, is built upon habitat patches and linkages (or least-cost paths) (Lechner et al. 2015, 2017). Patches are areas of core habitat of sufficient size and structure to support faunal populations. Linkages are the least-cost paths within the landscape that species can use to disperse between habitat patches, effectively connecting them in a fragmented landscape. The linkage represents the shortest, least-hostile path between two patches utilising stepping-stones (areas of refuge) that a species may use to facilitate movement.

Referred to as 'structural connectivity elements' in the framework, these stepping-stones may be patches of vegetation which are too small to be considered a habitat patch (e.g. a single paddock tree) or other non-habitat features which could be use as short-term refuge (e.g. garden beds).

Resistance and barriers

In order to accurately represent the difficulty, or 'cost', of travelling across different land cover types, 'resistance' is incorporated into the model. For many species, parklands are considered to have no resistance, however, as it does not act as a stepping-stone a species will only move so far across this land type before it decides this risk is too high and 'turns back'. As the land cover changes so too does the risk or cost of the movement, which in turn reduces the distance a species will travel to reach another patch. Urban landscapes, for example, may not prevent dispersal completely, however they may make movement more difficult, resulting in lower dispersal distances. Where the resistance is so great the species cannot move through the landscape, such as across a busy highway or watercourse, it is considered to be impenetrable and is referred to as a 'barrier'.

Networks and components

To assist in the interpretation and weighing of connectivity features and allow the development of a landscape scale 'connectivity network', the modelling assigns 'nodes' and 'edges' to each patch and linkage respectively. These terms can be used interchangeably when interpreting the modelling, however only patches, linkages and connectivity elements represent real-life features present within the study area.

In the graph theoretic approach applied within the Graphab software (Foltête et al 2021), isolation and fragmentation are represented by 'component boundaries'. These define a group of patches that are linked to each other but isolated from patches in other components. They thereby show where habitat is isolated and where it is connected. The size, shape, and number of patches they contain characterise levels of fragmentation in the landscape and barriers to connectivity.

The significance of patches and linkages in the connectivity network is estimated using graph theoretic approach and metrics calculated in Graphab. The metrics considered in this study are 'delta Integral Index of Connectivity'. The delta Integral Index of Connectivity (dIIC) is defined as the probability that two points randomly placed within a landscape fall into habitat areas that can be reached (Pascual-Hortal and Saura, 2006). Values for this metric increase with greater connectivity from zero to one and attempt to identify the most critical patches and linkages contributing to the maintenance of overall landscape connectivity.

1.4.3 Conceptualising dispersal behaviour

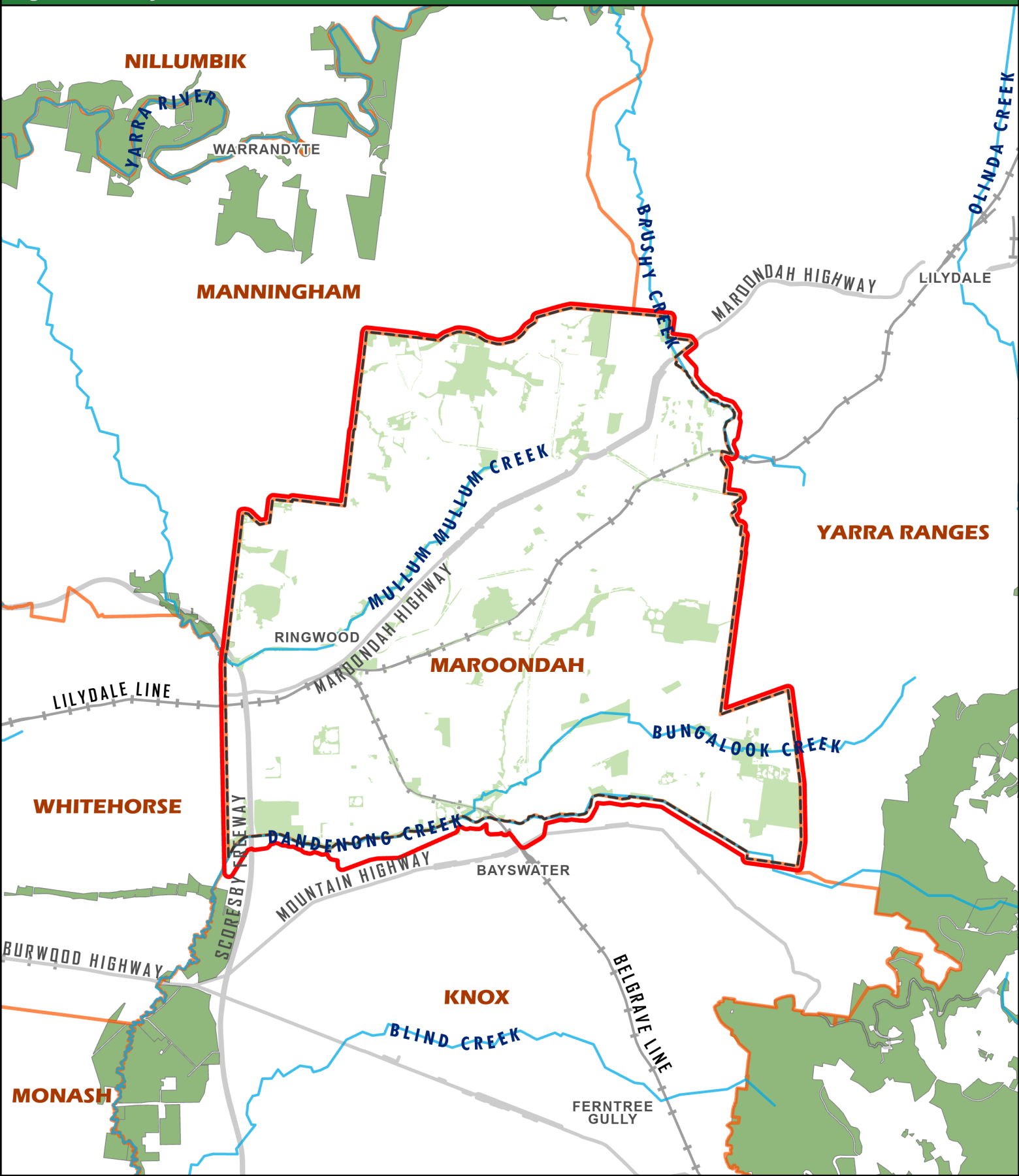
The model is based on the dispersal requirements of select groups of native species. To allow parameterisation of the model, a model species is selected and defined by its habitat and dispersal traits as a representative of the associated 'dispersal guild' and/or habitat type. This allows the model to analyse the dynamics of a particular dispersal behaviour taking into account the various habitat types within the municipality. Refer to Section 3.3 for species selection.

Key requirements identified for each species includes:

- Landcover types that represent habitat and the minimum patch size for that species.
- Landcover types that could act as stepping-stones and facilitate dispersal (i.e. structural connectivity elements).
- The relative resistance value of all other landcover types within the landscape (often defined as a percentage or multiplier).
- The maximum distance an individual is willing to travel between patches along a linkage, referred to as the 'inter-patch distance'.
- The maximum 'gap-crossing distance' an individual is willing to travel between structural connectivity elements.

These requirements (or 'parameters') represent the maximum distance an animal can move along linkages between stepping-stones and ultimately habitat patches. For example, recent studies have found that several Australian woodland birds rarely cross gaps greater than 100 m and distances of greater than 1 km between patches (Doerr et al. 2011, Smith, Forbes & Betts 2013). The model considers these thresholds and calculates whether animals can move between habitat patches based on these movement traits and the arrangement of structural connectivity elements between them.

Figure 1: Study area



Study area
City of Maroondah
Local Govt Areas
Sites of biological significance (Maroondah)
State-managed Parks and Reserves
Major watercourse
Major roads
Railways

N

0 1 2 4 Km

Scale 1:80,000

Client name: Maroondah City Council

Project number: 15905

Date: 26/10/2021

Version: 3

Spatial Reference: GDA 1994 MGA Zone 55

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2. Maroondah's biodiversity

The following provides a summary of the 'Biodiversity in Maroondah' report (Vol 1 and 2, Lorimer 2020).

2.1 Regional and historical context

The City of Maroondah is located on the fringe of metropolitan Melbourne, approximately 30 km to the east of the central business district and situated at the base of the Dandenong Ranges and Warrandyte State Park within the Gippsland Plain and Highlands Southern Fall bioregions. It is comprised of 6,138 hectares of primarily urban residential land with scattered parks and reserves and two main waterways; the Dandenong Creek and Mullum Mullum Creek. Prior to 1945, most of Maroondah's native vegetation had already been cleared with the few currently remaining patches of native vegetation containing a higher density of eucalypts as a result of the regrowth from clearing (Lorimer, 2020). Drainage works and urbanisation have also contributed to changes in the movement of water through soil and waterways; further increasing fragmentation of habitat for fauna (Lorimer, 2020).

2.2 Vegetation and habitat

Thirteen ecological vegetation classes (EVCs) occur throughout Maroondah, of those seven are listed as 'endangered' and five as 'vulnerable' within the Gippsland Plain bioregion (DSE, 2004 and Lorimer, 2020). Native forest EVCs are found in the north and south-east of Maroondah, these include Grassy Dry Forest (EVC 22), Valley Grassy Forest (EVC 47), Herb-rich Foothill Forest (EVC 23), Grassy Forest (EVC 128) and Lowland Forest (EVC 16). Along creeks such as Dandenong and Mullum Mullum there are segments of Riparian Forest (EVC 18) and Swampy Riparian Woodland (EVC 83) (Lorimer, 2020). Swampy Woodland (EVC 937) and Swamp Scrub (EVC 53) occur on poorly drained soils near Kilsyth South and Croydon (Lorimer, 2020). Other EVC's that occur include Creekline Herb-rich Woodland (EVC 164), Valley Heathy Forest (EVC 127) and Swampy Riparian Complex (EVC 126). Stream channels were distinguished as a separate ecological community with their own suite of flora, fauna and ecological processes in the study.

Fauna habitat was broadly grouped into ten categories (Lorimer 2020):

- Natural and semi-natural forest and woodland, which provide habitat for the broadest range of fauna.
- Bushland residential areas with natural and semi-natural forest interspersed with homes and associated constructions. These areas support a subset of the fauna found in larger, less interrupted patches of forest.
- Fragmented strips and small patches of semi-natural forest and revegetation beside roads and railway lines, supporting principally birds, insects and possums, and probably bats.
- Fragmented strips and small patches of semi-natural forest and revegetation beside streams, supporting common fauna as well as birds that move regularly along stream corridors, such as Ibis and the White-faced Heron.
- Streams, which provide habitat for microorganisms, worms, molluscs, yabbies, many insect larvae, fish, waterbirds, Buff-banded Rail, Rakali and Platypus.
- Wetlands, which provide habitat for microorganisms, aquatic invertebrates, birds, Shortfin Eel, Flathead Gudgeon, frogs and lizards.

- Nature strips with mature street trees of species that are locally indigenous or Australian native. The trees provide food, nest sites, protective cover and movement corridors for birds and insects.
- Open expanses such as parklands, which provide habitat for a small number of bird species such as swallows, Black-shouldered Kites and Masked Lapwings.
- The municipality's three golf courses, which combine artificial wetlands, strips of trees and open expanses.
- Public parks and residential gardens not falling into the previous categories, supporting common indigenous and introduced fauna such as possums, Rainbow Lorikeets, Magpies and Marbled Geckoes.

2.3 Biodiversity

2.3.1 Flora

A total of 556 indigenous plant species have been recently or historically recorded within Maroondah and of those, 429 are known or considered likely to remain (Lorimer, 2020). Flowering plants represent the majority of this total, followed by moss, ferns and a small number of liverworts (Lorimer, 2020). Orchids represent the largest family group within the flowering plants (13%). Rare or threatened flora include the nationally listed Kilsyth South Spider-orchid *Caladenia* sp. aff. *venusta* (Kilsyth South), Matted Flax-lily *Dianella amoena* and state listed species Dandenong Range Cinnamon Wattle *Acacia stictophylla,* Famine Flat-pea *Platylobium infecundum,* Golden Cowslips *Diuris behrii,* Floodplain Groundsel *Senecio campylocarpus,* Red-tip Greenhood *Pterostylis clivosa,* Sharp Greenhood *Pterostylis × ingens*, Veined Spear-grass *Austrostipa rudis* subsp. *australis* and Yarra Gum *Eucalyptus yarraensis* (Lorimer, 2020).

Flora species considered to be at the greatest risk of becoming locally extinct within Maroondah include orchids and species confined to floodplain soils due to the effects of climate change, drainage works, urbanisation and sensitivity to extended periods of drying soil (Lorimer, 2020).

2.3.2 Fauna

Habitat for native fauna within Maroondah comprises natural and semi-natural bushland reserves, creeks, wetlands, parks and gardens, nature strips, and golf courses (Lorimer, 2020). Birds and frogs have been the most commonly recorded species groups through 'citizen science programs', followed by mammals (excluding bats) which allows for more certainty as to their presence within Maroondah (Lorimer, 2020). State listed threatened species known or considered likely to remain include Barking Owl *Ninox connivens,* Eastern Great Egret *Ardea modesta,* Glossy Grass Skink *Pseudemoia rawlinsoni,* Hardhead *Aythya australis,* Intermediate Egret *Ardea intermedia,* Powerful Owl *Ninox strenua* and Swamp Skink *Lissolepis coventryi*, along with the nationally listed migratory species Rufous Fantail *Rhipidura rufifrons* and Satin Flycatcher *Myiagra cyanoleuca* (Lorimer, 2020).

2.4 Biodiversity assets

Key biodiversity areas make up 12% of Maroondah's total area (109 sites identified as Sites of Biological Significance; Lorimer, 2020). This includes sites that meet the state government's listing criteria titled *'Standard Criteria for Sites of Biological Significance in Victoria'* (Amos 2004) for nationally significant (18 sites) and state significant (65 sites) due to the presence of highly threatened plant species and

vegetation types (Lorimer, 2020). There are a further 26 sites of regional and local significance, which contain vulnerable vegetation types and/or rare plant species, and at the local level provide movement corridors for fauna (Lorimer, 2020). The remaining four sites require more detailed and formal assessments to determine their significance to the state or regional level (Lorimer, 2020). Key threats to biodiversity are listed in Table 1 (Lorimer, 2020).

Table 1. Key threats to biodiversity conservation within Maroondah

Environmental	Land use
• Climate change • Drying of floodplains • Effects of water pollution on aquatic flora and fauna • Eucalypt dieback • Loss of plant species with low populations • Weeds	• Drainage works • Urbanisation of catchments

3. Methods

3.1 Approach

Connectivity can be thought of as the extent to which a landscape facilitates the movements of organisms and their genes (Rudnick et al. 2012). The maintenance and restoration of connections between habitat patches is designed to maximise 'functional connectivity', which is the degree to which organisms move through the landscape between patches, successfully breed and contribute to gene flow and ultimately persist (Belisle 2005; Doerr et al. 2010). Underlying this is the concept of 'structural connectivity' composed of natural features (such as trees, patches, or corridors of vegetation) which facilitate wildlife movements and are critical to achieving functional connectivity among populations (Fischer and Lindenmayer 2007; Van Der Ree et al 2004).

The 'General Approach to Planning Connectivity from Local to Regional Scales' (GAP CLoSR) method combines both a species approach with a general landscape features analysis, characterising connectivity for species based on dispersal and habitat characteristics (Lechner et al. 2017). For this study, we have adapted the same dispersal guild concept and modelling approach.

In addition, a landscape scale analysis was completed using Circuitscape modelling tools (e.g. Pinchpoint Mapper). This process identified the movement probabilities of individuals along the least-cost paths identified through the GAP CLoSR analysis.

Key steps in the modelling process included:

1. Preparation of model inputs including creation of habitat, gap-crossing and resistance surface models for each of the species which describes how land cover effects movement within the landscape.
2. Model fine-scale connectivity using the Graphab software to identify the optimal paths among all patches, where a least-cost path can be generated. A least-cost path between two patches will exist if the cumulative cost distance is below the interpatch dispersal distance threshold.
3. Use a graph theoretical approach to mathematically determine the priority connectors (patches and linkages) critical for connecting wildlife in the landscape.
4. Using Linkage mapper to characterise least-cost corridors and then apply Circuitscape to model movement probability within these corridors to represent movement in the matrix (non-habitat areas) and associated pinch-points (a.k.a. bottlenecks or choke points).
5. Review model outputs and update model inputs accordingly, and re-run steps 2 - 4.
6. Based on model outputs for 'existing' connectivity, identify key questions and management assumptions for 'potential' connectivity scenarios. Update model inputs to reflect these assumptions and run steps 2 – 4 for additional scenarios.

Outputs of the connectivity modelling include the identification for each species of:

- 'Core habitat' patches based on the minimum size considered viable to sustain a population
- Least-cost paths ('linkages') based on the species dispersal parameters (i.e. gap-crossing threshold, interpatch distance, structural connectivity elements and resistance to landcover types).

- A connectivity index for each patch and linkage (indicating the relative importance and contribution to connectivity across the entire network).
- Component boundaries, delineating the boundary of interconnected habitat.
- A 'heat map' of movement probability along the least-cost corridors.

The landscape-scale network of linkages connecting core habitats are collectively referred to as 'biolinks'. These are used as the focal point of habitat connectivity improvements within the municipality.

3.2 Study area

The connectivity study area encompasses the Maroondah City Council municipality and adjacent land associated with creek reserves (Figure 1).

3.3 Species selection

A dispersal guild approach was used to characterise connectivity for groups of species based on shared dispersal behaviour and ecological requirements (Lechner et al. 2015b, Lechner et al. 2017). The intent is to select dispersal guilds representative of the biodiversity present within the study area and which may be limited by connectivity.

As an initial step, a set of 'engagement species' were selected in collaboration with Maroondah City Council and the project reference group (Appendix A) via a series of workshops in 2020 and 2021. The engagement species will be used as a focus for engaging the community around conservation management, including planning, monitoring and community education, as well as informing the connectivity study. The following selection criteria were therefore used to select the final 23 engagement species listed in Appendix B:

- Represent a range of different faunal groups.
- Represent a range of different habitat types.
- Have varying levels of presence and abundance within or adjacent to Maroondah.
- Have the potential to engage the public or specific interest groups/ organisation.
- Could be used as indicators of ecosystem health and function.
- Are of a range of different threatened status.
- Have good survey efficacy.
- Represent a range of different dispersal abilities and guilds.

During the workshops, reference group members were also asked to identify important habitats that are considered significant for the conservation of biodiversity within Maroondah. This resulted in the following three habitat types being selected as a focus for the connectivity modelling:

- Forest and woodlands: dry eucalypt dominated woodlands and forests supporting a structurally diverse understorey.
- Riparian: woody vegetation (woodlands or scrubs) associated with a waterway.
- Wetlands: permanent and/or ephemeral wetlands supporting primarily non-woody vegetation.

Drawing from the list of indicator species, one species was selected for each of the three habitat types for use in the connectivity modelling analysis (Table 2). These species represent low and moderate mobility species within dispersal guilds most affected by fragmentation, which is a key limiting factor for fauna species in urban landscapes (Seto et al. 2012). These species were selected based on the following additional criteria:

- Are likely to significantly benefit from connectivity improvements throughout Maroondah.
- Represent different fauna groupings (guilds) with similar movement/dispersal characteristics, focusing on those for which connectivity may currently be restricted in the Maroondah context.
- Ability to elicit dispersal requirements from the existing literature or relevant experts.

Habitat and dispersal required for each species was identified based on previous modelling studies, data collected through the species selection process, and expert opinion gathered from the workshops and subsequent consultation. A summary of habitat and dispersal requirements for each species is presented in Table 3. Detailed species parameters are presented in Appendix D.

Table 2. Species selection and rationale

Habitat type	Forest and woodlands	Riparian	Wetlands
Species	Superb Fairy-wren *Malurus cyaneus*	Rakali *Hydromys chrysogaster*	Marsh Frogs *Limnodynastes tasmaniensis* and *L. peroni*
Rationale	• Representative of large fauna guild of significance to Maroondah (e.g. woodland birds). • Lower dispersal ability than larger birds (e.g. raptors). • Sensitive to urban environments due to reliance on dense vegetation to facilitate dispersal. • Requires understory structure for foraging and nesting, limiting use of open parklands and other 'semi-natural' areas.	• Utilises both aquatic and terrestrial habitats for movement allowing for connectivity between waterbodies to be examined. • Moderate dispersal ability through modified urban environments using a diversity of natural and artificial covers. • Requires permanent waterbodies. • Sensitive to cover and structure of riparian vegetation.	• Lower dispersal ability compared with other aquatic faunal groups (e.g. waterbirds) however still able to utilise terrestrial environments to disperse. • Requires standing or slow-moving water as core habitat however can utilise waterways as corridors. • Can utilise both permanent and ephemeral waterbodies. • Requires fringing vegetation with limited woody cover.

Table 3. Species' attribution and model treatment (summary)

Habitat	Species	Mobility	Patch size	Connectivity elements	Urban tolerance
Forests and woodlands	Superb Fairy-wren	Low-moderate	> 2 ha	Shrubby forest and woodlands	Low
Aquatic, riparian and swamps	Rakali	Moderate-high	> 3 ha	Vegetated waterways	Low
Wetlands	Marsh Frogs	Low-moderate	> 0.1 ha	Wetlands, dams and waterways	Moderate

3.4 Landcover classification

The objective of this step is to separate land cover types into distinct classes based on their overall contribution and/or resistance to fauna movement. The fine-scale classification of land cover is an essential step for developing appropriately detailed input maps of habitat, structural connectivity elements and landcover that is consistent across Maroondah and at a resolution suitable to support the GAP CLoSR modelling framework.

3.4.1 Spectral analysis

A preliminary assessment of the spectral difference between the desired land cover classes was undertaken using a supervised classification within remote sensing software (ENVI 5.5). The analysis was carried out on Council supplied Enhanced Compression Wavelet (ECW) imagery captured in May 2018 and March 2020 at a scale of 7.5cm and 6cm respectively. The supervised classification utilized the Maximum Likelihood method, a probability threshold of 0.8 and a minimum of 5 training points for differing land cover classes.

The format of the imagery and large size of the dataset resulted in a number of computational limitations making it difficult to process the data in its raw state. Despite further processing, limited success was achieved using the unsupervised classification on the 2018 imagery. Due to the lowered thresholds, high resolution of the imagery and the characteristics of the landscape; the resultant model was highly granulated with low classification confidence.

3.4.2 Auxiliary datasets and manual corrections

Whilst the remote sensing data could have been refined through the application of additional training information, data smoothing and data aggregation, it was determined that it would be more beneficial to create a land cover classification using a compilation of existing spatial datasets, including the Tree Ledger™ (machine learning foliage cover mapping product) and other auxiliary datasets (e.g. roads and waterways). A list of the datasets and steps to prepare each is provided in Appendix C.

Several manual edits were made to the land cover layer based on ground-truthing completed in November 2020 and subsequent aerial interpretation of high-resolution imagery. A focus of the manual corrections was to accurately capture the extent of wetland and riparian vegetation types associated with creeks, ponds and lakes throughout Maroondah.

The final compilation of the landcover layers was based on individual spatial layer accuracy related to species needs. Due to the variation between habitat and functional requirements, a separate landcover map was produce for each species modelled.

3.5 Habitat categorisation

Landcover classes which may provide habitat or stepping stones for species were further sub-classified by structural and functional habitat values, with a particular focus on the presence (‘complex’) or absence (‘simple’) of a structurally diverse understorey as a proxy for habitat function.

Sub-classifications were derived from a combination of the woody vegetation and groundcover classes identified in the primary classification (Appendix C). This was done by ‘clumping’ vegetation using the ‘aggregate polygons’ cartography tool within Arc Pro based on the specified distance. Further grouping of the complex habitat sub-classification areas was conducted by increasing the aggregation specified

distance to 20m and clipping the sub-classification to its own convex hull minimum bounding geometry, created within Arc Pro. This resulted in five habitat sub-classifications being created (Table 4).

Table 4. Landcover sub-classifications for modelling fauna habitat

Habitat Sub-classification	Woody Vegetation	Ground cover class	Aggregation (m)
Dry forest (complex)	Dry forest	Unmanaged grassland	12
Dry forest (simple)	Dry forest	Managed grassland	12
Exotic forest (complex)	Garden planting and Street tree	Unmanaged grassland	7
Riparian vegetation (complex)	Riparian vegetation	Unmanaged grassland	12
Riparian vegetation (simple)	Riparian vegetation	Managed grassland	12

In addition, the modelling took into account habitat outside of Maroondah (up to 5km) based on the classification of the current EVC mapping into the habitat sub-classifications and manual digitisation of vegetation along waterways based on aerial imagery.

Based on the primary and secondary land cover classifications, habitat sub-classifications have been incorporated into the connectivity parameters for each species (Appendix D). These were used in the modelling to determine the nature and extent of connectivity across the landscape for each species modelled.

3.6 GAP CLoSR analysis

3.6.1 Least-cost path and graph analysis

Modelling was conducted using the Graphab software (Foltete 2021). Graphab is used to identify the optimal paths among all patches, where a least-cost path can be generated. A least-cost path between two patches will exist if the cumulative cost distance is below the interpatch dispersal distance threshold. A least-cost path will not be generated if the cumulative cost to traverse the distance between the two patches exceeds the interpatch dispersal distance threshold. The cumulative cost distance describes the accumulated travel cost from one location to another based on the resistance surface rather than actual distance. Patches were deemed to be part of a component where a least-cost path could be established between them. Spatial patterns of these components are useful for characterising fragmentation and barriers to connectivity at the regional scale (Lechner et al., 2015).

To account for the influence of habitat outside the municipality, the value of patches that were truncated by the study area boundary (referred to as 'link patches') was inflated to account for their true ecological importance. Within Graphab these link patches were given an additional patch capacity equal to twice the area of the largest patch within the study area. In some cases, a single component had multiple link patches connecting the same external contiguous area of habitat. Within these components the extra patch capacity was divided equally between all link patches. Where two separate external large habitat areas were truncated (i.e. in the case of Dandenong Creek for the Marsh Frogs) the patch capacity was increased by four times the study area's the largest patch. Link patches were only modelled where significantly large areas of habitat were truncated.

Using patch-scale graph metrics the importance of a patch or linkage for connecting the landscape was quantified. This used a delta Integral Index of Connectivity (dIIC) value for patches and linkages based on the relative importance of the associated nodes or edges. High dIIC values were represented by larger circles and/or thicker lines, indicating that a patch or linkage is important for connecting habitat in the landscape. The dIIC value can be used to identify the most important landscape elements contributing to the maintenance of connectivity and the impact on biodiversity caused by the removal of a focal patch or link relative to the overall network (Pascual-Hortal & Saura, 2006; Saura & Pascual-Hortal, 2007).

3.6.2 Review and testing

Preliminary modelling of connectivity was undertaken using the habitat landcover classifications and dispersal and resistance parameters for each of the three species. Outputs from the initial 'test scenarios' were reviewed by the project reference group and compared to species records contained in the Victorian Biodiversity Atlas and Atlas of Living Australia.

Based on this review, the following adjustment were made to the model inputs and/or approach prior to completing the final run (Table 5).

Table 5: Major issues addressed through test scenarios

Issue	Description	Solution
Patch extent for Superb Fairy Wren	Stakeholders felt many core habitat patches were too small or narrow to support viable populations within the Maroondah context.	Minimum core habitat patch size increased from 1.5ha to 2ha. Removed habitat patches identified by stakeholders as being of poor quality (i.e. not complex habitat) or too narrow. Patches with small gaps that were an artefact of the landcover mapping process were connected.
Connectivity for Rakali	Concern model is over-estimating connectivity in the north of the Shire given urbanised nature of land between patches and the presence of ridgelines.	Reduced inter-patch distance from 3000m to 2000m and gap crossing threshold from 1000m to 750m. Patches with small gaps that were an artefact of the landcover mapping process were connected.
Habitat for Marsh Frogs	Habitat mapping under-represented extent of wetland habitat.	Habitat layer updated by joining wetland patches where there were small gaps and adding additional patches based on stakeholder feedback and further review of aerial imagery.
Creek corridors	Connectivity modelling not taking into account full extent of Dandenong Creek and Brushy Creek corridors and associated habitats due to being excluded by municipality boundary.	Study area boundary was extended to private property boundary on opposite side of creek corridor from Maroondah and Brushy Creeks, with landcover mapping updated for these areas and incorporated into modelling.

3.7 Least-cost corridor and circuitscape analysis

In addition to Graphab, Linkage Mapper (with Circuitscape) (McRae et al 2008; McRae and Kavanagh 2011) was used to characterise least-cost corridors and individual movement probabilities within those corridors. The least-cost corridors represent areas with cost-weighted distances below the interpatch dispersal distance threshold. Within the least-cost corridors we used Circuitscape to characterise movement probabilities based on random walk patterns using an algorithm derived from circuit theory (McRae et al. 2008). Using this combination of methods means connectivity can be characterised based

on the two dispersal thresholds (interpatch and gap crossing) while also characterising dispersal behaviour more realistically based on a random walk within corridors.

The Circuitscape analysis shows areas of high and low current density. Pixels with high current density represent areas with a higher probability of a random individual moving between patches. Locations with high current density, constrained to a small number of pixels represent pinchpoints. These areas are where animal movement is funnelled and most vulnerable to being severed (McRae et al. 2008). Commonly the least-cost paths and pinchpoints overlap. This analysis is useful for showing redundancy in the least-cost paths and how species utilise the matrix.

3.8 Potential connectivity

To identify potential linkages in the landscape and inform management priorities, several 'potential' connectivity scenarios were completed using the GAP CLoSR and Cicuitscape analysis described above. The rationale and changes for each scenario are outlined in Table 6. Detailed species parameters are presented in Appendix D.

By comparing differences in the model outputs for each species, and the change in component boundaries and dIIC, potential connectivity improvements can be elicited. This approach is useful for understanding the level of fragmentation in a landscape and where small actions may provide significant benefits.

Potential linkages identified for the three species have been deducted and classified by their relative Index of Connectivity to provide an indication of priorities for future connectivity investment.

Table 6. Potential connectivity scenarios

Scenario	Rationale	Changes
1.2	**Superb Fairy-wren:** This model is based on doubling the dispersal parameters and reducing the threshold for core habitat extent to understand the potential local corridors in the landscape that would require the least effort to establish. In realising this potential connectivity, the focus would be on creating core habitat between existing patches to reduce inter-patch distances and increasing the functional extent of existing large habitats which do not currently meet species requirements.	Update dispersal parameters: • Reduce minimum patch size from 2 to 1.5ha. • Increase gap-crossing threshold from 60 to 120 m. • Increase interpatch-crossing distance threshold from 500 to 1000 m.
1.3	**Superb Fairy-wren:** This model is based on changes to the underlying landcover to reflect the implementation of targeted management actions on public and private land. Actions are focused on increasing the extent and function of habitat along the Belgrave Rail line, the Ridgeline Corridor and through the Bayswater Industrial precinct. Potential management actions include a mixture of wildlife gardening and habitat creation and improvement on public land not traditionally used for conservation purposes (e.g. road reserves and unused/underutilised land).	Update landcover classification mapping with: • 1000 m wide 'ridgeline habitat' corridor based on changing simple habitat types to complex. • 300 m wide 'ridgeline habitat' corridor based on changing simple habitat types to complex. • 'public land habitats' based on changing simple habitat types to complex on land zoned for public use. • 'Bayswater habitat' based on creation of connectivity elements (complex vegetation) along roadsides within Bayswater industrial precinct.

Scenario	Rationale	Changes
2.2	**Rakali:** This model is based on doubling the dispersal parameters and reduce landcover resistance to understand the potential local corridors in the landscape that would require the least effort to establish for this species. In realising this potential connectivity, the focus would be on creating core habitat between existing patches to reduce inter-patch distances and removing the movement resistance and barriers through residential areas.	Update dispersal parameters: • Increase gap-crossing threshold from 500 to 750 m. • Increase interpatch-crossing distance threshold from 1500 to 2000 m. Reduce resistance for a range of landcover types (see Appendix D).
2.3	**Rakali:** This model is based on investment in the quality and extent of habitat on public and private lands (primarily along waterways and around permanent waterbodies) to improve functional connectivity in the landscape. Actions are focused on increasing the structural complexity of riparian vegetation within public land and adjoining private lands (focusing on understorey and fringing vegetation) and improving the condition and diversity of aquatic habitats (e.g. deep pools, instream timber and rocks, fast flowing reaches etc).	Update 'rakali habitat' classification to: • include 'simple' riparian habitat types. • Increase the distance from waterways from 50 to 100 m.
3.2	**Marsh Frogs:** This model is based on increasing the number of core habitats throughout the municipality and reducing barriers associated with roads and rail lines. Key management actions will involve daylighting of creeks, wetland creation in public reserves and creation of crossing structures along key corridors that intersect road and rail reserves.	Update landcover classification mapping with: • Wetlands at least 0.1 ha in size located within all public parks and reserves • Daylighting of drains and piped waterways (i.e. change to 'channel – natural). Reduce resistance associated with roads and rail lines (see Appendix D).

3.9 Modelling outputs

A connectivity model output was produced for each current and potential connectivity scenario based on the final land classification layer and species dispersal and resistance parameters. For each species the model identifies habitat patches, least-cost paths and stepping stones. These outputs represent the current habitat connectivity for each species.

Individual species models were combined into a single interpretive 'landscape connectivity' map which incorporates the dIIC weightings to provide an overview of landscape connectivity for a variety of dispersal guilds, allowing the identification of biolinks and priority habitats and wildlife passages.

3.10 Prioritisation framework

To help understand priority locations for conservation actions over the next ten years, a prioritisation analysis of biodiversity values across Maroondah was completed. The outputs will be used to inform conservation priorities and planning activities, along with supporting a range of other financial, administrative and operational decisions and activities.

The primary objective of the prioritisation analysis is to identify areas with highest biodiversity conservation value taking into account current, or potential, connectivity across the municipality along with common biodiversity significance metrics. As a secondary objective, the prioritisation analysis will

also consider those locations with the greatest opportunity to allow people to 'connect' with nature, and thus incorporate a social benefit aspect to the prioritisation of conservation actions.

The analysis combines a range of datasets, including those generated as part of the connectivity study, across three themes:

- Biodiversity value
- Connectivity value
- Connecting to nature value

A suite of decision criteria has been developed based on previous studies and feedback from Council (Table 7). The criteria represent the factors a conservation planner or manager may need to consider when determining which biodiversity assets to protect, enhance or create through future investment. Indicator datasets for each decision criteria were selected based on the best available data with regards to resolution, accuracy, and reliability.

Preliminary ranking and weightings for each of the criteria datasets has been assigned by ELA. The criteria were ranked from 1 to 5 based on the themes outlined above (5 being the highest) (Table 8). Following the ranking process each criterion was collectively assigned a multiplier for the resultant criteria score, reflecting the relative importance of the criteria towards landscape connectivity within the context of the study area and major values for biodiversity and conservation.

A summary of the steps involved in data preparation requirements for the analysis and associated criteria, rationale, data layers, rank and weightings proposed are outlined in Appendix E.

The conservation index score is the sum of the rank and weighting for each of the statutory and landscape decision criteria (Appendix E). The final scores were normalised to provide an index ranging from 0 to 100 using the following formula:

$$X \text{ normalised} = ((X - X \text{ min})/(X \text{ max} - X \text{ min})*100)$$

The resultant normalised values were then categorised into five conservation priority categories (Table 9).

Table 7. Decision criteria for the Maroondah prioritisation framework

Category	Decision Criteria	Rationale
Biodiversity value	Consolidated habitat cover	The extent to which habitat is consolidated in the landscape as a proxy for patch size.
	Vegetation condition	The modelled condition of vegetation as a proxy for habitat diversity and quality.
	Threatened ecological communities	The presence of threatened or endangered vegetation communities listed under the *Flora and Fauna Guarantee Act 1988* or with an Endangered Bioregional Conservation Status.
	Threatened flora and fauna	The presence of rare or threatened flora and fauna listed under the *Flora and Fauna Guarantee Act 1988* and/or *Environment Protection and Biodiversity Conservation Act 1999*.

Category	Decision Criteria	Rationale
Connectivity value	Regional connectivity	The overall contribution of habitat patches to connectivity across the landscape.
	Local connectivity	The relative contribution of local least-cost paths to habitat connectivity based on the probability of dispersal.
Connecting to nature value	Conservation areas	State recognised conservation areas that are associated with key biological values and/or identified within government approved plans/strategies, including Sites of Biological Significance identified by Graeme Lorimer. Defined as sites with specific purpose is for nature conservation.
	Public land	Parks, reserves and public spaces accessible to the public, with a primary purpose other than nature conservation.
	Paths	Pathways which transport people through areas of nature (roads, rail, tracks or trails). Weighted by mode of transport (e.g. driving vs. walking) and nature of area.
	Private land	Private lands with a close proximity to habitat areas which may be considered a priority for land management engagement.

Table 8. Summary of rank and weighting values

Rank	Assigned Weight	Rationale
5	x3	Values that are recognised as being of greatest conservation value due to the significance biodiversity they support, the role they play in connecting the landscape and/or the ability to engage people with nature.
4		
3	x2	Values that are recognised as being of moderate conservation value due to the value they have in supporting biodiversity, connectivity, and community engagement at a local scale.
2		
1	x1	Values that have limited biodiversity and connectivity values and facilitate connection with nature on a basic level.

Table 9. Conservation priority categories

Very High	Areas supporting values that are recognised as being of greatest conservation value due to the significant biodiversity they support, the role they play in connecting the landscape and the ability to engage people with nature. Management efforts should be focused on protecting and improving the biodiversity and connectivity associated with these areas.
High	Areas supporting values that are recognised as being of high conservation value due to the significant biodiversity they support, the role they play in connecting the landscape and the ability to engage people with nature. Management efforts should be focused on protecting and improving the biodiversity and connectivity associated with these areas.
Moderate	Areas supporting values that are recognised as being of moderate conservation value. Management efforts should be focused on protecting and improving these areas where specific outcomes are identified, or they improve regional outcomes associated with high value areas.

Low	Areas supporting values that are recognised as being of limited conservation value. Management efforts should be focused on protecting and improving these areas only where it may improve regional outcomes associated with high value areas.
Very low	Areas considered to be of the least value for biodiversity conservation and engagement. Management of these areas should be focused only on prevention of threatening process that may have a broader impact (e.g. invasive weeds).

4. Results

4.1 Landcover classification

Whilst Maroondah is dominated by urban development in the form of residential areas and commercial and industrial precincts, the city still supports extensive areas of vegetation (Table 10; Figure 2). This includes more than 55% vegetated groundcover (e.g. managed and unmanaged grasslands) and more than 37% woody vegetation cover (noting the total cover of land classified exceeds Maroondah's area due to overlapping layers).

A significant portion of this vegetation exists within residential gardens and public streets (48% of groundcover and 25% of woody vegetation). The remainder is situated within public use zones or larger private parcels where bushland communities cover approximately 12% of Maroondah. These were split equally between simple (i.e. absent or limited understorey) and complex (i.e. structurally diverse understorey) habitat types.

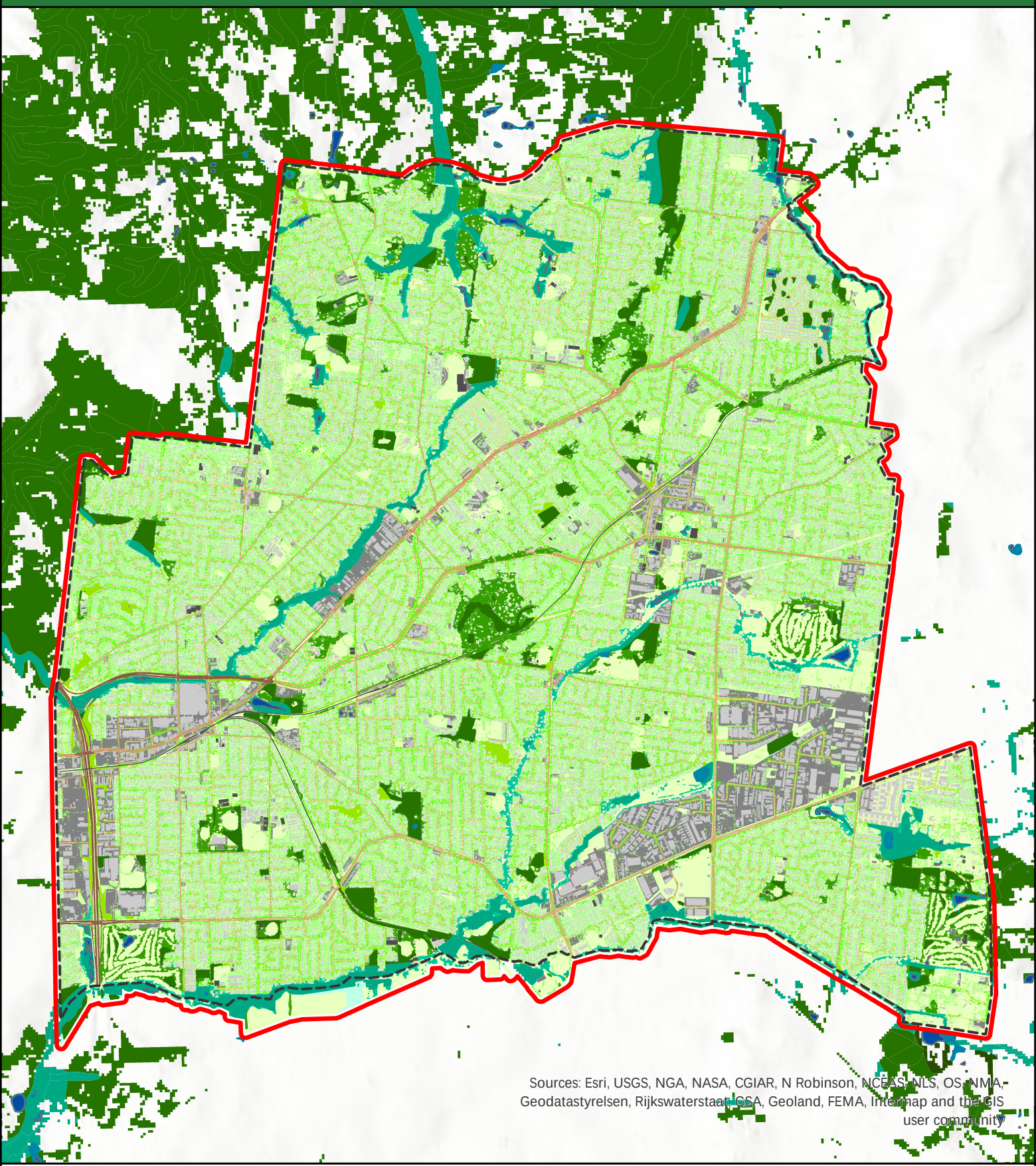
Despite creeklines being a prominent landscape feature, the extent of open water and associated fringing or aquatic vegetation accounts for less than 1% of Maroondah.

Non-vegetation landcover types covered approximately 30% of Maroondah, with buildings (16%), hardstand (6%) and roads (8%) being the most extensive.

Table 10: Landcover classifications and area based on remote sensing analysis

Classification	Area (ha)	Percent of LGA	Classification	Area (ha)	Percent of LGA
Waterbody	11	0.18%	**Groundcover vegetation**	**3435**	**55.96%**
Channel - natural	0.76	0.01%	Residential ground cover	2921	47.59%
Drain - cement	0.69	0.01%	Managed grassland	134	2.18%
Drain - grass	0.71	0.01%	Unmanaged grassland	380	6.19%
Buildings	994	16.19%	**Woody vegetation**	**2268**	**36.96%**
Hardstand	360	5.87%	Dry forest (complex)	185	3.01%
Hardcourt	9	0.15%	Dry forest (simple)	226	3.68%
Freeway	29	0.47%	Exotic forest (complex)	30	0.49%
Highway	30	0.49%	Riparian vegetation (complex)	164	2.67%
Major Road	127	2.07%	Riparian vegetation (simple)	111	1.80%
Minor Road	307	5.00%	Garden plantings	835	13.60%
Rail	0.16	0.00%	Street trees	719	11.71%
Path	38	0.62%	**Wetlands**	**26**	**0.42%**

Figure 2: Landcover classification by cover and habitat



City of Maroondah
Study area
Dry forest (complex)
Dry forest (simple)
Exotic forest (complex)
Riparian vegetation (complex)
Riparian vegetation (simple)
Wet forest (complex)
Garden planting
Street tree
Waterbody
Wetlands
Rail
Freeway
Hardstand
Highway
Major road
Minor road
Path
Buildings
Hardstand
Hardcourt
Managed grassland
Residential ground cover
Unmanaged grassland

0 0.5 1 2 Km

Scale 1:50,000

1

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4.2 Species connectivity

Existing and potential habitat connectivity modelling was completed for three dispersal guilds, using Marsh Frogs, Rakali, and Superb Fairy-wren as the target species (Section 3; Table 3). All exhibited significant differences in their responses to the Maroondah landscape as discussed below.

4.2.1 Superb Fairy-wren

Superb Fairy-wren represents a woodland species with low to moderate dispersal ability, that requires forest and woodland habitat with a shrubby understorey of at least two hectares in size. Connectivity elements were assumed to be any vegetation consisting of canopy trees or dense shrubs which provide temporary refuge from predators whilst dispersing through the landscape.

Existing connectivity

Despite the abundance of connectivity elements for Superb Fairy Wren throughout Maroondah, including small woodland pockets, gardens and street trees, core habitats remain isolated due primarily to the distance between each and dispersal resistance associated with the heavily urbanised landscape (Figure 3). Whilst limited, significant areas supporting multiple, interconnected patches of core habitat include:

- Croydon Hills reserves (Warranwood Reserve, Yarrunga Reserve and Narr-Maen Reserve) and the interconnecting bushlands associated with Jumping Creek.
- Hochkins Ridge Flora Reserve and smaller parks and reserves to the south within Croydon North.
- Dandenong Creek and surrounding reserves west of the confluence with Bungalook Creek.
- Bungalook Conservation Reserve and Eastwood Golf Course, including woodlands on private property along Tereddan Drive.

Additional large, but isolated, patches of core habitat included woodlands and forests associated with: Warrien Reserve, Douglas Maggs Reserve, Landau Drive Reserve, Andersons Creek East Branch, Monterey Bush Park, Mullum Mullum Creek between Oban Road and Dublin Road Drain, BJ Hubbard Reserve, Mullum Mullum Creek Reserve, Ringwood Lake Park, Webster Ave, Ruthven Way, Eastfield Park, Dorset Golf Course, Bungalook Creek west section, Tintern Grammar and Primary School, Wombolano Park, Jubilee Park, Heathmont Reserve, Clipsal Drive and Apple Tree Hill Reserve.

The modelled lack of connectivity is supported by the distribution of species records collated from the Victorian Biodiversity Atlas (VBA) and Atlas of Living Australia (ALA). Many of the isolated patches of core habitat, and in particular those in the centre of Maroondah (such as Mullum Mullum Creek, Warrien Reserve, Tintern Grammar and woodlands associated with Webster Ave and Ruthven Way) have few or no records of this species. In contrast those areas with multiple, interconnected patches, such as the reserves within the north of the City, have an abundance of records.

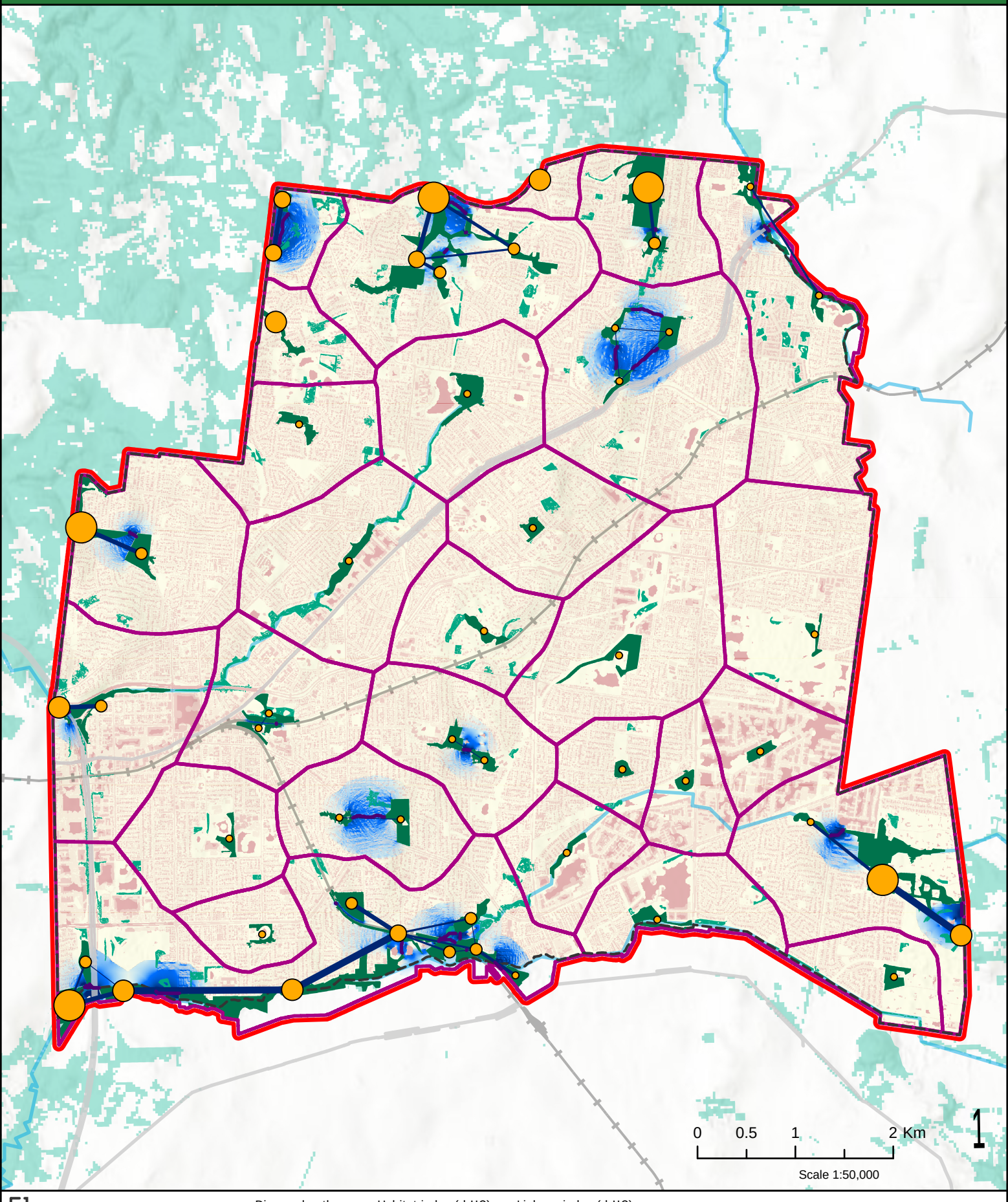
Whilst notable ‘corridors’ of interconnected habitat facilitating landscape-scale dispersal across Maroondah are limited for this species, both the Croydon Hills reserves and Dandenong Creek are notable exceptions. These provide connectivity within their local vicinity and to habitats outside the municipality. No corridors through Maroondah were identified in the modelling.

Potential connectivity

Potential connectivity for Superb Fairy Wren has been modelled based on two scenarios (Section 2, Table 6). Scenario 1.2 shows the potential to dramatically improve the connectivity for this species in both the north of the municipality through Warranwood, Croydon and Croydon Hills and in the south along Bungalook Creek, and the ridgeline corridor through Ringwood East (Figure 4). When targeted management actions are applied in Scenario 1.3, connectivity along the ridgeline corridor and Mullum Mullum Creek is also considered viable (Figure 5), noting that the former will require significant improvement of habitat on private land to realise this goal.

Both potential connectivity models still show a lack of connectivity along the upper reaches of Dandenong Creek, indicating significant investment is required through this corridor to see benefits for this faunal group.

Figure 3: Superb Fairy Wren - Existing habitat connectivity (Scenario 1.1)



City of Maroondah
Study area
Habitat patches (>2 ha)
Potential habitat patches (<2ha)
Habitat outside Maroondah (approx.)
Component boundaries

Dispersal pathways
Many/shortest
Few/longest

Habitat index (d IIC)
Less important
More important

Linkage index (d IIC)
Less important
More important

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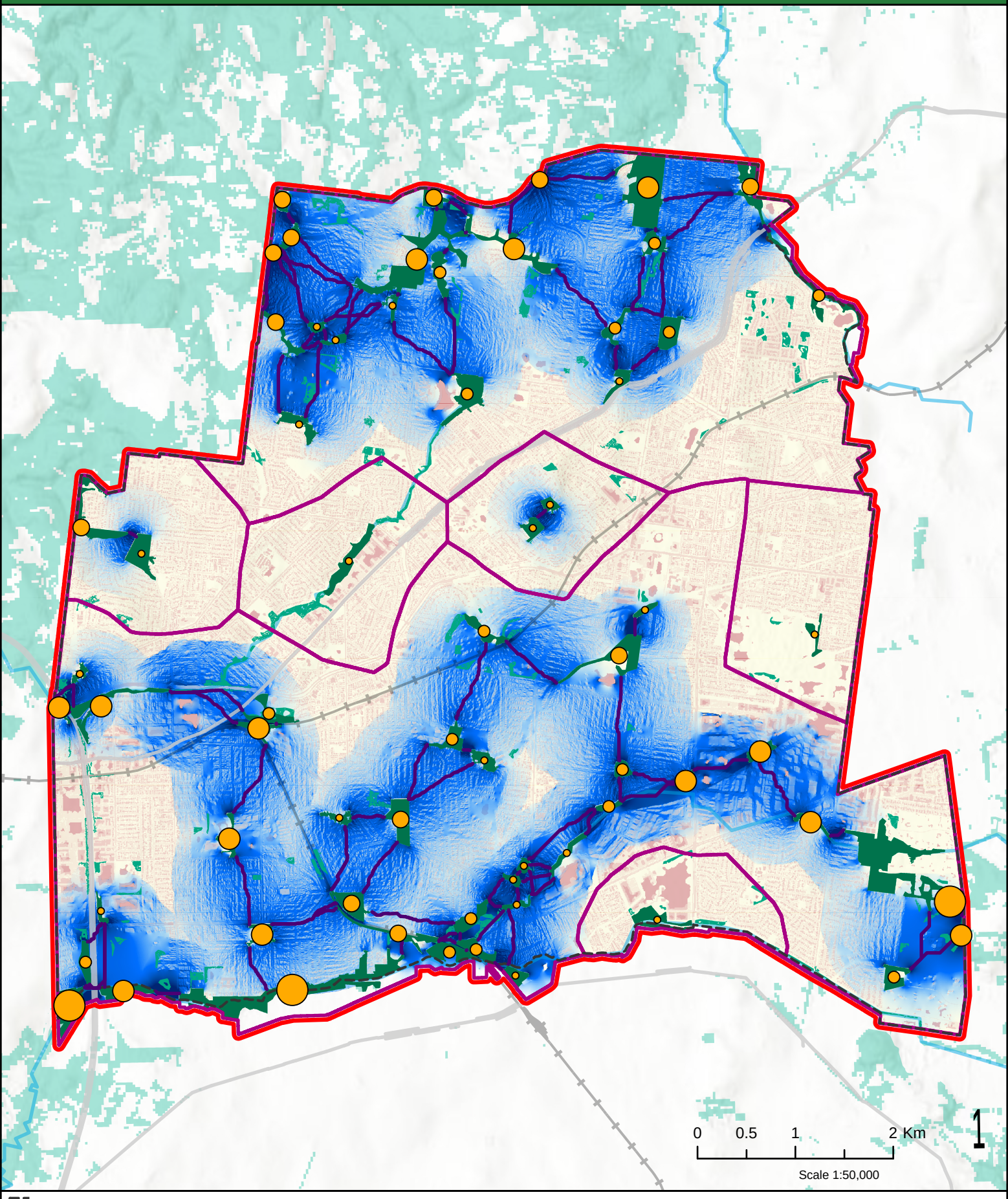
Figure 4: Superb Fairy Wren - Potential habitat connectivity (Scenario 1.2)



City of Maroondah
Study area
Habitat patches (>1.5 ha)
Potential habitat patches (<1.5 ha)
Habitat outside Maroondah (approx.)
Component boundaries

Dispersal pathways
Many/shortest
Few/longest
Least-cost paths

Habitat index (d IIC)
Less important
More important

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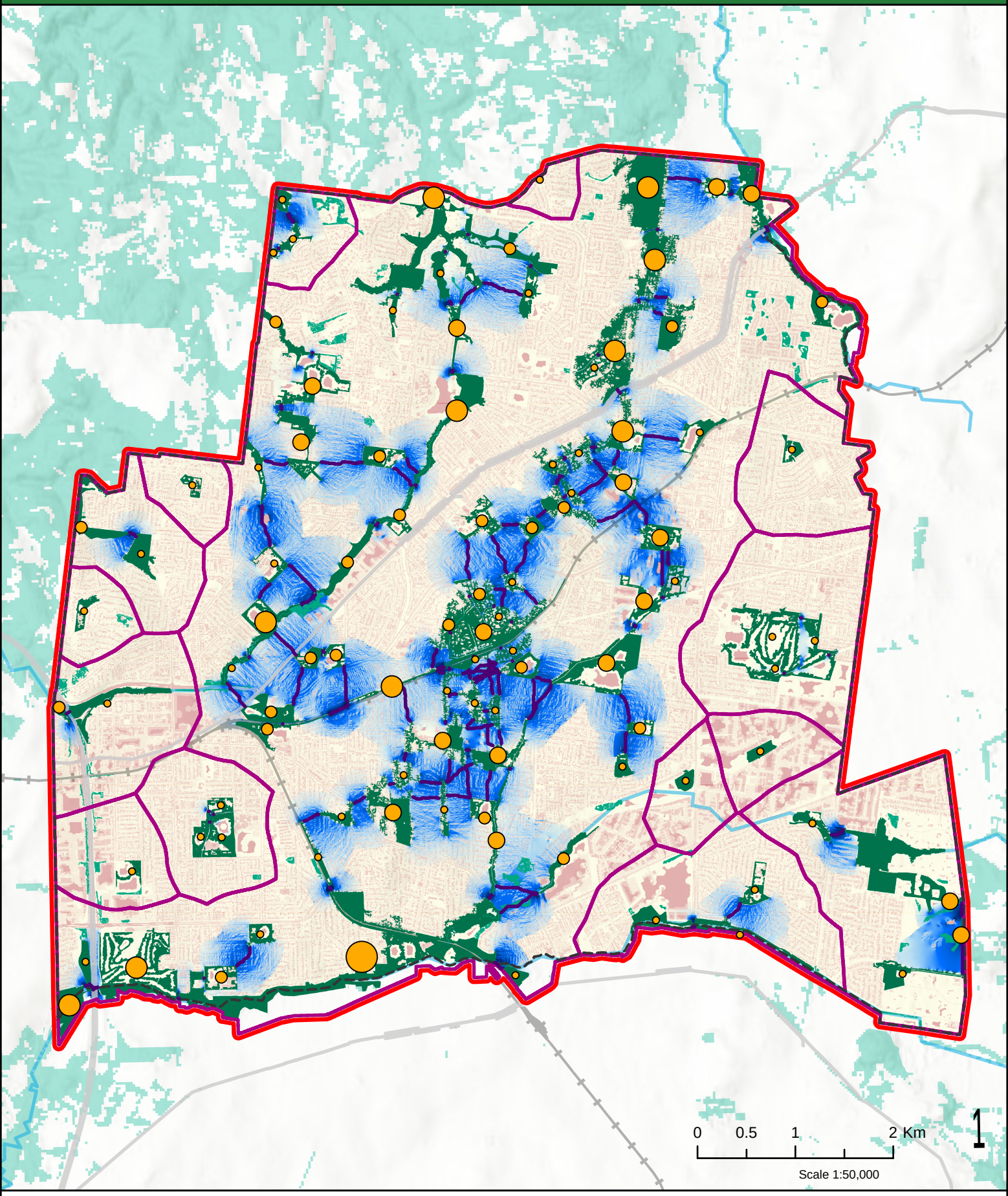
Figure 5: Superb Fairy Wren - Potential habitat connectivity (Scenario 1.3)



City of Maroondah
Study area
Habitat patches (>2 ha)
Potential habitat patches (<2ha)
Habitat outside Maroondah (approx.)
Component boundaries

Dispersal pathways
Many/shortest
Few/longest
Least-cost paths

Habitat index (d IIC)
Less important
More important

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4.2.2 Rakali

Rakali is an aquatic mammal with moderate to high dispersal abilities that requires permanent aquatic habitat, including vegetated waterways and swamps of at least three hectares in size. Connectivity elements were assumed to be vegetation with a dense understorey of low shrubs and/or tall grasses, which would provide foraging opportunities and refuge from predators during dispersal.

Existing connectivity

Given the association with permanent water, patches of core habitat are limited for this species within the municipality (Figure 6). This can be attributed in part to the removal and modification of waterways due to urbanisation. As a result, interconnected patches of core habitat were restricted to 'natural' creek lines supporting mature woodlands with dense or unmanaged understories. This includes:

- Jumping Creek and associated tributaries in Croydon Hills.
- Mullum Mullum Creek between Plymouth Road and the Ringwood Bypass.
- Brushy Creek in Croydon North.
- Dandenong Creek and Bungalook Creek west of Bayswater Road.

Smaller, isolated patches of core habitat were also identified along the western-most section of Mullum Mullum Creek, Nangathan Flora Reserve, Andersons Creek East Branch, Bungalook Creek eastern section and little Bungalook Creek.

Despite Rakali's higher dispersal ability, connectivity between waterways and associated core habitat is not shown to be present in Maroondah. This can be attributed to the high level of resistance this ground-dwelling species would encounter in an urbanised landscape (including the prevalence of domesticated predators such as cats and dogs) and the distances between core habitat across ridgelines delineating water catchments. Given this species would normally disperse along waterways utilising points of confluence to reach other parts of the landscape, the compartmentalisation shown in the modelling is unsurprising.

Records of Rakali within existing databases (VBA and ALA) are limited, however a dead individual was recorded from Oliver St, Ringwood near Mullum Mullum Creek in 2019 (Lorimer 2020). Prior to this, the species has been recorded along Andersons Creek East Branch on the western edge of the municipality in 1996 (Lorimer 2020). Whilst this species may persist within the city in low numbers, the accuracy of the modelling cannot be assessed against the species distribution based on past records. Targeted surveys for this species will provide additional data against which modelling can be reviewed and interpreted.

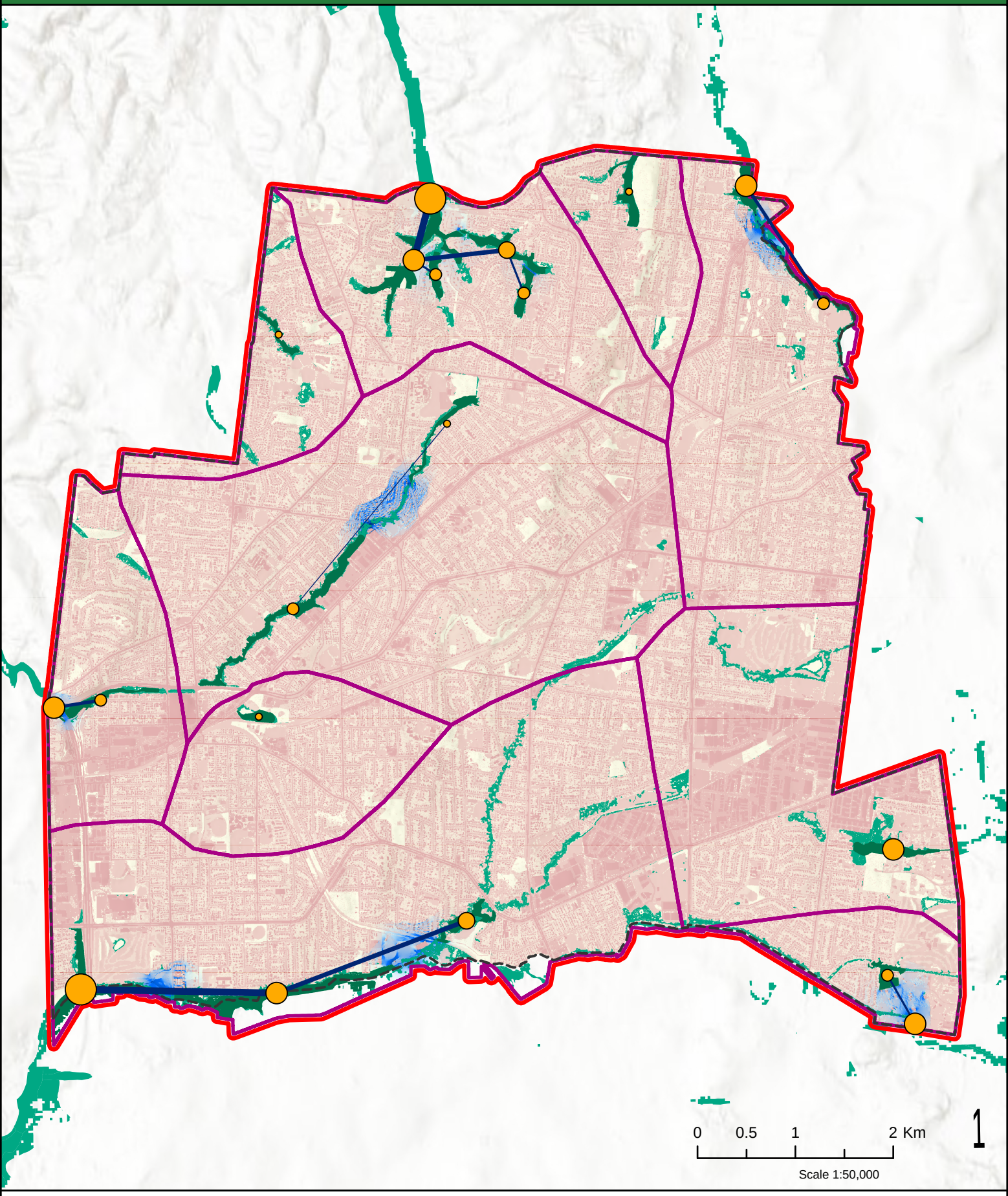
Potential connectivity

Potential connectivity for Rakali has been modelled based on two scenarios (Section 2, Table 6). Scenario 2.2 shows the potential to improve the connectivity for this species between core habitats in the north of the municipality and those along Mullum Mullum Creek (Figure 7). When targeted management actions are applied in Scenario 2.3, without modifying movement parameters, an improvement in connectivity is only apparent along existing creek corridors, with Tarralla Creek showing the greatest potential for improvement (Figure 8). Given the reliance on aquatic environs for this species, the feasibility of establishing additional core habitats to facilitate movement between existing patches, along with reducing movement barriers within heavily urbanised landscapes, may be difficult. Scenario

2.3 is therefore considered a more realistic representation of potential improvements to connectivity within the Maroondah context.

Like Superb Fairy Wren, potential connectivity models for Rakali show a lack of connectivity along the upper reaches of Dandenong Creek due to a lack of high-quality riparian vegetation and permanent water (i.e. piped sections).

Figure 6: Rakali - Existing habitat connectivity (Scenario 2.1)



City of Maroondah
Study area
Habitat patches (>3ha)
Potential habitat patches (<3ha)
Habitat outside Maroondah (approx.)
Component boundaries

Dispersal pathways
Many/shortest
Few/longest

Habitat index (d IIC)
Less important
More important

Linkage index (d IIC)
Less important
More important

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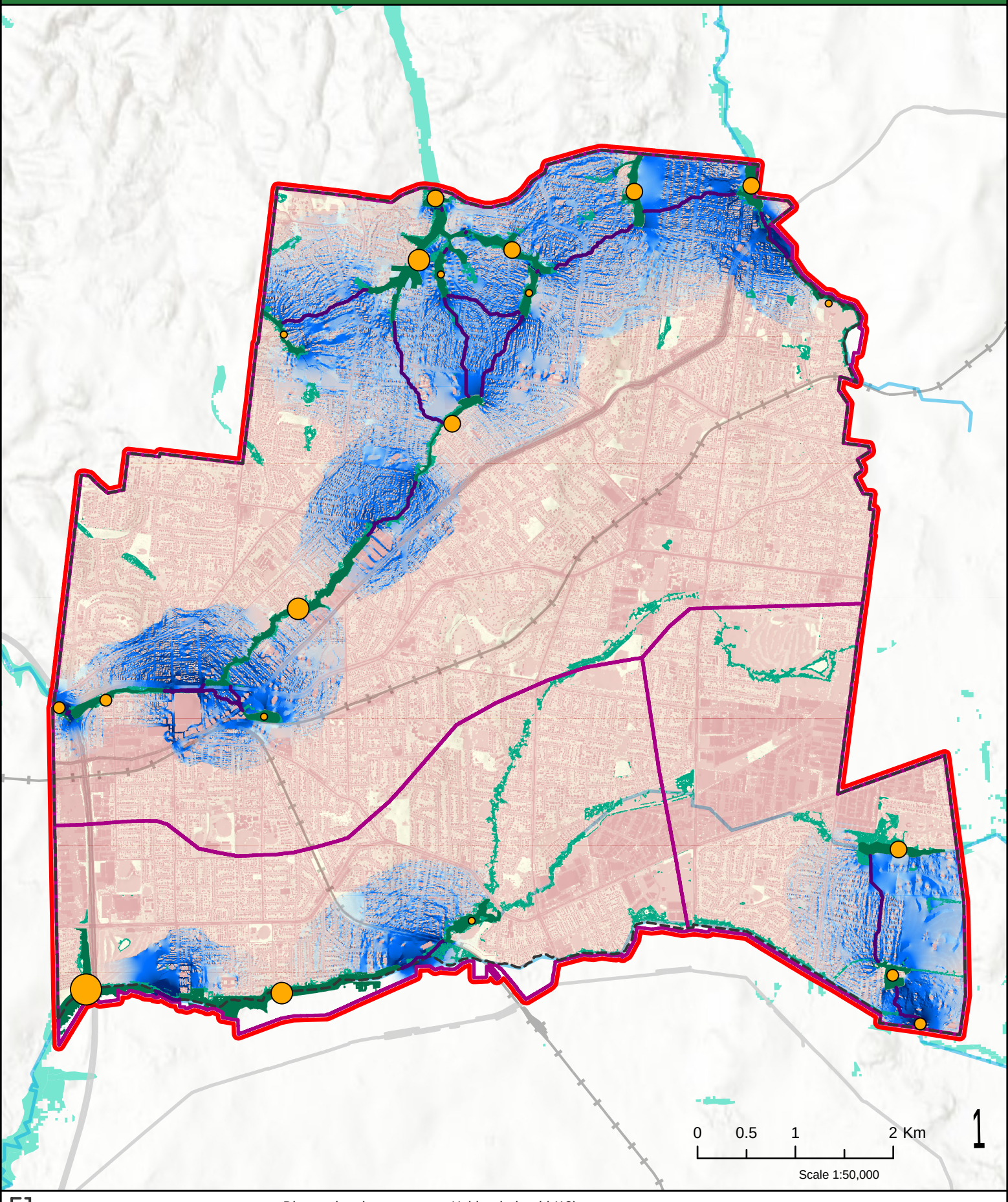
Figure 7: Rakali - Potential habitat connectivity (Scenario 2.2)



City of Maroondah
Study area
Habitat patches (>3 ha)
Potential habitat patches (<3ha)
Habitat outside Maroondah (approx.)
Component boundaries

Dispersal pathways
Many/shortest
Few/longest
Least-cost paths

Habitat index (d IIC)
Less
More

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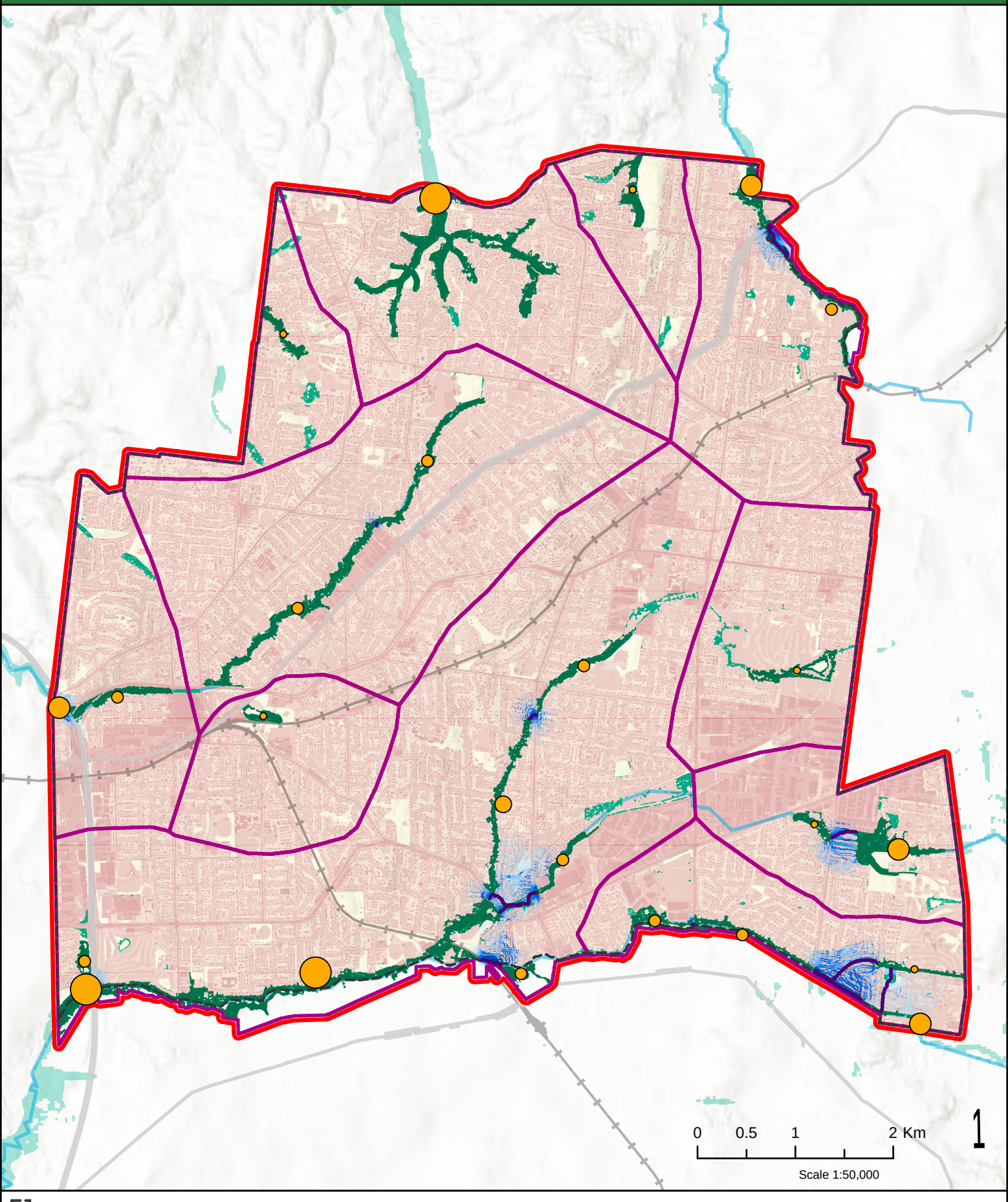
Figure 8: Rakali - Potential habitat connectivity (Scenario 2.3)



City of Maroondah
Study area
Habitat patches (>3ha)
Potential habitat patches (<3ha)
Habitat outside Maroondah (approx.)

Dispersal pathways
Many/shortest
Few/longest
Least-cost paths

Habitat index (d IIC)
Less important
More important

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4.2.3 Marsh Frogs

Marsh Frogs, referring to *Limnodynastes tasmaniensis* and *L. peroni*, represent species within the municipality with low to moderate dispersal abilities that require permanent or semi-permanent waterbodies of at least 0.1 hectares in size. Connectivity elements include a broad range of vegetation with a dense ground layer of low shrubs and/or tall grasses, which would provide refuge from predators during dispersal.

Existing connectivity

Core habitat for Marsh Frogs were primarily identified along riparian corridors, with the modelling showing multiple interconnected ponds and wetlands in these locations (Figure 9). Like Rakali, connectivity between core habitat was strongly correlated to catchment boundaries, with waterbodies away from streams and creeks frequently showing as isolated in the modelling. Significant clusters of core habitat were associated with:

- Jumping Creek and associated tributaries in Croydon Hills.
- Andersons Creek East Branch south to Monterey Bush Park.
- Brushy Creek in Croydon North.
- Middle reach of Mullum Mullum Creek between Plymouth Road and the Ringwood Bypass.
- Lower reach of Mullum Mullum Creek along the Ringwood Bypass.
- Waterbodies associated with Dorset Golf Course.
- The eastern reach of Bungalook Creek and waterbodies associated with Eastwood Golf Course.
- Dandenong Creek, the western reach of Bungalook Creek and Little Bungalook Creek.

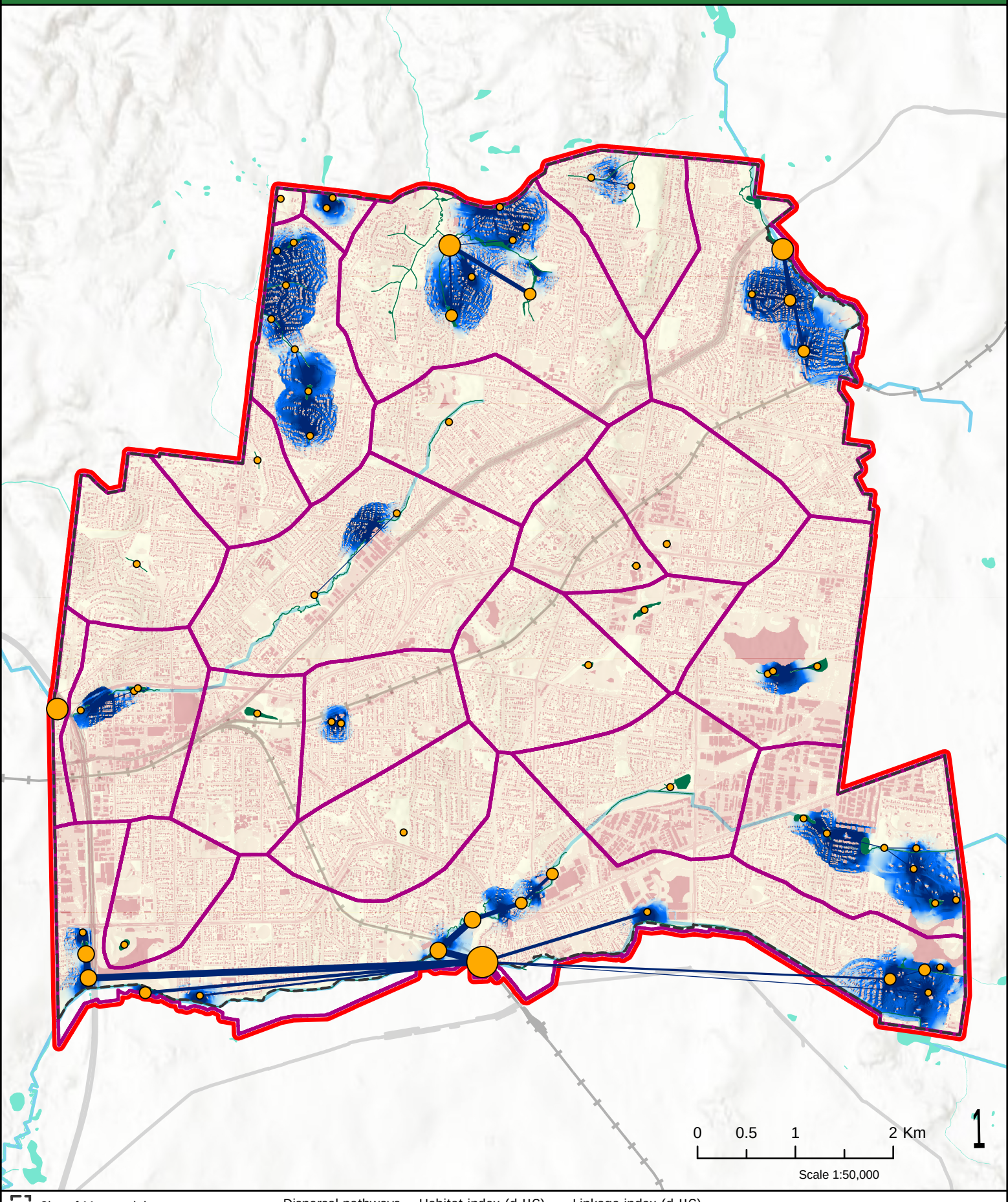
Isolated core habitats were identified in numerous locations associated with constructed or modified wetlands within reserves and parklands, and along minor drainage lines such as Tarralla Creek. Despite this, records from the VBA and ALA indicate these species persist within these locations but at a lower abundance than connected habitats along major drainage lines. This is potentially indicative of the species ability to disperse via micro-habitats (e.g. roadside drains, wet depressions and backyard ponds) during periods of higher rainfall. Regardless, the lack of persistent core habitat across the municipality, preventing more frequent dispersal of this species, is likely a key driver of the fragmentation seen in the modelling.

Potential connectivity

Potential connectivity for Marsh Frogs has been modelled based on a single scenario (Section 2, Table 6). This model shows an improvement in connectivity along existing waterways and low-lying areas supporting complex remnant vegetation (Figure 10). This was notable along Taralla Creek, Bungalook Creek and Mullum Mullum Creek, and the southern extent of the Hochkins Ridge and Stringybark Rise/Exeter Ridge woodlands.

The establishment of wetlands (core habitat) within public land not directly associated with existing waterways does not appear to improve landscape-scale connectivity across the municipality. However, as previous records indicate, these species have been found in locations not associated with major water bodies and may therefore disperse between and make use of new ‘public land’ wetlands when conditions are suitable. Furthermore, many small backyard ponds which may provide suitable habitat or act as stepping-stones in the landscape are unlikely to have been picked up by the modelling and may further complement benefits associated with additional habitat creation on public lands.

Figure 9: Marsh Frogs - Existing habitat connectivity (Scenario 3.1)



City of Maroondah
Study area
Habitat patches (>0.1 ha)
Habitat outside Maroondah (approx.)
Component boundaries

Dispersal pathways
Many/shortest
Few/longest

Habitat index (d IIC)
Less important
More important

Linkage index (d IIC)
Less important'
More important

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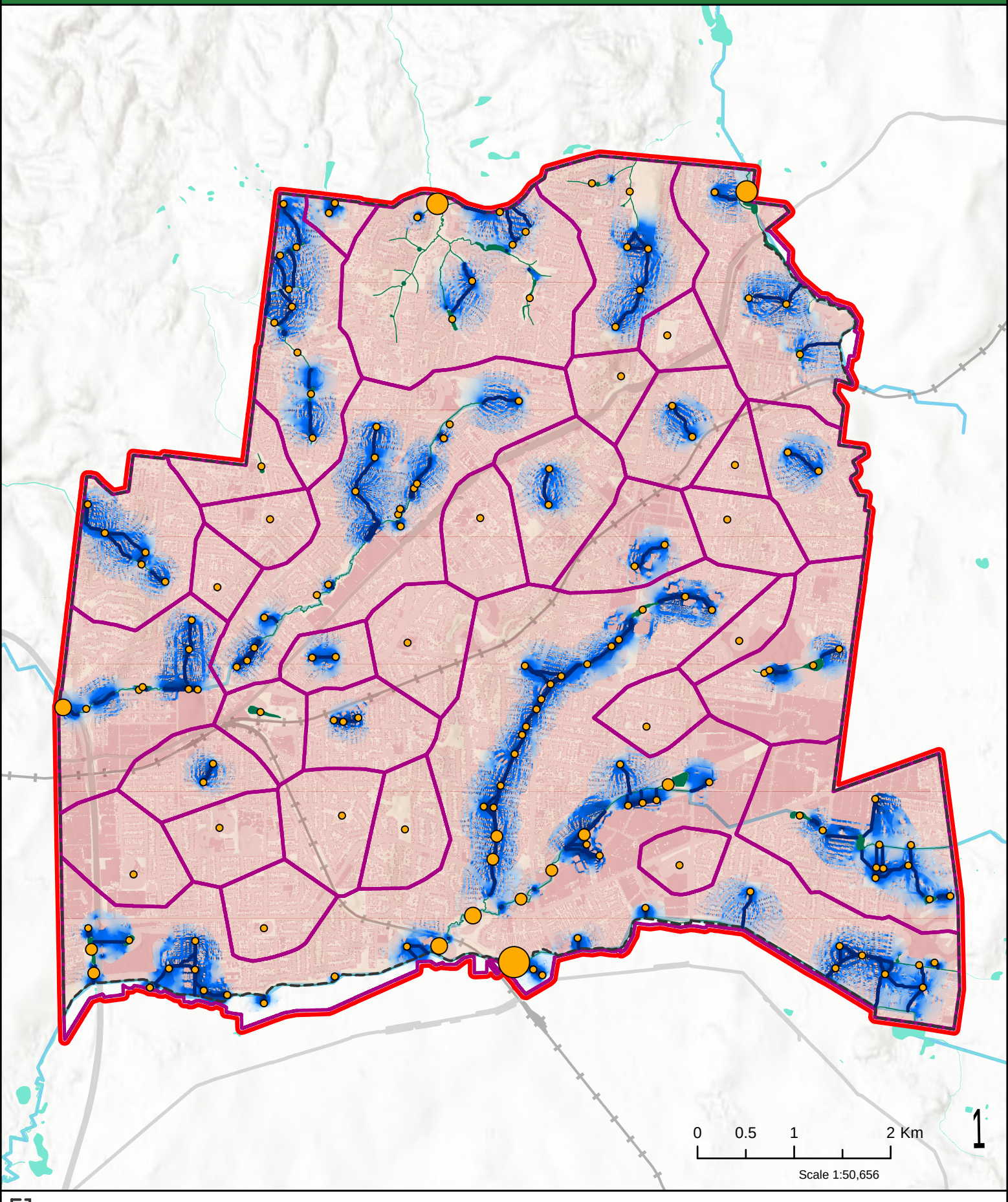
Figure 10: Marsh Frogs - Potential habitat connectivity (Scenario 3.2)



City of Maroondah
Study area
Habitat patches (>0.1 ha)
Habitat outside Maroondah (approx.)

Dispersal pathways
Many/shortest
Few/longest
Least-cost paths

Habitat index (d IIC)
Less important
More important

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4.3 Landscape connectivity

To provide an overview of connectivity across the landscape for all terrestrial species, data from the various connectivity scenarios was compiled into a single, weighted map (Figure 11). Given the combination of different models, this map is considered valuable for consideration of landscape-scale priorities only.

Based on this analysis, seven 'biolink corridors' have been identified within Maroondah. Each are described below in further detail.

4.3.1 Northern hills biolink

This biolink is centred on the foothills in the north of Maroondah and represents the most significant area of interconnected habitat within the municipality (Figure 11). It supports forest and woodland communities, ranging from dry grassy forest with low shrub cover along the ridgelines to riparian woodlands with tall, dense shrubs. These areas are well connected to extensive habitat associated with less urbanised areas to the north and north-west outside Maroondah.

Based on the connectivity modelling, the biolink currently contains four discrete clusters of well-connected habitat associated with the following drainage lines and reserves:

- Brushy Creek.
- Hochkins Ridge Flora Reserve.
- Jumping Creek, Warranwood Reserve, Narr-Maen Reserve, Candlebark Walk Reserve and Yarrunga Reserve.
- Anderson Creek and Landau Drive Reserve.

Whilst these areas are well connected locally, east-west linkages between them are limited or non-existent. The connection of these clusters may have significant benefits for biodiversity within the north of the municipality and improve dispersal of species into more urbanised regions to the south.

Potential connectivity modelling indicates that movement between the habitat clusters is feasible for Superb Fairy Wren and Rakali, however this would require the establishment of areas of core habitat between the clusters to facilitate movement. Whilst this may be feasible for Superb Fairy Wren, it is unlikely for Rakali due the requirement for permanent water to be present within core habitats.

4.3.2 Mullum Mullum Creek biolink

The Mullum Mullum creek biolink extends from Narr Maen Reserve in the north to Ringwood Lake Park in the south and Ringwood Bypass in the west (Figure 11). It provides an important north-south corridor linking the Northern Hills biolink with the Rail corridor and Dandenong Creek biolinks in the south. In particular, modelling indicates it provides extensive, connected habitats for Rakali.

The narrow corridor supports modified riparian forests and swampy woodlands, along with the aquatic environments of Mullum Mullum Creek. Modelling indicates the structure and function of the understorey varies along the creek, with connectivity subsequently affected for Superb Fairy-wren. In addition, the Ringwood Bypass represents a major barrier for ground dwelling fauna.

Whilst BJ Hubbards Reserve and Loughies Bushland both represent sizeable areas of core habitat to the west, modelling indicates these are not connected to the Mullum Mullum Creek biolink. This is due to

an absence of core habitat between the two reserves and the biolink. The potential connectivity modelling did not identify any opportunities to address this issue.

4.3.3 Wicklow Ridgeline biolink

This biolink extends from Warrien Reserve in the north to Wombolano Park and Bungalook Creek in the south, via small pocket parks, large established residential gardens and street reserves along the existing ridgeline where vegetation cover is highest (Figure 11). It recognises the influence of planning controls in creating and maintaining larger lot sizes with more extensive vegetation cover, complemented by a limited number of high-quality conservation reserves. Habitat through this biolink has been substantially modified, however remnant elements are typically derived from dry forest types including Grassy Dry Forest, Grassy Forest and Valley Heathy Forest. This corridor can also be expanded to connect into the Tarralla Creek Biolink at multiple locations.

Whilst the biolink supports several patches of core habitat, these are isolated from one another with poor connectivity between each. With significant investment to improve the extent and quality of habitat on both public and private land (e.g. wildlife gardening), there is the potential to establish connectivity for more mobile species through this corridor. This would require the creation of core habitat between existing patches to reduce interpatch distance, involving participation from a large number of stakeholders across a wide area to see a meaningful improvement in connectivity. As a result, development of this biolink should be considered a long-term priority for Council.

If established, the biolink would provide a second north-south corridor through the City.

4.3.4 Tarralla Creek biolink

This biolink runs along the Tarralla Creek corridor from Fred Geale Oval in the north to the confluence with Bungalook Creek and Dandenong creek in the south (Figure 11). It includes linkages with the Wicklow Ridgeline biolink at several locations.

Similar to Bungalook Creek, Tarralla Creek would have historically supported a diversity of wetlands, swampy woodlands and riparian scrub communities prone to periodic flooding. As a result of urban development and the underground piping of the much of the creek, native vegetation now consists of a modified woodland with limited understorey structure and/or aquatic environs. The dominant vegetation type is therefore managed, exotic grasslands occupying the shallow overflow channel. Melbourne Water is currently undertaking works to daylight the upper reaches of Tarralla Creek in Croydon, with the aim to restore wetland and aquatic habitats and riparian woodland communities. This includes a major wetland to the south of Fred Geale Oval as part of Stage 1 works.

Modelling indicates that connectivity is currently non-existent along the corridor for the species considered, likely as a result of a lack of functional core habitat and aquatic environs. However, when actions such as the daylighting of the entire creekline and functional improvement of existing riparian vegetation (through the addition of understorey structure) is considered, the modelling indicates a significant improvement in the viability of the corridor for Rakali and Marsh Frogs (i.e. species associated on aquatic environs). Whether these improvements would be sufficient to create core habitat for woodland birds such as Superb Fairy Wren, and facilitate dispersal along this narrow, busy corridor, is uncertain.

Whilst not identified in the modelling, there is potential to establish connectivity with the Dorset Golf Course from the northern end of the biolink. As part of this, opportunities to incorporate habitat and connectivity elements should be considered for future rezoning of industrial land near Fred Geale Oval and the Carrum-Warburton Trail, as well as the western and northern edges of the golf course.

4.3.5 Bungalook Creek biolink

This biolink connects the eastern and western reaches of Bungalook Creek to the lower reach of Dandenong Creek, including significant habitat areas associated with Bungalook Conservation Reserve in the east (Figure 11). Relative to the rest of the municipality, Bungalook Creek and Dandenong Creek are of low elevation and historically would have supported a diversity of wetlands, swampy woodlands and riparian scrub communities prone to flooding. Whilst significantly modified, native remnants and regrowth remain in varying condition, particularly around Lower Bungalook Creek and the confluences with Taralla Creek and Dandenong Creek.

Modelling indicates the aquatic environs of the creek below the Bungalook Creek Corridor are well connected and extend into Dandenong Creek downstream. However, the lack of functional connectivity due to limited or poor vegetation structure is an issue for woodland birds between the Bungalook Creek Corridor and Lower Bungalook Creek and for all species upstream of these areas.

Due to the presence of a wide, currently unused freeway reservation extending along Bungalook Creek through to Dorset Golf Course (and beyond the City's boundary), this biolink presents the greatest opportunity for the creation of new core habitats within the City. Revegetation of the freeway reservation would create large areas of diverse aquatic and terrestrial habitats and significantly improve connectivity in the south-eastern corner of the City. This would also establish connectivity with the currently isolated Dorset Golf Course, which itself supports large areas of habitat. Whilst more challenging, the creation of a habitat corridor and/or stepping-stones through the Bayswater Industrial precinct through to the Cardinia Road Retarding Basin would establish a link with the extensive native woodlands associated with the Bungalook Conservation Reserves and habitats further east.

4.3.6 Belgrave Rail biolink

The Belgrave Rail Biolink represents a potentially valuable corridor connecting the northern Mullum Mullum Creek Biolink at Ringwood Lake Park, with the Dandenong Creek and Bungalook Creek Biolinks in the south (Figure 11).

Modelling indicated this corridor does not currently support connectivity for the target species, with core habitats being restricted to the northern and southern ends. Despite assuming improvements in the extent and function of habitat both within the rail reserve and on adjoining public and private land, potential connectivity scenarios did not show a viable connection along this biolink for any of the species.

Despite this, the rail line represents the only feasible corridor to establish connectivity between the Mullum Mullum Creek and Dandenong Creek biolinks (outside of the Wicklow Ridgeline biolink) and further analysis of potential management options should be a priority for consideration.

A potential alternative route would be along the Lilydale Rail corridor to link into habitat around Ruthven Way – Vasey Concourse Precinct. This however assumes the Wicklow Ridgeline Biolink is functional,

which as indicated, is not currently the situation and will require substantial investment from private and public stakeholders before this occurs.

Whilst the modelling did show the potential for connectivity from Mullum Mullum Creek to Dandenong Creek via Jubilee Park and Heathmont Reserve, this would require the establishment of areas of core habitat between these features to reduce interpatch crossing distances. Given the density of residential development and lack of candidate sites this is considered to be unviable, and would likely only benefit a small number of species were it to be achieved.

4.3.7 Dandenong Creek biolink

The Dandenong Creek biolink is well recognised as a significant regional corridor linking the high-quality habitats of the Dandenong Ranges to the east with extensive aquatic and floodplain habitats, and major reserves such as Churchill National Park, to the south (Figure 11). The biolink includes the main creek channel and associated riparian vegetation, as well as numerous parklands, reserves and wetlands bordering the waterway.

Whilst urbanisation has resulted in significant modification of riparian vegetation through Maroondah, recent investment in 'daylighting' a section of the Dandenong Creek has extended aquatic and terrestrial habitats further upstream from the lower reaches. This section now supports functionally diverse riparian woodlands and aquatic environments. Upstream of the confluence with Bungalook Creek, through to Colchester Road, habitat extent and quality deteriorates due to the creek flowing through underground pipes and much of the 'creek line' resembling a linear parkland of mature trees and mown grassland. As a result, connectivity is severely limited through this section. Given the presence of extensive core habitats up and downstream, and the importance as a regional corridor, actions to improve habitat function and connectivity along the upstream reach (i.e. daylighting and associated revegetation) could result in significant biodiversity gains for the region. This section should therefore be considered a priority for investment given both land use (i.e. waterway) and land manager (i.e. Melbourne Water) present a significant opportunity to achieve the improvements required.

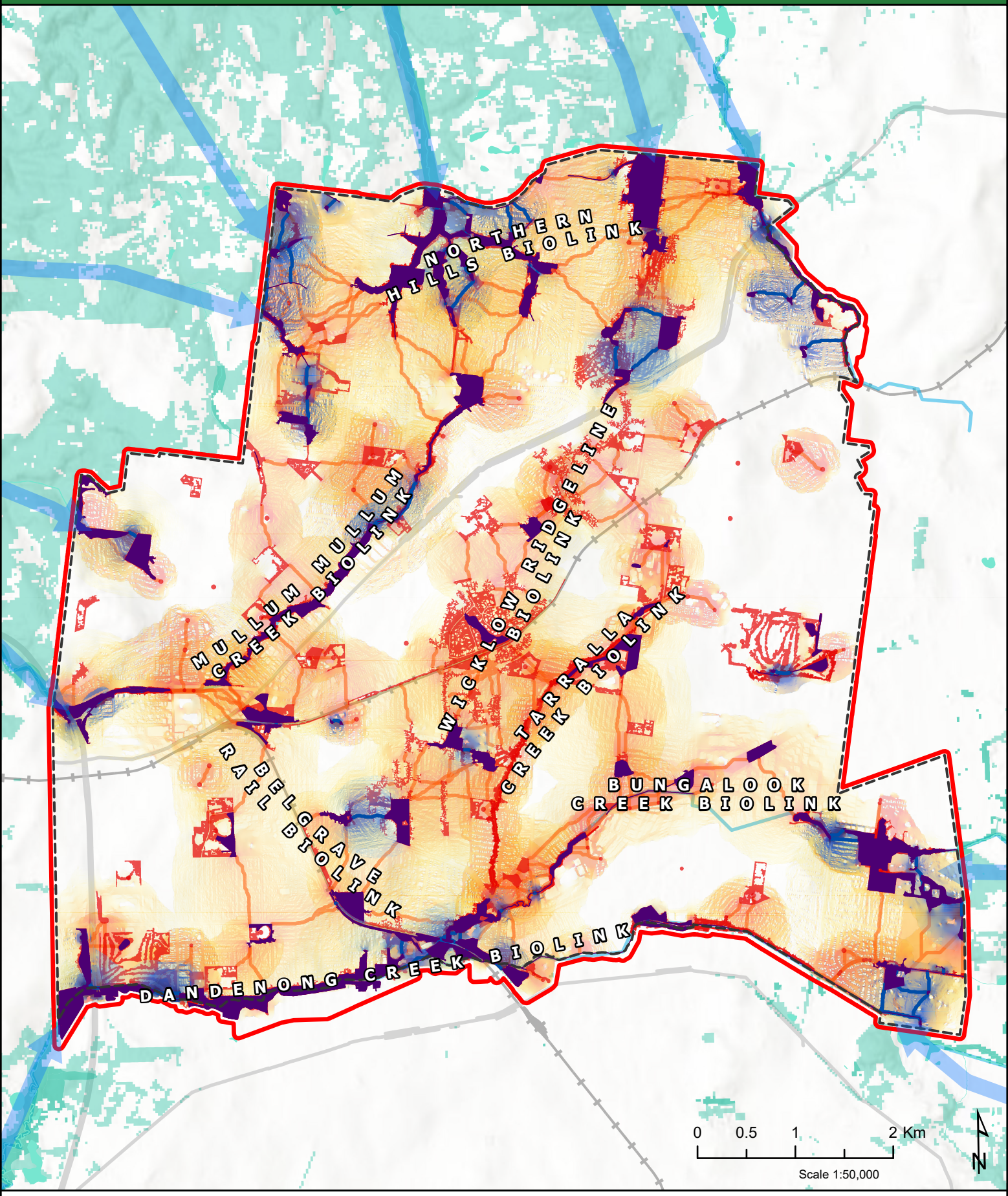
4.3.8 Other notable landscape features

In addition to the seven biolinks identified above, a number of other landscape-scale habitat features where identified in the analysis. These are primarily locations or land-use contexts which were not directly associated with a biolinks but are still considered valuable biodiversity assets. They may provide connectivity for fauna groups not included in this study (e.g. urban-tolerant birds or reptiles) or habitat outside of Maroondah. These include:

- Reserves, waterways and parklands along the western edge of Maroondah which are likely well connected to the lower reaches of Mullum Mullum Creek via tributaries outside the municipality. These areas were modelled as core habitat (either currently or potentially) and include BJ Hubbard Reserve, Loughies Bushland Reserve, Mahon Reserve and land associated with Ringwood North Primary School and Ringwood Heights Primary School.
- Lilydale Rail corridor between Ringwood Lake Park and Cheong Wildlife Sanctuary. Modelling indicated this corridor has the potential to provide connectivity between Mullum Mullum Creek and the Wickow Ridgeline biolink, however it currently lacks core habitat to facilitate movement with few opportunities to address this limitation given current land use.

- Small and linear reserves (road, rail and pocket parks) supporting indigenous vegetation, often with intact understoreys. The Biodiversity in Maroondah study (Lorimer 2020) identified numerous reserves with high biodiversity values which have not been picked up in the connectivity modelling due to their size, fragmented nature and/or lack of complementary core habitat. However, these sites provide habitat and connectivity for a variety of common wildlife and are important for maintaining the diversity and abundance of fauna in the municipality. Of note are the sites within the north-east of Maroondah associated with Lincoln Road, Lilydale Rail Line, 'The Range' Reserves (consisting of multiple small parks and reserves), Brentwood Park and Silcock Reserve, all of which likely support some degree of connectivity between Brushy Creek and the Wicklow Ridgeline biolink.

Figure 11: Landscape connectivity



Existing connectivity
- Least-cost paths
- Habitat patches

Dispersal probability
- High
- Low

Potential connectivity
- Least-cost paths
- Habitat patches

Dispersal probability
- High
- Low

- City of Maroondah
- Study area
- Habitat outside Maroondah (approx.)
- Regional connections

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5. Connectivity priorities

A landscape with high ecological connectivity is one which provides sufficient structure to allow free movement of individuals and genes, supporting critical life cycle events, ecosystem functions (e.g. pollination) and viable populations (e.g. recruitment). Management priorities therefore need to consider the physical location and nature of habitat and connectivity elements (often referred to as 'structural connectivity') in addition to the ecological needs and behaviour of the species that are the target of conservation efforts. The combination of these factors (often referred to as 'functional connectivity') underpins a species ability to persist and thrive within a landscape, and is vital to the development of successful connectivity priorities for the conservation of biodiversity across Maroondah.

This section provides the priorities for connectivity within Maroondah at both a regional (biolink) and local (passage) level. It presents priorities under the themes of 'protect, improve and connect'.

5.1 Protect and improve

Management priorities to 'protect and improve' focus on existing areas of vegetation which may or may not currently be considered core habitat for one or more target species.

Areas identified for 'protection' recognise the significant role they currently play in supporting biodiversity and facilitating connectivity within the landscape. The focus is therefore on securing their future and continued management to minimise threatening processes and promote further enhancement of existing biodiversity.

In contrast, areas identified for 'improvement' are those which, based on the modelling, do not currently act as core habitat due to being either too small or fragmented, or lacking function (e.g. structurally diverse understoreys). The priority for these areas is therefore to improve the extent and/or function of existing habitats with the aim to create core habitats or allow a broader range of species to effectively use as a stepping-stone.

Key management themes to protect or improve habitat connectivity include:

- Prevent the loss of habitat and connectivity elements associated with existing core habitats, prioritising management of key threats.
- Consolidate and expand areas of potential core habitat, focusing on improving the structural complexity and diversity of habitats.
- Implement appropriate planning measures or management incentives to prevent the loss of existing or potential core habitat, focusing on improving vegetation structure and habitat features.

Locations prioritised for 'protect' and 'improve' actions are presented in Table 11 and Figure 12. Management specifications to guide implementation of these priorities are presented in Section 6.

5.2 Connect

Opportunities to 'connect' focus on establishing or improving connectivity between existing or potential areas of core habitat, for a range of faunal groups, along 'wildlife passages'.

Key management priorities to connect habitats include:

- Create new core habitats along wildlife passages to reduce interpatch distances between existing core habitats. Focus on vacant private land or unused public land, irrespective of future land use or development.
- Improve functional connectivity between existing or potential core habitats along wildlife passages through the addition or enhancement of vegetation structure and habitat resources (e.g. shrubs, tree canopy, grass, litter, and logs) for multiple faunal groups with the aim to create a mosaic of habitat types across the landscape.
- Reduce the resistance associated with barriers (e.g. roads) through implementation of crossings or other mitigation measures along wildlife passages.
- Implement appropriate planning measures to promote the improvement of habitats and structural connectivity on private land with a particular focus on wildlife passages.

Locations prioritised for 'connect' actions are presented in Table 11 and Figure 12. Connect priorities must be guided by the target faunal groups, existing habitat values and current land tenures (and associated management context). Management specifications to guide implementation of these priorities are presented in Section 6.

5.3 Prioritisation

The prioritisation output is shown in Figure 13 and is based on a 10-metre square grid with values ranging between 0 (no biodiversity value) and 100 (highest biodiversity value). As is expected, the highest biodiversity values are associated with areas supporting extensive core habitat along Dandenong Creek, Mullum Mullum Creek, Bungalook Creek Conservation reserve in the east and Jumping Creek reserves and Hochkins Ridge Flora reserve in the north.

Table 11. Connectivity priorities for biolink corridors in Maroondah (ranked highest to lowest by prioritisation score [PS] mean)

Focus	PS (mean)	PS (max)	SBS ID (Lor 2020)	ID (Fig 12)	Name	Key fauna groups (Appendix B)	Key management specifications (Section 6)
Northern Hills biolink • Improve east-west connectivity between core habitat clusters.							
Protect	**74**	96	17	4	Candlebark Walk Reserve.	Amphibians Birds: Backyard Birds: forests and woodland Invertebrate Mammals: aquatic Mammals: arboreal Mammals: ground-dwelling Mammals: microbats and flying-foxes Reptiles	1.1 Conservation reserves 1.2 Parklands 1.3 Residential gardens 1.5 Creek corridors 1.6 Streetscapes 1.9 Vacant or unused land and utility easements 2.1 Fences 2.2 Roads and rail 2.4 Human-activity 2.5 Predation 2.6 Aggressive species
	64	91	16	7	Warranwood Environmental Living Precinct.		
	64	81	51	3	Hochkins Ridge Flora Reserve.		
	64	73	14	5	Jumping Creek Valley.		
	59	77	15	6	Warranwood Reserve.		
	51	81	56	2	Brushy Creek Corridor north.		
	49	70	56	1	Brushy Creek Corridor south.		
	49	69	9	10	Andersons Creek east.		
	49	57	12	8	Wonga Road woodlands.		
	43	61	11	9	Yanggai Barring Reserve.		
Improve	**55**	73	18	B	Yurrunga Reserve.		
	50	71	19	C	Settlers' Orchard Reserve Croydon Hills.		
	44	76	15	F	Warranwood Reserve south.		
	32	53	50a	A	Exeter Ridge eastern slope.		
	30	42	8	D	Melbourne Rudolf Steiner School.		
	26	56	6, 7, 99	E	Quambee Reserve and Monterey Bush Park		
Connect	**69**	96	53, 102, 86	d	Connect Hochkins Ridge Flora Reserve and Jumping Creek reserves via Yarra Road Reserve, Knee Lane Reserve and Patterdale Court reserve utilising existing unused easements (with walking tracks) and Yarra Road		

Focus	PS (mean)	PS (max)	SBS ID (Lor 2020)	ID (Fig 12)	Name	Key fauna groups (Appendix B)	Key management specifications (Section 6)
					reserve. Should also include consideration of Yarra Road Primary School Bush.		
	64	81	103	c	Connect Hochkins Ridge Flora Reserve and Jumping Creek reserves via Power Street reserve and vegetation along Gatters Road, including private land between Gatters Road and Kerry Road.		
	58	81	-	a	Connect Brushy Creek and Hochkins Ridge Flora reserve via Holloway Road reserve (outside but immediately adjacent to Maroondah's northern boundary.		
	58	81	-	b	Connect Brushy Creek and Hochkins Ridge Flora reserve via Griff Hunt Reserve and private property to the east.		
	53	73	136, 84, 13	e	Connect Jumping Creek reserves to Anderson Creek and Landau Drive Reserve via existing corridor crossing Gibsons Road, Brysons Road and running through private land to the north of Reids Lane and Wonga Road.		
	46	77	8	f	Connect Jumping Creek reserves to Anderson Creek and Landau Drive Reserve via heavily vegetated private land along Kardinia Drive, crossing Wonga Road and continuing through Melbourne Rudolf Steiner School to Andersons Creek.		
Mullum Mullum Creek biolink • Improve quality and function of aquatic and terrestrial habitats along entire creek corridor. • Establish connectivity with Northern Hills biolink to the north.							
Protect	**63**	87	24	12	Mullum Mullum Creek between Oban Road and Glen Cairn Avenue.	Amphibians Birds: Backyard Birds: forests and woodland Birds: grassland and lightly timbered woodland	1.2 Parklands 1.3 Residential gardens 1.4 Wetlands and waterbodies 1.5 Creek corridors 1.6 Streetscapes
	61	79	26	14	Ringwood Lake Park/Bedford Park.		
	60	82	25	13	Mullum Mullum Creek west.		
	59	75	22	11	Yarra Valley Grammar School forest.		
Improve	**50**	80	21	G	Narr-Maen reserve south.		

Focus	PS (mean)	PS (max)	SBS ID (Lor 2020)	ID (Fig 12)	Name	Key fauna groups (Appendix B)	Key management specifications (Section 6)
	50	75	24	H	Mullum Mullum Creek between Douglas Maggs Reserve and Oban Road.	Birds: wetland and riparian vegetation Fish Invertebrate Mammals: aquatic Mammals: arboreal Mammals: microbats and flying-foxes Reptiles	2.1 Fences 2.2 Roads and rail 2.3 In-stream barriers 2.4 Human-activity 2.5 Predation 2.6 Aggressive species 2.7 Light 2.8 Sound
	44	72	24	I	Mullum Mullum Creek between Glen Cairn Avenue and Ringwood bypass.		
Connect	**55**	80	21, 83	g	Narr-Maen Reserve south with Yarra Valley Grammar School forest via existing, vegetation walking track.		
	53	80	83	h	Warranwood Reserve with Yarra Valley Grammar School forest via the associated southern branch of Jumping Creek as it extends through private property and along Warranwood/Plymouth road.		
	52	82/79	25	i, j	Mullum Mullum Creek habitats to the south-west and Ringwood Lake Park via fauna crossing to mitigate impacts of the Ringwood Bypass.		
Wicklow Ridgeline biolink • Establish second north-south corridor. • Connect core habitats present through corridor.							
Protect	**52**	63	33	19	Wombolano Park.	Birds: Backyard Birds: grassland and lightly timbered woodland Invertebrate Mammals: arboreal Mammals: microbats and flying-foxes Reptiles	1.2 Parklands 1.3 Residential gardens 1.6 Streetscapes 1.7 Rail reserves 1.8 Industrial and commercial precincts 2.1 Fences 2.2 Roads and rail 2.4 Human-activity 2.6 Aggressive species 2.7 Light 2.8 Sound 2.9 Buildings
	44	51	47	15	Warrien Reserve.		
	39	55	40	16	Former Benedict Monastery.		
	34	48	34	18	Tintern Grammar School woodlands.		
Improve	37	61	37	L	Ruthven Way – Vasey Concourse Precinct.		
	34	55	46, 45, 104	J	Richardson Road Residential precinct.		
	11	47	43	K	Former Croydon School council reserves, Croydon Primary School reserve, Alto Reserve and Grandfill Reserve and private gardens in between.		
Connect	**52**	63	123	p	Wombolano Park with Belgrave rail reserve via Herman Pump Reserve and private residences in local vicinity.		

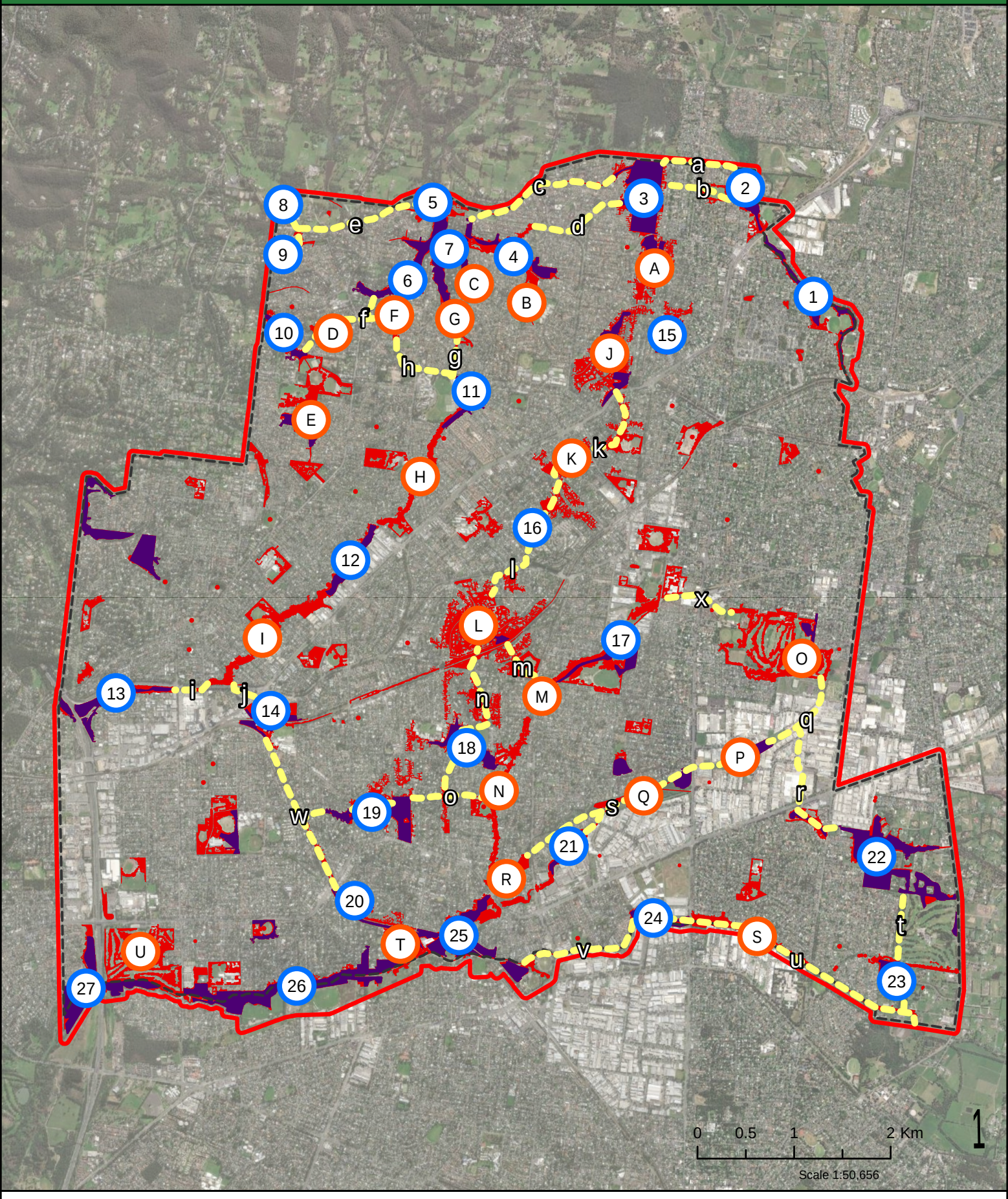
Focus	PS (mean)	PS (max)	SBS ID (Lor 2020)	ID (Fig 12)	Name	Key fauna groups (Appendix B)	Key management specifications (Section 6)
	45	63	-	o	Tintern Grammar school with Wombolano Park and Tarralla Creek via road reserves and private gardens in local vicinity.		
	38	61	38	l	Former Benedict Monastery to Ruthven Way-Vasey Concourse precinct via Mount Dandenong Road and associated private gardens and residential streets.		
	36	62	35, 92	m	Ruthven Way-Vasey Concourse with Tarralla Creek via private gardens, Cheong Park and Eastfield Road reserve.		
	36	61	28, 36	n	Ruthven Way-Vasey Concourse with Tintern Grammar school via Lilydale rail reserve, Cheong Wildflower Sanctuary and Long View Road and associated private gardens.		
	28	55	44	k	Richardson Road Residential precinct and the Former Benedict Monastery via Former Croydon School council reserves, Alto Reserve and Grandfill Reserve and private gardens in between.		
Tarralla Creek biolink • Improve habitat function along Tarralla Creek.							
Protect	**61**	75	61	17	Benson Oval/Eastfield Park.	Amphibians Birds: Backyard Birds: forests and woodland Birds: grassland and lightly timbered woodland Birds: wetland and riparian vegetation Fish Invertebrate Mammals: aquatic Mammals: arboreal	1.2 Parklands 1.3 Residential gardens 1.4 Wetlands and waterbodies 1.5 Creek corridors 1.6 Streetscapes 2.1 Fences 2.2 Roads and rail 2.3 In-stream barriers 2.4 Human-activity 2.6 Aggressive species 2.7 Light
Improve	38	62	62	N	Tarralla Creek south.		
	34	62	62	M	Tarralla Creek north.		
Connect	36	58	62	x	Benson Oval/Eastfield Park with Dorset Golf Course via Tarralla Creek and Carrum-Warburton Trail.		

Focus	PS (mean)	PS (max)	SBS ID (Lor 2020)	ID (Fig 12)	Name	Key fauna groups (Appendix B)	Key management specifications (Section 6)
						Mammals: microbats and flying-foxes Reptiles	2.8 Sound
Bungalook Creek biolink • Utilise freeway reserve to establish extensive, diverse core habitats. • Connect to Dorset Golf Course and eastern reaches of Creek.							
Protect	**72**	89	66, 67, 68	22	Bungalook Conservation reserves.	Amphibians Birds: Backyard Birds: forests and woodland Birds: grassland and lightly timbered woodland Birds: wetland and riparian vegetation Fish Invertebrate Mammals: aquatic Mammals: arboreal Mammals: ground-dwelling Mammals: microbats and flying-foxes Reptiles	1.1 Conservation reserves 1.2 Parklands 1.4 Wetlands and waterbodies 1.5 Creek corridors 1.8 Industrial and commercial precincts 1.9 Vacant or unused land and utility easements 2.2 Roads and rail 2.3 In-stream barriers 2.5 Predation 2.6 Aggressive species 2.7 Light 2.8 Sound 2.9 Buildings
	44	55	131	21	Western end of Bungalook Creek Corridor.		
Improve	40	51	64	Q, P	Freeway Reservations.		
	36	59	134, 131, 92	R	Tarralla Creek and Bungalook Creek confluence.		
	35	65	62	O	Dorset Golf Course and recreation reserve		
Connect	**72**	89	68	t	Bungalook Conservation Reserves with Little Bungalook Creek via Eastwood Golf Club.		
	57	89	65	r	Bungalook Creek north of Bayswater industrial precinct and Canterbury Road Retarding Basin via existing parkland, carparks (convert) and Stephenson Road.		
	47	79	64	s, q	Tarralla Creek and lower reaches of Bungalook Creek with Dorset Golf Course via Freeway Reservation.		

Focus	PS (mean)	PS (max)	SBS ID (Lor 2020)	ID (Fig 12)	Name	Key fauna groups (Appendix B)	Key management specifications (Section 6)
Belgrave Rail biolink • Connect Mullum Mullum Creek with Dandenong Creek.							
Protect	**53**	69	32	20	Uambi Reserve.	Birds: Backyard Birds: grassland and lightly timbered woodland Invertebrate Mammals: arboreal Mammals: microbats and flying-foxes Reptiles	1.3 Residential gardens 1.6 Streetscapes 1.7 Rail reserves 2.1 Fences 2.2 Roads and rail 2.4 Human-activity 2.6 Aggressive species 2.7 Light 2.8 Sound 2.9 Buildings
Connect	**57**	79	29	w	Ringwood Lake Park/Bedford Park with Uambi Reserve via Belgrave Rail reserve and nearby road reserves and private gardens.		
Dandenong Creek biolink • Protect habitat in lower reaches of Dandenong Creek • Improve habitat and connectivity in upper reaches through daylighting of creek corridor							
Protect	**71**	89	70, 133	23	Appletree Hill Reserve/Lillypilly Lane woodlands.	Amphibians Birds: Backyard Birds: grassland and lightly timbered woodland Birds: wetland and riparian vegetation Fish Invertebrate Mammals: aquatic Mammals: arboreal	1.2 Parklands 1.4 Wetlands and waterbodies 1.5 Creek corridors 2.3 In-stream barriers 2.4 Human-activity 2.5 Predation 2.6 Aggressive species 2.7 Light 2.8 Sound
	64	93	69	27	Lower reaches of Dandenong Creek (Freeway).		
	62	100	69, 79	26	Lower reaches of Dandenong Creek.		
	61	96	72b	24	Connolly Crescent Reserve.		
	59	88	29d,74, 73, 75	25	Confluence of Bungalook Creek and Dandenong Creek and surrounding reserves.		
Improve	**58**	100	75	T	H.E. Parker Reserve and adjoining Belgrave Rail reserve.		
	52	96	69	S	Dandenong Creek corridor upstream of Connolly Crescent Reserve.		
	46	65	128	U	Ringwood Public Golf Course.		

Focus	PS (mean)	PS (max)	SBS ID (Lor 2020)	ID (Fig 12)	Name	Key fauna groups (Appendix B)	Key management specifications (Section 6)
Connect	**60**	96	69	v	Connolly Crescent Reserve with Marie Wallace Bayswater Park (outside municipality boundary) via existing creek corridor.	Mammals: ground-dwelling Mammals: microbats and flying-foxes Reptiles	
	56	96	69	u	Appletree Hill Reserve/Lillypilly Lane woodlands and Liverpool Road retarding basin (outside municipality boundary) with Connolly Crescent Reserve via existing creek corridor.		

Figure 12: Habitat connectivity priorities for Maroondah



City of Maroondah
Study area
Core habitat
Potential core habitat

Protect (core habitat)
Improve (potential core habitat)
Connect (wildlife passage)

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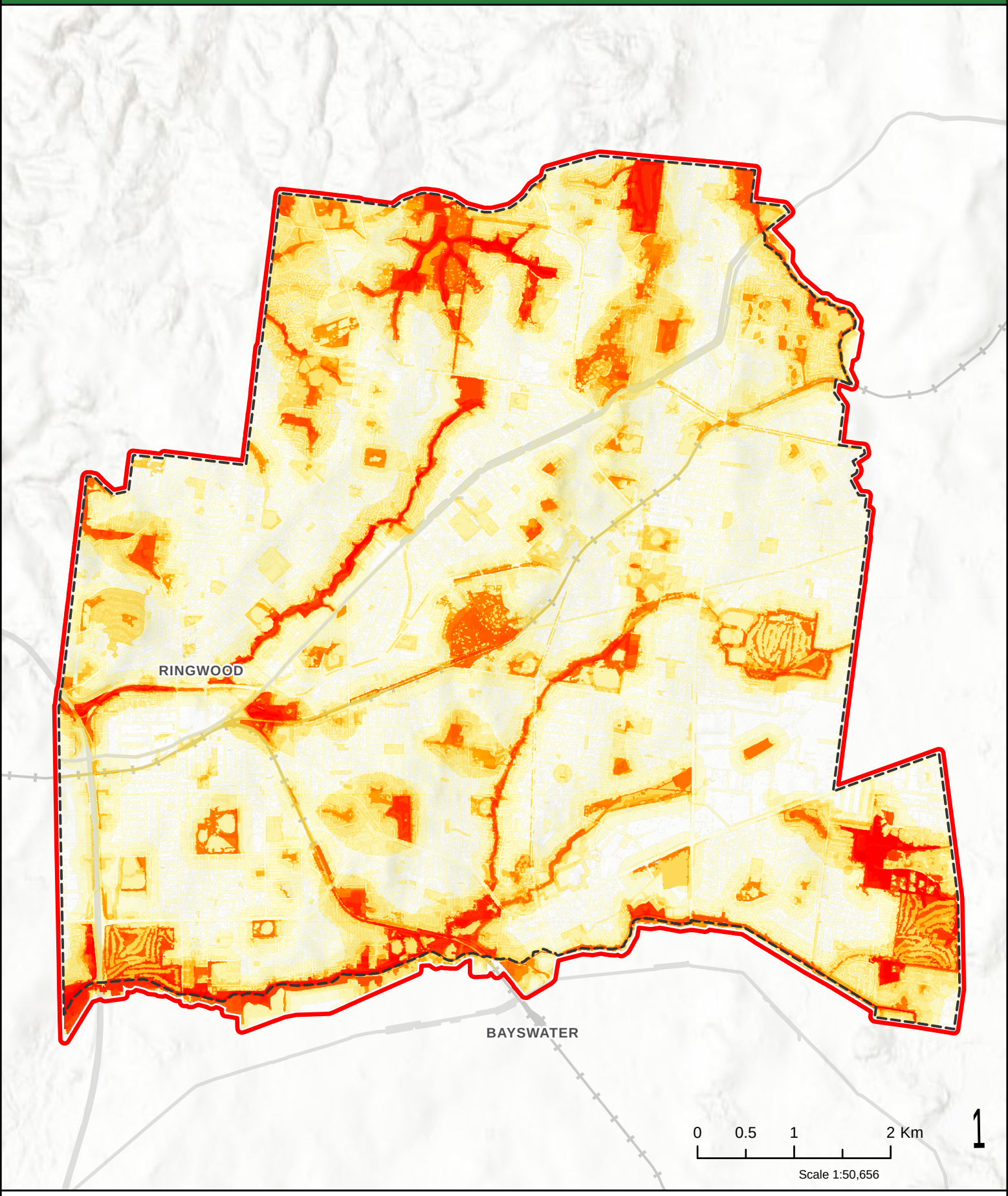
Figure 13. Biodiversity conservation priorities for Maroondah



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6. Improving connectivity

The on-ground implementation of management priorities will be influenced by a range of factors, including land tenure and use, ownership arrangements, the nature and extent of vegetation and the target species requirements. This section provides management priorities and specifications for the land use types and barriers present within Maroondah (Table 12), with reference to key faunal groups of relevance to each (Appendix B, Table B2). An example of functional habitat associated with the interface of a bush/creek reserve and neighbouring residential garden is shown in Figure 14.

6.1 Management principles

When considering actions to improve connectivity, the following principles should first be considered and addressed where applicable:

- Focus on priority locations – areas of core habitat and wildlife passages along biolink corridors should take precedence.
- Identify target species – understand the species for which connectivity is limited and could realistically be restored. This includes identifying and prioritising under-represented or poorly connected habitat types.
- Functional connectivity - identify functional improvements to existing habitats and connectivity elements that could be made to improve connectivity (e.g. improve structural complexity or availability of food resources).
- Minimise threats and barriers – consider biolink areas in the ongoing management of pest animals and plants, and road maintenance or design across the city. Integrate connectivity plan with the Maroondah Planning scheme to minimise or avoid degradation of existing habitat or connectivity elements.
- Increase extent – consider opportunities to expand, connect or infill existing habitat and wildlife passages to increase the extent and quality of habitat across the network.
- Build resilience – where possible, invest in multiple passages to build connectivity between areas of core habitat and ensure redundancy within the connectivity network.
- Engage and educate – support actions through education programs to ensure long-term engagement of key stakeholders.
- Monitor and review – undertake periodic review of biolink extent and efficacy of management actions to allow for adaptive management. This should include monitoring of wildlife activity based on biolink corridors focusing on the engagement species identified (Appendix B). Include connectivity metrics in relevant 'state of the environment' reporting.

6.2 Engage and educate

Community education and engagement is a key opportunity to support the connectivity priorities, demonstrate value to Maroondah rate payers in addressing the community strategic vision and to amplify investment outcomes through external collaborations. Council's network of environmental Friends groups represent key community stakeholders to assist in the delivery of these priorities, drawing on the trusted relationships that they have with the wider community. Simple case studies can

be developed to help provide guidance for community members on what they can do for ecological connectivity on their properties and in their local area.

Importantly, the engagement species (Appendix B, Table B1) should be used as a focus of local initiatives, providing a narrative for the role each landholder can play in contributing to the movement of species through their property and within the broader region. Existing and future resident environmental initiatives, such as the wildlife gardening programs and citizen science will encourage landholders to value and plant indigenous and native plants to contribute towards protecting and enhancing biolinks.

Council reserve master plans, nature strip policy and open space plans provide an opportunity to contribute to urban biolinks by being sympathetic to conservation outcomes within these plans' goals.

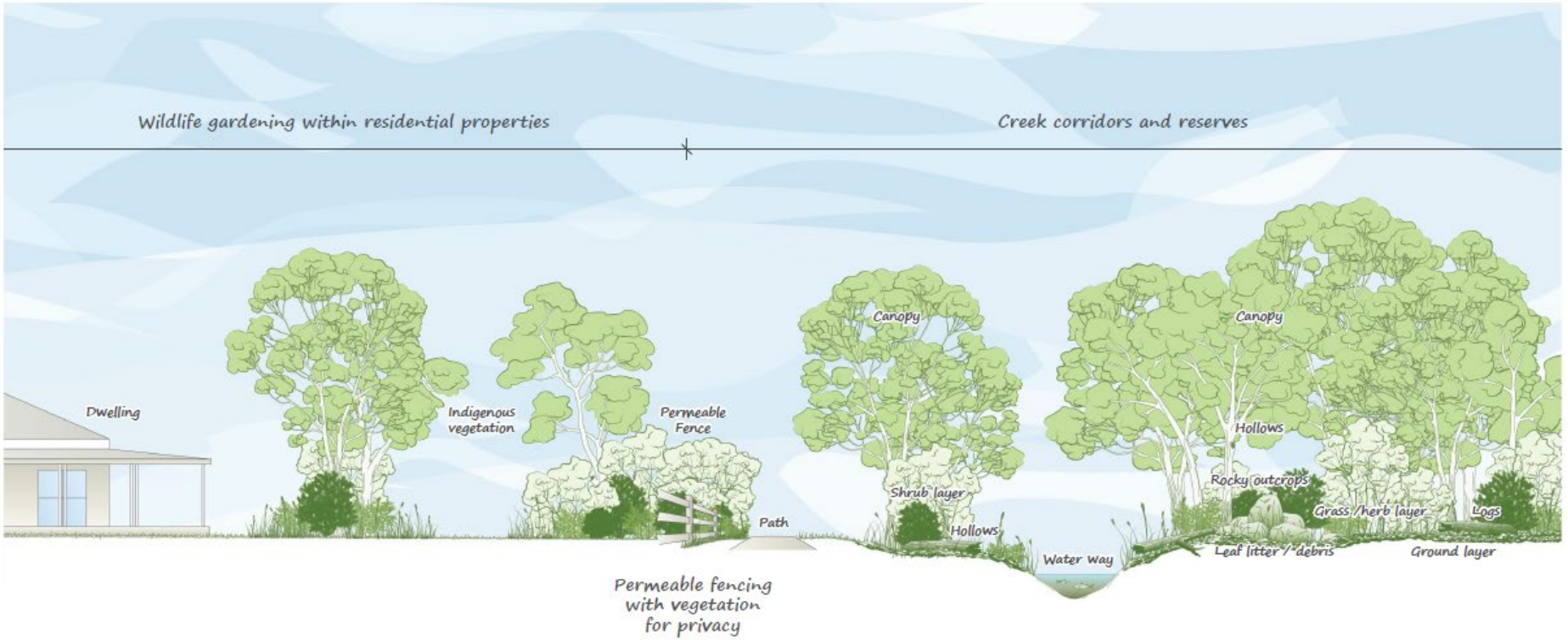


Figure 14. Cross-section of functional habitat providing connectivity across private and public lands

Table 12. Connectivity improvement specifications for Maroondah by land use type and barrier

Spec	Type	Description	Key actions	Priority fauna groups
		Land use		

1.1	Conservation reserves (public)	Conservation reserves play an important role in urban landscapes by providing extensive quality habitat for flora and fauna. They can also provide insight into pre-European vegetation. Within Maroondah, there are a number of reserves of national, state and local significance as identified in the Biodiversity in Maroondah report (Lorimer 2020).	• Expand on areas of remnant vegetation with plantings, using EVC benchmarks and Lorimer (2020) as a guide to lifeform cover and species composition. To maximise habitat values and connectivity ensure gaps in vegetation are no greater than:
			  ○ 20m for unmanaged groundcover.
			  ○ 50m for shrub and tree canopy.
			• Aim to maintain mixed-aged stands by ensuring adequate recruitment is occurring, and supplement with plantings when necessary.
			• Create structurally complex habitats and mosaics of unshaded habitat (reptiles), dense groundcover (mammals and birds), and shrub cover (birds and mammals).
			• Avoid slashing or mowing of indigenous groundcover within reserves.
			• Minimise areas of disturbance and large areas of bare ground or unvegetated exposed surface (e.g. minimise width of access tracks and trails).
			• Increase leaf litter, rock cover and large woody debris (logs) where below benchmark.
			• Retain all large and hollow-bearing old trees.
			• Where absent, create hollows or install artificial nesting structures.
				Amphibians
				Birds: forests and woodland
				Birds: grassland and lightly timbered woodland
				Invertebrates
				Mammals: arboreal
				Mammals: ground-dwelling
				Mammals: microbats and flying-foxes
				Reptiles

1.2	Parklands (public)	Public parks and gardens are common features across urban landscapes and provide the community with places to enjoy a variety of leisure activities. Parks and gardens also provide important habitat for native wildlife and facilitate dispersal through the landscape.	• Retain, expand, and improve the condition of areas of existing indigenous vegetation, including complementary plantings around scattered trees and small patches to increase patch size and function.
			• Use a variety of locally indigenous tree species with differing habitat values (e.g. stringybarks vs. smooth bark, dense vs. open, species with different flowering times etc). Unless providing alternative habitat (e.g. hollows or fruit), consider replacing low-habitat introduced species with indigenous species.
			• Create structurally complex habitats, using EVC benchmarks and Lorimer (2020) as a guide to lifeform cover and species composition, focusing primarily on adding:
			  ○ Tall groundcover of indigenous grasses and herbs (>30cm).
			  ○ a mix of tall and low indigenous shrubs.
				Amphibians
				Birds: Backyard
				Birds: grassland and lightly timbered woodland
				Invertebrates
				Mammals: arboreal
				Mammals: microbats and flying-foxes
				Reptiles

Spec	Type	Description	Key actions	Priority fauna groups
			○ leaf litter, rock cover and woody debris, particularly around edges of patches which can be used for basking, of varying sizes and configurations. ○ small patches (<1m) of bare ground. • Create 'no mow' areas where mowing is prohibited allowing tall groundcover to develop to >30cm. Ideally establish indigenous species in these areas e.g. tussock grasses. • To facilitate connectivity, ensure gaps between indigenous vegetation patches are no greater than: ○ 20m for unmanaged groundcover vegetation ○ 50m for shrubs and trees • Where possible create 'core habitat' by establishing structurally diverse, contiguous vegetation at least 1.5 hectares in size. • Retain all large and hollow-bearing old trees. • Retain cut limbs and trunks of native trees removed as part of council arboricultural works for use in habitat patches or other locations (e.g. reserves, private gardens etc). • Use native mulch in garden beds to increase invertebrate biodiversity and provide a food source for insectivorous bird species. • Where absent, create hollows or install artificial nesting structures. • Install public signage explaining importance of protecting and improving habitat connectivity and the rationale for associated management actions within parklands.	
1.3	Residential gardens (private)	Residential gardens make up a significant proportion of the green space within Maroondah. The floristic structure (indigenous vs exotic) of a single garden may not seem important, but, across the municipality collectively, residential gardens have a significant influence on the fauna that inhabit urban areas.	• Drawing on knowledge of local organisations (e.g. CRISP indigenous nursery and Council's bushland team), encourage residents to: ○ plant variety of locally indigenous tree and shrub species with differing habitat values (e.g. rough bark vs. smooth/ribbon bark, dense vs. open, different flowering times etc). ○ utilise indigenous herbs and graminoids in garden beds and lawns, with a particular emphasis on flowering species to promote indigenous insect diversity. ○ replace low-habitat value introduced species with indigenous species. ○ install habitat structures such as:	Amphibians Birds: Backyard Birds: grassland and lightly timbered woodland Invertebrates Mammals: arboreal Mammals: microbats and flying-foxes Reptiles

Spec	Type	Description	Key actions	Priority fauna groups
		Gardens with indigenous plant species attract more native wildlife than those with exotic species, however exotic species can have a beneficial role in the landscape by providing nesting resources, shelter and food. Understanding the contribution of plant species, both indigenous, native and exotic, in the landscape can inform decisions regarding their removal or persistence. Lot size can also play a key role, with larger lots offering greater scope for establishing gardens with good habitat value.	- leaf litter, rock cover and woody debris (logs) of varying sizes and configurations, particularly around garden borders which can be used for basking. - Rain gardens, water features or frog bogs with tall, fringing, and emergent vegetation. - artificial hollows and nest boxes in trees. - Water sources (e.g. bird bath). ○ use native mulch to increase invertebrate diversity. ○ install fauna-friendly fencing (see Spec 2.1). ○ avoid owning cats or dogs, or if owned are prevented from roaming freely beyond the property. ○ place screens on windows to reduce bird collisions. ○ Minimise herbicide/pesticide use. • Use EVC benchmarks and Lorimer (2020) as a guide to lifeform, cover and species composition across different parts of the municipality. • Apply planning controls that facilitate protection and creation of habitat connectivity and discourage removal of indigenous vegetation, particular mature trees and understorey elements. • Consider local significance of vegetation including importance for connectivity in future planning approvals, including sub-division or further development of large residential lots in high biodiversity value areas (see Section 5.3 Prioritisation analysis).	
1.4	Wetlands and waterbodies (private and public)	Wetlands represent important biological 'hot spots' in urban areas, as they encompass a wide range of aquatic and terrestrial habitats and may support diverse flora and fauna communities. They also help maintain the health of waterways by regulating flows, capturing sediment and reducing pollutant loads.	• Consider options for installation of constructed wetlands within public land with aim to create network of wetlands less than 1000m apart that also provide stormwater and other social/economic benefits. Focus on existing reserves and parklands and along creek corridors. Wetlands should create structurally diverse habitats, using EVC benchmarks and Lorimer (2020) as a guide to lifeform cover and species composition, incorporating: ○ Open water with submergent and floating species ○ Shallow and deep marshes with emergent species ○ Fringing vegetation ○ Fringing and submerged rocks and logs	Amphibians Birds: wetland and riparian vegetation Fish Invertebrates Mammals: aquatic Reptiles

Spec	Type	Description	Key actions	Priority fauna groups
			○ Maintenance facilities such as sediment/litter capture and ability to drain. • Manage hydrology of wetlands, lakes and waterways to prevent complete drying out of permanent deep pools and maintain refuges for aquatic species. • Care needs to be taken to not create extensive nesting sites for colonial bird species (such as cormorants, herons and ibises) as these can have a detrimental effect on wetland health and amenity. Design therefore needs to minimise fringing woody vegetation overhanging the wetland. • Consider options for creating 'micro-habitats' to provide stepping-stones with private and public land. This may include 'frog bogs', rain-water gardens, swales and ephemeral 'wet depressions' in low lying areas. Manage to ensure maintenance of tall, indigenous ground cover (e.g. *Juncus* sp.) in these areas. • Encourage use of Water Sensitive Urban Design that incorporates habitat elements in new developments.	
1.5	Creek corridors (public)	Natural waterways and the adjoining terrestrial habitats provide important connectivity for fauna within urban landscapes due to a lack of barriers associated with roads, housing, infrastructure and other intensive land uses. These are also integral to the blue and green grids promoted in the Maroondah Climate Change Risk and Adaptation Strategy 2018-2022. A key focus for conservation efforts should be maintaining and restoring riparian vegetation along these corridors to improve connectivity. Continuing to 'daylight' piped or channelised sections of major waterways should be a priority to restore diverse aquatic and riparian habitats within Maroondah.	• Daylight and naturalise creek corridors wherever possible, creating diversity of aquatic habitats including deep pools of standing or slow-moving water, shallow riffles of fast-flowing water and ephemeral or seasonal wetlands and floodplains. • Aim for contiguous habitat within corridors that is at least: ○ 20-50m in width from either bank for minor waterways ○ 50-100m in width from either bank for major waterways. • Create structurally complex habitats, using EVC benchmarks and Lorimer (2020) as a guide to lifeform cover and species composition, to create gradients of habitats from canopy over dense understorey, through to unshaded, water-fringing vegetation. Focus primarily on protecting or adding: ○ indigenous trees to achieve canopy gaps ranging from continuous to 30 m at maturity. ○ a mix of tall and low indigenous shrubs. ○ groundcover of indigenous grasses and herbs. ○ high cover of leaf litter, rock cover and woody debris including logs, of varying sizes and configurations. ○ Hollows and nest boxes. ○ in-stream aquatic and fringing indigenous vegetation. ○ submerged/in-stream logs, branches and rocks.	Amphibians Birds: grassland and lightly timbered woodland Birds: wetland and riparian vegetation Fish Invertebrates Mammals: aquatic Mammals: arboreal Mammals: ground-dwelling Mammals: microbats and flying-foxes Reptiles

Spec	Type	Description	Key actions	Priority fauna groups
			○ areas of limited canopy/shrub cover suitable for foraging and basking. • Manage high-threat riparian and aquatic weeds to maintain habitat diversity. • Where possible, ensure vegetation is contiguous with adjoining reserves, parklands and residential gardens to facilitate movement between creek corridor and surrounding habitats. • Avoid mowing/slashing of creek corridors unless required for public amenity. • Diversion of stormwater from pipes to rehydrate floodplain habitats that have been suffering from drying of the landscape due to climate change, urbanisation and drainage works (Lorimer 2020) • Amendment of the Local Planning Policy on Waterway Protection to recognise that streams, stream corridors and wetlands are very important for wildlife (Lorimer 2020).	
1.6	Streetscapes (public)	Road reserves play an important role in providing connectivity due to the persistence of remnant or recolonising vegetation in otherwise cleared landscapes. Whilst narrow, these corridors often support a diversity of structure and their linear nature are considered valuable for the role they play in providing functional connectivity through a landscape. However, the presence of habitat can also pose risks to fauna due to injury and mortality associated with transport activities, as well as the changes in foraging, reproduction and social behaviours associated with increased noise, light and movement. The management of roadsides also cater to a wide variety of uses ranging from the need to provide safe vehicle passage,	• Building on Maroondah's street tree guidelines, increase the extent of indigenous understorey vegetation in verges, nature strips, roundabouts, traffic islands and edges of carparks or other less frequented or unused areas. Use EVC benchmarks and Lorimer (2020) as a guide to lifeform cover and species composition across different parts of the municipality. • Prioritise locations where adjacent wildlife gardening is present or being promoted. • Where possible, identify 'habitat sides' to establish continuous vegetation, allowing other side of road to be used for amenity and utility purposes. • Protect or create structurally diverse, indigenous understorey based on local EVCs around existing canopy trees to act as stepping-stones for small fauna. Patches should be no more than 50 metres apart and can be small (e.g. 10m x 3m) with managed/mown areas between. • Refrain from mowing slashing groundcover in roadsides allowing tall groundcover to develop to >30cm. Ideally establish indigenous species in these areas e.g. tussock grasses. • Being conscious of utility constraints and public amenity/safety requirements, use locally indigenous tree species in streetscape plantings with high habitat values (e.g. stringybarks, hollow-developing species, nectar/pollen producing species). • Incorporate rocks and woody debris, including logs, into patches where applicable.	Birds: Backyard Birds: grassland and lightly timbered woodland Mammals: arboreal Mammals: microbats and flying-foxes

Spec	Type	Description	Key actions	Priority fauna groups
		location for utilities, drainage and recreational functions.	• Use native mulch to increase invertebrate biodiversity and provide a food source for insectivorous bird species. • Encourage residential properties to plant indigenous groundcover, shrubs and trees in front gardens to increase the extent and width of habitat along streets. • Where possible, maintain swales and open drains in roadsides, or install 'roadside rain gardens' to capture, filter and retain stormwater runoff, to provide ephemeral wet habitats. Plant areas with indigenous sedges and rushes tolerant of dry conditions.	
1.7	Rail reserves (public)	Rail reserves play an important role in providing connectivity due to the persistence of remnant or recolonising vegetation in otherwise cleared landscapes. Whilst narrow, these corridors often support a diversity of structure and their linear nature are considered valuable for the role they play in providing functional connectivity through a landscape.	• Wherever possible, increase the extent of indigenous understorey vegetation in rail reserves and associated land. Use EVC benchmarks and Lorimer (2020) as a guide to lifeform cover and species composition across different parts of the municipality. Works will require engagement with rail authorities and be consistent with management of corridors for transport/safety purposes. • Protect or create structurally diverse, indigenous understorey based on local EVCs around existing canopy trees to act as stepping-stones for small fauna. Patches should be no more than 50 metres apart with managed/mown areas between. • Refrain from mowing slashing groundcover in rail reserves allowing tall groundcover to develop to >30cm. Ideally establish indigenous species in these areas e.g. tussock grasses. • Use locally indigenous tree species in revegetation (e.g. stringybarks, hollow-developing species, nectar/pollen producing species). • Incorporate rocks and woody debris, including logs, into patches where applicable. • Use native mulch to increase invertebrate biodiversity and provide a food source for insectivorous bird species. • Encourage residential properties to plant indigenous groundcover, shrubs and trees in gardens adjacent to the reserve to increase the extent and width of habitat along corridor. • Encourage residential properties to install fauna-friendly fencing adjacent to rail reserve (see Spec 2.1). • Where possible, maintain swales and open drains in reserves, or install 'rain gardens' to capture, filter and retain stormwater runoff, to provide ephemeral wet habitats. Plant areas with indigenous sedges and rushes tolerant of dry conditions.	Birds: Backyard Birds: grassland and lightly timbered woodland Mammals: arboreal Mammals: microbats and flying-foxes

Spec	Type	Description	Key actions	Priority fauna groups
1.8	Industrial and commercial precincts (private and public land)	Land zoned for commercial or industrial use often contain no or limited vegetation cover. When combined with high levels of human activity (e.g. traffic and noise) they represent significant barriers to movement in an urban landscape. Despite this, many opportunities exist to increase vegetation cover due to large parcel sizes, wide road reserves, and areas of under-utilised land (e.g. carparks). Creation of stepping-stones in these areas may facilitate movement for a range of urban tolerant species.	• Work with private landholders to increase indigenous vegetation extent and quality along wildlife passages. This may include: o Plantings within undeveloped land contiguous to road reserves (e.g. road frontages) o reconfigure hardstand areas (e.g. carparks and storage areas) to increase contiguous vegetation cover and incorporate understorey elements. o reallocate hardstand to vegetation/habitat through alternative development options e.g. single-storey open carparks to multi-storey carparks with reduced footprints, consolidation of parking areas across multiple lots. • Support and encourage the design, installation and maintenance of green roofs and walls on new and existing buildings. • Work with industries to minimise pollutants (noise, chemicals, rubbish) entering adjacent habitats. • Review stormwater systems to incorporate localised, above-ground retention and treatment systems that incorporate wildlife habitat elements (e.g. constructed wetlands, rain gardens and bioswales).	Amphibians Birds: backyard Birds: grassland and lightly timbered woodland Mammals: arboreal Mammals: microbats and flying-foxes
1.9	Vacant or unused land and utility easements	All urban environments contain vacant or unused/under-utilised parcels which already do, or could potentially, provide short or long-term habitat for a variety of species. The significance and opportunities associated with these parcels varies due to landscape context, ownership and scale, however they present considerable opportunities to complement existing habitat or wildlife passages through revegetation or the addition of critical habitat resources. Similarly, utility easements present opportunities to create or supplement habitat through	• Identify vacant or under-utilised land associated with core habitat areas or wildlife passages for targeted landholder engagement. • Consider options to acquire land with high biodiversity habitat and/or connectivity values. • With the support of council resources, assist landholders to: o plant variety of locally indigenous tree and shrub species with differing habitat values (e.g. rough bark vs. smooth/ribbon bark, dense vs. open, different flowering times etc). o replace low-habitat value introduced species with indigenous species. o install habitat structures such: - leaf litter, rock cover and woody debris (logs) of varying sizes and configurations, particularly around garden borders which can be used for basking. - rain gardens and bioswales	Amphibians Birds: Backyard Birds: grassland and lightly timbered woodland Invertebrates Mammals: arboreal Mammals: microbats and flying-foxes Reptiles

Spec	Type	Description	Key actions	Priority fauna groups
		changes to land management practices that are complementary to the principal land use objective.	- artificial hollows and nest boxes in trees. ○ use native mulch to increase invertebrate diversity. ○ install fauna-friendly fencing (see Spec 2.1). • Use EVC benchmarks and Lorimer (2020) as a guide to lifeform cover and species composition across different parts of the municipality. • To encourage investment in short to medium term habitat creation on unused land, consider appropriate planning controls or measures that will ensure future development is not adversely affected (such as by restrictions on removal of native vegetation).	
		Barriers		
2.1	Fences	Fences are a common feature across the urban landscape, however some styles cause negative impacts to native wildlife through restricting movement leading to disruptions in migration, feeding, breeding and social patterns of native fauna, and in some cases death through entrapment. Conversely, fences can also have a positive effect. Barrier fencing along roadsides can funnel wildlife into fauna crossing structures, preventing road mortality.	• Use low height fences and plant trees on either side for privacy and facilitate fauna movement over fence. • Recommended fence types for connectivity (order of preference): ○ Post and timber rail with 30-50cm gap at bottom. ○ Post and wire with 2 or 3 strands and with 30-50cm gap at bottom. ○ Square wire mesh with holes no smaller than 100 x 100mm. ○ Timber paling or alternative with gaps (pales remove) at regular intervals. • Ensure wires are visible to fauna by attaching reflective/colourful tags and/or use borderline (white plastic coated) 'sighter' wire. • Fence designs to direct or prevent wildlife passage should include floppy tops, chain mesh and pinned down skirting to discourage climbing animals and kangaroos. Frog-resistance fences need to be dug down to a depth of at least 100 mm. Install wildlife crossing/passage signs to inform public of significance. • Do not use barbed wire. Where barbed wire is present, cover the top strand of barbed wire fences with poly-pipe to minimise the risk of injury/death or remove the barbed wire completely. • Remove fences where unnecessary or in a state of decline.	All
2.2	Roads and rail	Roads and rail can pose a considerable barrier to the movement of wildlife through the fragmentation of habitat,	• Consider the impact of road/rail extensions or upgrades to remnant vegetation and fauna hotpots and plan to reduce or avoid impacts where possible.	All

Spec	Type	Description	Key actions	Priority fauna groups
		leading to changes in foraging, reproduction and social behaviours. The further loss of roadside vegetation removes the safe passage that trees may provide, leading to an increase in vehicular mortality. Road-kill rates may differ on large high-volume roads compared with smaller low-volume roads and where roads dissect areas of intact habitat. The impact of road mortality may also differ dependent on the species and population size.	• Adjusting driver speed by lowering speed limits, installing reduce speed signs, rumble strips or speed humps and fauna crossing signs in vicinity of priority habitats and corridors. Where possible, reduce speed limits between dusk and dawn in particular. • Increase driver awareness of the hazards of driving at dusk and dawn. • Increase the canopy cover and shrub cover along roadsides and median strips to increase safe passage across roads. Likewise prevent removal of existing overhanging vegetation where possible. • Install wildlife crossing structures along priority corridors that key fauna groups can use to safely traverse a road or rail line (e.g. culverts for ground dwelling fauna, rope bridges or overhanging tree canopies for arboreal fauna). • Install barrier fences in high-volume crossing areas to discouraging movement and/or divert into crossing structures (see Sec 2.1 Fences). • Where waterways intersect roads or rail lines, build culverts with a ledge to increase fauna use when water is present in the culvert.	

2.3	In-stream barriers	Barriers that prevent the movement of fish and other aquatic or semi-aquatic species are common in urban waterways. These include weirs, culverts, pipes and concrete channels. Of the 83 species of freshwater fish in south-eastern Australia, half migrate at least once as part of their life cycle.	• Re-naturalise or 'daylight' sections of waterways that have been diverted into underground pipes.
			• Design culverts to improve fish movement through waterways in urban areas. Some examples of good culvert design include:
			  ○ made as wide as the original stream bed to maintain natural water velocity, and to prevent build-up of debris that can act as a further barrier
			  ○ ideally made less than 6 m long, or if longer, should include rest areas for fauna
			  ○ allow as much light in as possible through vents or openings along the length.
			• Consider use of fish ladders and rock ramps (structures to aid movement of fish over or around in-stream barriers such as culverts or weirs) if there is a known species that would benefit from these.
			• Use baffles (energy dissipaters) to regulate flow velocities. This can also create short bursts of high velocities to aid fish movement.
			• Use a natural substrate that does not impede water flow and creates habitat for aquatic macroinvertebrates.	

2.4	Human-activity	Human activity as a barrier to wildlife is a significant and far-reaching threat	• Restrict access in core habitats to established walking tracks and prevent access with vehicles or dogs.	All

Spec	Type	Description	Key actions	Priority fauna groups
		with many potential impacts, ranging from construction of a new housing estate, to people walking their dogs in a park. While some species have been able to adapt to the changes caused by human presence - such as possums living in roofs rather than hollow-bearing trees - most are affected negatively by human activity due to fear and avoidance. This applies to terrestrial and flying fauna.	• Remove/prevent access to tracks and bike trails which are detrimental to the conservation of core habitat. • Discourage the feeding of and interaction with (e.g. approaching or pursuing) native wildlife. • Design and place high activity areas (such as playgrounds, sports grounds and dog parks) to minimise impacts on priority habitat and linkages. Where present or unavoidable, establish disturbance buffers of dense vegetation. • Educate people about local fauna to promote community awareness and pride, which can lead to better environmental outcomes. • Limit dog walking and/or off-leash areas within priority habitat or linkages. Install signage to inform public of adverse impacts of domestic pets on wildlife.	
2.5	Predation	Introduced predators, whether they be wild foxes or domestic cats and dogs, are a major threat to the movement of wildlife through urban landscapes. Predators can act as a barrier for wildlife through a phenomenon known as the 'landscape of fear', whereby the presence of a predator can influence the behaviour, distribution, foraging, nesting, movement and timing of activity of prey species in the area.	• Undertake pest control for wild foxes and cats within priority habitat and linkages, being conscious of the potential adverse effects to native wildlife of control measures such as baiting. • Introduce cat curfews to keep cats and dogs indoors between sunset and sunrise as a minimum. Inside-only cats are the safest option for wildlife. • Encourage owners of dogs and cats in priority habitat and linkage areas to contain and control their animals to minimise impacts to wildlife and their movement. • Enforce dog leash laws with signage, patrols and fines. • Ensure rubbish bins have secure lids and avoid leaving uneaten pet food outside to limit the availability of 'easy food' for urban foxes. • Raise awareness and educate the community about native species in the local area, their importance and the impact of pets as predators.	All
2.6	Aggressive species	Some species are more adaptable than others in urban areas and have been very successful in dominating the little habitat remaining. These species, though often native, compete with less-successful species and can also be aggressive towards humans. A common example is native Noisy Miner and	• Create patches of shrubby understorey in vegetated areas, including acacias, to provide shelter and safe habitat for smaller birds, as Noisy Miners prefer open areas with eucalypts where they can get a view of their territory and forage on the ground. • Culling is the most effective and humane method of reducing aggressive species numbers and can result in rapid improvement of habitat condition and re-establishment of other native bird species. • Remove exotic berry-producing species such as Privet and Asparagus fern to reduce nest predators, such as the Pied Currawong, and encourage small birds to return.	All

Spec	Type	Description	Key actions	Priority fauna groups
		introduced Indian Myna, both of which are well adapted to urban environments and outcompete other native bird species. Over abundant Noisy Miners have been listed as a Key Threatening Process under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.	• Shrub species that produce copious nectar tend to cause an increase in aggressive Red Wattlebirds, which then displace a range of small, insect-eating birds. Restrict planting of such species where possible (Lorimer 2020).	
2.7	Light	Artificial night lighting can have impacts on terrestrial and aquatic ecosystems, such as altering ecological regimes, disrupting ecological processes and behaviour of fauna, causing increased mortality, and reducing both the fitness of populations and the ecological connectivity between them. Impacts on wildlife increase with longer lighting hours and increased use of brighter, whiter lighting (via cheaper LED lighting).	Reduce light pollution around priority habitats and linkages by: • Using no or fewer lights and limit the time that lighting is used e.g. turn off lights when not needed. • Use alternatives to lighting such as low-light LEDs installed in pavements, fluorescent or reflective paint. • Apply structural changes to the design of lights, so that light is only directed to where it is needed and does not spill into habitat or movement corridors or the sky above e.g. use aeroscreens on streetlights to reduce light spill. Reduce height of lighting wherever possible. • Use physical barriers such as densely planted vegetation to block or reduce light pollution from roads and buildings e.g. wall barriers along freeways. • Use narrow spectrum light sources which will reduce the number of species affected and avoid ultra-violet light (peaks no higher than 550 nm) and white and blue wavelengths – use warm/yellow colour temperature (<4,200 kelvin) where required to balance blue light. • Plan and design large developments and associated human activities to avoid impacts. Includes encourage lighting on timers for commercial buildings, particularly between 11pm to 4am. • Plan for 'dark areas' for fauna refuge in wildlife corridors.	All

Spec	Type	Description	Key actions	Priority fauna groups
2.8	Sound	Anthropogenic (man-made) noise pollution is a side-effect of increased human population size and urbanisation. Traffic and construction are examples of the types of noise pollution which have direct impacts on wildlife, through the interference of auditory cues, and altered behaviour and physiological responses. Broader impacts include changes to reproductive success, movement patterns and habitat use, survival and foraging efficiency. The extent to which noise affects a species seems to be species-specific.	Reduce sound pollution around priority habitats and linkages by: • Install noise reducing barriers around major roads. • Utilising green roofs and walls on buildings and other hard structures to absorb noise and provide extra habitat. • Limit access to wetlands to reduce noise and disturbance to wildlife. • Identify noise-producing facilities in the municipality and look at ways to reduce their impact, e.g. quieter machines and sound barriers. • Avoiding generating excessive noise during the mating season, especially around wetlands. Schedule works outside of this time. • Re-routing trucks and other heavy vehicles. • Reducing speed limits. • Carefully plan and assess future developments to address their noise-producing ability.	
2.9	Buildings	Buildings are an obvious barrier to native fauna, especially for movement of terrestrial, non-flying wildlife, however some impacts are less apparent and can affect all kinds of animals and ecological processes. These include loss of habitat and fragmentation due to subdivision and development, and altered hydrology by limiting infiltration and diverting to waterways via stormwater.	• Consider building design and the impact of buildings on birds. Buildings with glass may result in an increase in bird deaths. Glass with UV coat treatments, ceramic frit patterns, vertical lines no wider than 2 inches apart can reduce bird deaths. • Design into new buildings and maintain green roofs and walls to provide habitat and facilitate movement through the landscape. • Consider incorporation into building design/structure nesting and roosting structures and associated access via trees or rope bridges. Many fauna will utilise cracks, holes and other cavities or ledges on older buildings which can be replicated in the design of new developments.	

7. References

Adriaensen F, Chardon JP, De Blust G, Swinnen E, Villalba S, Gulinck H and Matthysen E (2003) The application of 'least-cost' modelling as a functional landscape model. Landscape Urban Planning 64, 233-247.

Bierwagen, B. G. (2007). Connectivity in urbanizing landscapes: The importance of habitat configuration, urban area size, and dispersal. Urban Ecosystems, 10(1), 29-42.

Crossman, N. D., Bryan, B. A. and King, D. 2009. *Integration of landscape scale and site scale metrics for prioritising investments in natural capital*. 18th World IMACS/MODSIM Congress, 13-17th July, Cairns, Australia.

DELWP, 2020. *Victorian Biodiversity Atlas [Online Resource].* Department of Environment, Land, Water and Planning, Victoria. Accessed 05/11/2020. https://vba.dse.vic.gov.au/vba/index.jsp.

Department of Environment, Land, Water and Planning 2020. Bioregions and EVC Benchmarks. Available: https://www.environment.vic.gov.au/biodiversity/bioregions-and-evc-benchmarks [22 January 2020).

Doerr VAJ, Doerr ED and Davies MJ (2010) Does structural connectivity facilitate dispersal of native species in Australia's fragmented terrestrial landscapes?, CEE review 08-007 (SR44), p. 70.

Doerr, V.A.J., Doerr, E.D. and Davies, M.J. (2010). Does structural connectivity facilitate dispersal of native species in Australia's fragmented terrestrial landscapes? Systematic Review No. 44, Collaboration of Environmental Evidence. CSIRON. Canberra.

Drielsma, M. and Ferrier, S. (2009). Rapid evaluation of metapopulation persistence in highly variegated landscapes. *Biological Conservation*. 142: 529-540.

Ecology Australia 2009. Assessment of riparian setback widths required to support biodiversity values.

Fischer, J., and Lindenmayer, D. B. (2007). Landscape modification and habitat fragmentation: a synthesis. Global ecology and biogeography, 16(3), 265-280.

Foltête J-C, Vuidel G, Savary P, et al (2021) Graphab: An application for modeling and managing ecological habitat networks. Softw Impacts 8:100065. doi: 10.1016/j.simpa.2021.100065

Lechner AM, Doerr V, Harris RMB, et al (2015) A framework for incorporating fine-scale dispersal behaviour into biodiversity conservation planning. Landsc Urban Plan 141:11–23. doi: 10.1016/j.landurbplan.2015.04.008

Lechner AM, Lefroy EC (2014) General Approach to Planning Connectivity from LOcal Scales to Regional (GAP CLoSR): combining multi-criteria analysis and connectivity science to enhance conservation outcomes at regional scale. Centre for Environment, University of Tasmania. www.nerplandscapes.edu.au/publication/GAP_CLoSR

Lechner AM, Sprod D, Carter O, Lefroy EC (2017) Characterising landscape connectivity for conservation planning using a dispersal guild approach. Landsc Ecol 32:99–113. doi: 10.1007/s10980-016-0431-5

Lechner, A.M., D. Sprod, O. Carter, E.C. Lefroy (2017) Characterising landscape connectivity for conservation planning using a dispersal guild approach. Landscape Ecology. 32: 99-113

Lechner, A.M., Sprod, D., Carter, O. and Lefroy, E.C. (2016) Characterising landscape connectivity for conservation planning using a dispersal guild approach. Landscape Ecology, 1-15.

Lechner, A.M., V. Doerr, R.M.B. Harris, E. Doerr, T. Lefroy (2015b) A framework for multi-scale connectivity modelling incorporating fine-scale dispersal behaviour. Landscape and Urban Planning. 141: 11–23

Linstone, H. A. and Turoff, M. 1975. *The Delphi Method: Techniques and Applications*. Reading, Mass: Adison-Wesley.

Lorimer, G. 2020. Biodiversity in Maroondah. Volumes 1 and 2. Report prepared for Maroondah City Council.

Melbourne Water 2013. Waterway Corridors—Guidelines for greenfield development areas within the Port Phillip and Western Port Region.

Mendoza, G. A., and Macoun, P. 1999. *Guidelines for Applying Multi-Criteria Analysis to the Assessment of Criteria and Indicators*. Centre for International Forestry Research, Jakarta Indonesia

Minor, E. S., and Urban, D. L. (2008). A graph-theory framework for evaluating landscape connectivity and conservation planning. Conservation biology, 22(2), 297-307.

Pascual-Hortal, L., Saura, S., 2006. Comparison and development of new graph-based landscape connectivity indices: towards the priorization of habitat patches and corridors for conservation. Landscape Ecol. 21 (7), 959–967.

Rayfield B, Fortin MJ and Fall A (2011) Connectivity for conservation: A framework to classify network measures. Ecology 92, 847-858.

Recher, H.F., Shields, J., Kavanagh, R., and Webb, G. 1987. Retaining remnant Mature Forest for Nature Conservation at Eden, New South Wales: A review of theory and practice. *Nature Conservation: The role of remnants of native vegetation.* Surrey Beatty and Sons, New South Wales.

Rudnick DA, Ryan SJ, Beier P, Cushman SA, Dieffenbach F, Epps CW, Gerber LR, Hartter J, Jenness JS, Kintsch J, Merenlender AM, Perkl RM, Preziosi DV and Trombulak SC (2012) The role of landscape connectivity in planning and implementing conservation and restoration priorities, Issues in ecology, Vol. 16, pp. 20-20

Saaty, T. L. 1980. *The Analytic Hierarchy Process*. New York, McGraw Hill.

Saunders, D. A., Hobbs, R. J., and Margules, C. R. (1991). Biological consequences of ecosystem fragmentation: a review. Conservation biology, 5(1), 18-32.

Sawyer SC, Epps CW and Brashares JS (2011) Placing linkages among fragmented habitats: Do least-cost models reflect how animals use landscapes? J. Appl. Ecol. 48, 668-678

Seto, K. C., Güneralp, B., and Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences, 109(40), 16083-16088.

Urban, D., and Keitt, T. (2001). Landscape connectivity: a graph-theoretic perspective. Ecology, 82(5), 1205-1218.

Victorian Rail Industry Environmental Forum 2007. Vegetation Management Guidelines for Rail Corridors.

Appendix A Project reference group

Name	Organisation and role
Anthony Bigelow	President, First Friends of Dandenong Creek.
Chris Howells	Team Leader, Tree Maintenance, Maroondah Council.
Craig Mauger	Team Leader, Bushland, Maroondah Council.
Dale Bristow	Team Leader, Strategic Planning and Sustainability, Maroondah Council.
Daniel Flaim	Biodiversity Officer, Bushland, Maroondah Council.
David De Angelis	Ecologist, Abzeco.
Derek Ashton	Community Liaison Officer, Bushland, Maroondah Council.
Elspeth De Fanti	Community representative, Maroondah Environment Advisory Committee.
Gary Presland	Editor, The Victorian Naturalist, Field Naturalists Club of Victoria.
Gwenda Short	Member, Croydon Conservation Society.
Judith Cooke	Member, Ringwood Field Naturalists Club.
Julia Franco	Local resident, Biodiversity Officer, Nillumbik Shire Council.
Melissa Carmody	Waterways and Land Officer, Melbourne Water.
Nicole Palombi	Water Sensitive Urban Design Officer, Bushland, Maroondah Council.
Roger Lord	Environmental Planner, Statutory Planning, Maroondah Council.
Stefanie Black	Strategic Asset Planner (Open Space), Assets, Maroondah Council.
Tim Louis	Team Leader, Parks and Open Space, Maroondah Council.

Appendix B Engagement species and faunal groups

Table B1. Engagement species

Scientific name	Common name	Faunal group	Habitat types	Presence and abundance	Engagement potential	Indicators of health	Monitoring	Threatened status	Dispersal ability	Dispersal mode
Amegilla (Zonamegilla) cingulata	Blue-banded Bee	Invertebrate	Forest, Woodland, Heath, Urban	Rare	High	Moderate	Poor	-	Low	Aerial
Anguilla australis	Southern Short-fin Eel	Fish	Creeks	Common in parts	High	Moderate	Good	-	High	Aquatic
Callocephalon fimbriatum	Gang-gang Cockatoo	Bird	Forest, woodlands	Common in parts	High	Low	Good	-	High	Aerial
Eopsaltria australis	Eastern Yellow Robin	Bird	Woodland, Heath	Common in parts	Moderate	Moderate	Excellent	-	Moderate	Aerial
Galaxias maculatus	Common Galaxias	Fish	Rivers, Creeks	Common in parts	Moderate	Moderate	Good	-	High	Aquatic
Hydromys chrysogaster	Rakali	Mammal	Riparian, Wetlands, Swamplands	Rare	Moderate	Moderate	Good	-	Moderate	Ground-dwelling, Aquatic
Hypotaenidia philippensis	Buff-banded Rail	Bird	Wetlands	Present outside Maroondah	Moderate	Moderate	Good	-	Moderate	Ground-dwelling
Limnodynastes peronii	Striped Marsh Frog	Amphibian	Wetland, Grassland, Woodland, Urban	Rare	Moderate	Moderate	Excellent	-	Low	Ground-dwelling, Aquatic
Limnodynastes tasmaniensis	Spotted Marsh Frog	Amphibian	Wetland, Grassland, Woodland, Urban	Rare	Moderate	Moderate	Excellent	-	Low	Ground-dwelling, Aquatic
Malurus cyaneus	Superb Fairy-wren	Bird	Woodlands, Urban	Common in parts	Moderate	Low	Excellent	-	Low-moderate	Aerial

Scientific name	Common name	Faunal group	Habitat types	Presence and abundance	Engagement potential	Indicators of health	Monitoring	Threatened status	Dispersal ability	Dispersal mode
Neochmia temporalis	Red-browed Finch	Bird	Grassy woodland, Riparian	Rare	Moderate	Low	Excellent	-	Moderate	Aerial
Ninox strenua	Powerful Owl	Bird	Forest, woodland	Rare	High	Moderate	Excellent	State	High	Aerial
Ornithorhynchus anatinus	Platypus	Mammal (like)	Rivers, Creeks	Present outside Maroondah	High	Moderate	Poor	-	Moderate	Ground-dwelling, Aquatic
Pachycephala pectoralis	Golden Whistler	Bird	Woodland	Common in parts	Moderate	Moderate	Excellent	-	Moderate	Aerial
Petaurus breviceps	Sugar Glider	Mammal	Woodland, Riparian	Rare	High	Low	Good	-	Low	Arboreal
Petroica boodang	Scarlet Robin	Bird	Woodland	Rare	Moderate	Moderate	Excellent	-	Moderate	Aerial
Podargus strigoides	Tawny Frogmouth	Bird	Open Woodland	Common and widespread	High	Low	Good	-	High	Aerial
Pseudemoia rawlinsoni	Glossy Grass Skink	Reptile	Margins of Creeks, Swamps	Common in parts	Moderate	Moderate	Good	State	Low	Ground-dwelling
Tachyglossus aculeatus	Short-beaked Echidna	Mammal	Open Forests, Woodlands, Grassy Woodlands	Rare	High	Low	Good	-	High	Ground-dwelling
Tadarida australis	White-striped Freetail Bat	Bat	Woodland	Rare	High	Moderate	Good	-	Moderate	Aerial
Tiliqua nigrolutea and Tiliqua scincoides	Blue-tonged Lizard	Reptile	Woodland, Grassland, Urban	Rare	High	Low	Excellent	-	Low-moderate	Ground-dwelling
Multiple	Butterflies	Invertebrate	Grassland, Woodland	Rare	Moderate	Moderate	Poor	-	High	Aerial

Table 13. Fauna species recorded within 5km of Maroondah (VBA 2020), ranked by record count (highest to lowest)

Scientific Name	Common Name	Significance	Engagement species
Amphibians			
Crinia signifera	Common Froglet		
Litoria ewingii	Southern Brown Tree Frog		
Limnodynastes tasmaniensis SCR	Spotted Marsh Frog SCR		Yes
Geocrinia victoriana	Victorian Smooth Froglet		
Limnodynastes dumerilii	Southern Bullfrog (ssp. unknown)		
Limnodynastes tasmaniensis	Spotted Marsh Frog (race unknown)		Yes
Limnodynastes peronii	Striped Marsh Frog		Yes
Pseudophryne semimarmorata	Southern Toadlet	State	
Litoria verreauxii verreauxii	Verreaux's Tree Frog		
Litoria fallax	Eastern Dwarf Tree Frog		
Pseudophryne bibronii	Brown Toadlet	State	
Litoria raniformis	Growling Grass Frog	National	
Litoria peronii	Peron's Tree Frog		
Birds: Backyard			
Gymnorhina tibicen	Australian Magpie		
Anthochaera carunculata	Red Wattlebird		
Trichoglossus molucannus	Rainbow Lorikeet		
Corvus mellori	Little Raven		
Platycercus eximius	Eastern Rosella		
Grallina cyanoleuca	Magpie-lark		
Manorina melanocephala	Noisy Miner		
Strepera graculina	Pied Currawong		
Acanthorhynchus tenuirostris	Eastern Spinebill		
Eolophus roseicapilla	Galah		
Cacatua galerita	Sulphur-crested Cockatoo		
Ptilotula penicillata	White-plumed Honeyeater		
Rhipidura leucophrys	Willie Wagtail		
Phylidonyris novaehollandiae	New Holland Honeyeater		
Anthochaera chrysoptera	Little Wattlebird		
Vanellus miles	Masked Lapwing		
Ocyphaps lophotes	Crested Pigeon		

Scientific Name	Common Name	Significance	Engagement species
Psephotus haematonotus	Red-rumped Parrot		
Cracticus torquatus	Grey Butcherbird		
Acanthiza pusilla	Brown Thornbill		Yes
Cacatua sanguinea	Little Corella		
Cacatua tenuirostris	Long-billed Corella		
Birds: forests and woodland			
Turnix varius	Painted Button-quail		
Dacelo novaeguineae	Laughing Kookaburra		
Platycercus elegans	Crimson Rosella		
Rhipidura albiscapa	Grey Fantail		Yes
Pardalotus punctatus	Spotted Pardalote		
Sericornis frontalis	White-browed Scrubwren		
Zosterops lateralis	Silvereye		
Eopsaltria australis	Eastern Yellow Robin		Yes
Manorina melanophrys	Bell Miner		
Colluricincla harmonica	Grey Shrike-thrush		
Acanthiza lineata	Striated Thornbill		
Calyptorhynchus funereus	Yellow-tailed Black-Cockatoo		
Pachycephala pectoralis	Golden Whistler		Yes
Strepera versicolor	Grey Currawong		Yes
Coracina novaehollandiae	Black-faced Cuckoo-shrike		
Cormobates leucophaea	White-throated Treecreeper		
Phaps chalcoptera	Common Bronzewing		
Callocephalon fimbriatum	Gang-gang Cockatoo		
Podargus strigoides	Tawny Frogmouth		
Glossopsitta concinna	Musk Lorikeet		
Oriolus sagittatus	Olive-backed Oriole		
Alisterus scapularis	Australian King-Parrot		
Pachycephala rufiventris	Rufous Whistler		
Melithreptus lunatus	White-naped Honeyeater		
Cacomantis flabelliformis	Fan-tailed Cuckoo		
Caligavis chrysops	Yellow-faced Honeyeater		
Corvus coronoides	Australian Raven		
Nesoptilotis leucotis	White-eared Honeyeater		
Pardalotus striatus	Striated Pardalote		Yes

Scientific Name	Common Name	Significance	Engagement species
Dicaeum hirundinaceum	Mistletoebird		
Chrysococcyx lucidus	Shining Bronze-Cuckoo		
Falcunculus frontatus	Eastern Shrike-tit		
Smicrornis brevirostris	Weebill		Yes
Petroica boodang	Scarlet Robin		
Acanthiza nana	Yellow Thornbill		
Daphoenositta chrysoptera	Varied Sittella		
Accipiter fasciatus	Brown Goshawk		
Ninox strenua	Powerful Owl	State	
Ninox boobook	Southern Boobook		
Hirundapus caudacutus	White-throated Needletail	National	
Artamus cyanopterus	Dusky Woodswallow		
Chrysococcyx basalis	Horsfield's Bronze-Cuckoo		
Acanthiza chrysorrhoa	Yellow-rumped Thornbill		
Falco berigora	Brown Falcon		
Falco longipennis	Australian Hobby		
Acanthiza reguloides	Buff-rumped Thornbill		
Cacomantis pallidus	Pallid Cuckoo		
Myiagra cyanoleuca	Satin Flycatcher		
Falco peregrinus	Peregrine Falcon		
Zoothera lunulata	Bassian Thrush		
Rhipidura rufifrons	Rufous Fantail		
Corcorax melanorhamphos	White-winged Chough		
Aegotheles cristatus	Australian Owlet-nightjar		
Parvipsitta pusilla	Little Lorikeet		
Myiagra inquieta	Restless Flycatcher		
Petroica rosea	Rose Robin		
Melithreptus brevirostris	Brown-headed Honeyeater		
Microeca fascinans	Jacky Winter		
Myzomela sanguinolenta	Scarlet Honeyeater		
Pyrrholaemus sagittatus	Speckled Warbler	State	
Trichoglossus chlorolepidotus	Scaly-breasted Lorikeet		
Tyto alba	Barn Owl		
Phaps elegans	Brush Bronzewing		
Cacomantis variolosus	Brush Cuckoo		

Scientific Name	Common Name	Significance	Engagement species
Accipiter novaehollandiae	Grey Goshawk	State	
Myiagra rubecula	Leaden Flycatcher		
Anthochaera phrygia	Regent Honeyeater	National	
Petroica phoenicea	Flame Robin		
Meliphaga lewinii	Lewin's Honeyeater		
Petroica rodinogaster	Pink Robin		
Climacteris erythrops	Red-browed Treecreeper		
Lathamus discolor	Swift Parrot	National	
Petrochelidon nigricans	Tree Martin		
Climacteris picumnus	Brown Treecreeper	State	
Phylidonyris pyrrhopterus	Crescent Honeyeater		
Pachycephala olivacea	Olive Whistler		
Eurystomus orientalis	Oriental Dollarbird		
Parvipsitta porphyrocephala	Purple-crowned Lorikeet		
Petroica goodenovii	Red-capped Robin		
Gerygone olivacea	White-throated Gerygone		
Ninox connivens	Barking Owl	State	
Stagonopleura bella	Beautiful Firetail		
Neophema chrysostoma	Blue-winged Parrot		
Taeniopygia bichenovii	Double-barred Finch		
Psophodes olivaceus	Eastern Whipbird		
Petrochelidon ariel	Fairy Martin		
Philemon corniculatus	Noisy Friarbird		
Barnardius zonarius zonarius	Port Lincoln Parrot		
Ptilonorhynchus violaceus	Satin Bowerbird		
Dicrurus bracteatus	Spangled Drongo		
Cinclosoma punctatum	Spotted Quail-thrush	State	
Menura novaehollandiae	Superb Lyrebird		
Gerygone fusca	Western Gerygone		
Artamus superciliosus	White-browed Woodswallow		
Lalage tricolor	White-winged Triller		
Gerygone mouki	Brown Gerygone		
Melopsittacus undulatus	Budgerigar		
Scythrops novaehollandiae	Channel-billed Cuckoo		Yes
Calamanthus pyrrhopygius	Chestnut-rumped Heathwren	State	

Scientific Name	Common Name	Significance	Engagement species
Acanthiza uropygialis	Chestnut-rumped Thornbill		
Nymphicus hollandicus	Cockatiel		
Phasianus colchicus	Common Pheasant	State	
Geopelia cuneata	Diamond Dove	State	
Eudynamys orientalis	Eastern Koel		
Ptilotula fusca	Fuscous Honeyeater		
Sericornis magnirostra	Large-billed Scrubwren		
Cracticus nigrogularis	Pied Butcherbird		
Merops ornatus	Rainbow Bee-eater		
Tyto tenebricosa	Sooty Owl	State	
Calamanthus fuliginosus	Striated Fieldwren		
Polytelis swainsonii	Superb Parrot	National	
Artamus leucorynchus	White-breasted Woodswallow		
Eurostopodus mystacalis	White-throated Nightjar		
Burhinus grallarius	Bush Stone-curlew	State	
Birds: grassland and lightly timbered woodland			
Neochmia temporalis	Red-browed Finch		
Bubulcus coromandus	Eastern Cattle Egret		
Elanus axillaris	Black-shouldered Kite		
Accipiter cirrocephalus	Collared Sparrowhawk		
Falco cenchroides	Nankeen Kestrel		
Aquila audax	Wedge-tailed Eagle		
Poodytes gramineus	Little Grassbird		
Cincloramphus mathewsi	Rufous Songlark		
Apus pacificus	Fork-tailed Swift		
Hieraaetus morphnoides	Little Eagle		
Haliastur sphenurus	Whistling Kite		
Lophoictinia isura	Square-tailed Kite	State	
Taeniopygia guttata	Zebra Finch		
Anthus australis	Australian Pipit		
Falco subniger	Black Falcon	State	
Coturnix pectoralis	Stubble Quail		
Birds: wetland and riparian vegetation			
Chenonetta jubata	Australian Wood Duck		
Gallinula tenebrosa	Dusky Moorhen		Yes

Scientific Name	Common Name	Significance	Engagement species
Egretta novaehollandiae	White-faced Heron		
Fulica atra	Eurasian Coot		
Porphyrio melanotus	Australasian Swamphen		
Microcarbo melanoleucos	Little Pied Cormorant		
Anas gracilis	Grey Teal		
Anas castanea	Chestnut Teal		
Todiramphus sanctus	Sacred Kingfisher		
Phalacrocorax sulcirostris	Little Black Cormorant		
Tachybaptus novaehollandiae	Australasian Grebe		
Acrocephalus australis	Reed-Warbler		
Ardea pacifica	White-necked Heron		
Pelecanus conspicillatus	Australian Pelican		
Chroicocephalus novaehollandiae	Silver Gull		
Poliocephalus poliocephalus	Hoary-headed Grebe		
Ardea alba modesta	Eastern Great Egret	State	
Aythya australis	Hardhead	State	
Cygnus atratus	Black Swan		
Ardea alba	Great Egret	State	
Oxyura australis	Blue-billed Duck	State	
Platalea flavipes	Yellow-billed Spoonbill		
Elseyornis melanops	Black-fronted Dotterel		
Hypotaenidia philippensis	Buff-banded Rail		
Porzana pusilla	Baillon's Crake	State	
Biziura lobata	Musk Duck	State	
Phalacrocorax varius	Pied Cormorant	State	
Ceyx azureus	Azure Kingfisher	State	
Spatula rhynchotis	Australasian Shoveler	State	
Platalea regia	Royal Spoonbill	State	
Circus approximans	Swamp Harrier		
Himantopus leucocephalus	Pied Stilt		
Anas superciliosa	Pacific Black Duck		
Hirundo neoxena	Welcome Swallow		Yes
Threskiornis molucca	Australian White Ibis		
Threskiornis spinicollis	Straw-necked Ibis		
Gallinago hardwickii	Latham's Snipe	State	

Scientific Name	Common Name	Significance	Engagement species
Cisticola exilis	Golden-headed Cisticola		
Nycticorax caledonicus	Nankeen Night-Heron	State	
Phalacrocorax carbo	Great Cormorant		
Anhinga novaehollandiae	Australasian Darter		
Haliaeetus leucogaster	White-bellied Sea-Eagle	State	
Ixobrychus dubius	Australian Little Bittern	State	
Tadorna tadornoides	Australian Shelduck		
Egretta garzetta	Little Egret	State	
Porzana tabuensis	Spotless Crake		
Fish			
Anguilla australis	Southern Shortfin Eel		
Galaxias maculatus	Common Galaxias		
Austroargiolestes icteromelas	Common Flatwing		
Galaxias brevipinnis	Climbing Galaxias		
Philypnodon grandiceps	Flatheaded Gudgeon		
Macquaria australasica	Macquarie Perch	National	
Galaxias truttaceus	Spotted Galaxias		
Mordacia mordax	Shorthead Lamprey		
Invertebrate			
Trapezites symmomus soma	Splendid Ochre, Symmomus Skipper		
Dispar compacta	Dispar (or Barred) Skipper		
Toxidia doubledayi	Doubleday's Skipper, Lilac Grass-skipper		
Signeta flammeata	Bright Shield-skipper		
Hesperilla ornata ornata	Spotted Skipper, Spotted Sedge-skipper		
Taractrocera papyria	White-banded Grass-dart		
Ocybadistes walkeri sothis	Yellow-banded Dart, Greenish Grass-dart		
Cephrenes augiades sperthias	*Orange Palm-dart		
Papilio aegeus	*Orchard Swallowtail or Orchard Butterfly		
Papilio anactus	*Dainty Swallowtail		
Delias harpalyce	Imperial Jezebel		
Belenois java teutonia	Caper White		
Tisiphone abeona albifascia	Varied Swordgrass Brown		
Xenica Geitoneura klugii	Klug's (or Marbled) Xenica		Yes
Heteronympha merope merope	Common Brown		
Heteronympha penelope	Shouldered Brown		

Scientific Name	Common Name	Significance	Engagement species
Junonia villida	Meadow Argus		
Vanessa kershawi	Australian Painted Lady		
Danaus plexippus	*Monarch or Wanderer Butterfly		
Paralucia aurifer	Bright Copper		
Hypochrysops delicia	Moonlight (or Blue) Jewel		
Jalmenus evagoras	Imperial Hairstreak		
Pseudalmenus chlorinda zephrys	Silky Hairstreak		
Zizina otis labradus	Common Grass-blue		
Cherax destructor destructor	Common Yabby		Yes
Heteronympha merope	Common Brown Butterfly		
Pieris rapae	Cabbage White Butterfly		
Ischnura aurora	Aurora Bluetail		
Adversaeschna brevistyla	Blue-spotted Hawker Dragonfly		Yes
Ischnura heterosticta	Common Bluetail Damselfly		
Vanessa itea	Australian Admiral Butterfly		
Harmonia conformis	Common Spotted Ladybird		
Engaeus cunicularius	Granular Burrowing Crayfish		Yes
Orthetrum caledonicum	Blue Skimmer Dragonfly		
Papilio (Eleppone) anactus	Dainty Swallowtail Butterfly		
Myrmecia pilosula	Hopper Ant		
Austroagrion watsoni	Eastern Billabongfly		
Engaeus victoriensis	Foothill Burrowing Crayfish	State	
Synlestes weyersii	Bronze Needle Damselfly		
Paratya australiensis	Common Freshwater Shrimp		
Phalaenoides glycinae	Grapevine Moth		
Argiope keyserlingi	St Andrew's Cross Spider		
Coccinella transversalis	Transverse Ladybird		
Laxta granicollis	Bark Cockroach		Yes
Amegilla (Zonamegilla) cingulata	Blue-banded Bee		
Plebs eburnus	Bush Orb-weaver Spider		
Euastacus woiwuru	Central Highlands Spiny Crayfish		
Vespula germanica	European Wasp		
Apricia jovialis	Jovial Jumping Spider		
Eristalinus (Lathyrophthalmus) punctulatus	Native Drone Fly		
Geitoneura acantha	Ringed Xenica		

Scientific Name	Common Name	Significance	Engagement species
Austrolestes analis	Slender Ringtail		
Acrodipsas myrmecophila	Small Ant Blue Butterfly	State	
Diplacodes bipunctata	Wandering Percher Dragonfly		
Lampona cylindrata	White-tailed Spider		
Neosparassus diana	Badge Huntsman Spider		
Mammals: aquatic			
Ornithorhynchus anatinus	Platypus	State	
Hydromys chrysogaster	Water Rat		
Mammals: arboreal			
Pseudocheirus peregrinus	Eastern Ring-tailed Possum		
Trichosurus vulpecula	Common Brush-tailed Possum		
Petaurus breviceps	Sugar Glider		Yes
Phascolarctos cinereus	Koala		
Phascogale tapoatafa	Brush-tailed Phascogale	State	
Trichosurus cunninghami	Mountain Brush-tailed Possum		Yes
Mammals: ground-dwelling			
Tachyglossus aculeatus	Short-beaked Echidna		
Macropus giganteus	Eastern Grey Kangaroo		
Wallabia bicolor	Black-tailed Wallaby		
Vombatus ursinus	Bare-nosed Wombat		
Rattus fuscipes	Bush Rat		Yes
Antechinus agilis	Agile Antechinus		Yes
Antechinus mimetes	Mainland Dusky Antechinus		
Rattus lutreolus	Swamp Rat		
Dasyurus maculatus maculatus	Spot-tailed Quoll	National	
Mammals: microbats and flying-foxes			
Tadarida australis	White-striped Freetail Bat		
Nyctophilus geoffroyi	Lesser Long-eared Bat		
Vespadelus vulturnus	Little Forest Bat		
Pteropus poliocephalus	Grey-headed Flying-fox	National	
Chalinolobus gouldii	Gould's Wattled Bat		
Vespadelus darlingtoni	Large Forest Bat		
Vespadelus regulus	Southern Forest Bat		
Miniopterus schreibersii GROUP	Common Bent-wing Bat	State	
Chalinolobus morio	Chocolate Wattled Bat		Yes

Scientific Name	Common Name	Significance	Engagement species
Chiroptera spp.	Bat		
Nyctophilus gouldi	Gould's Long-eared Bat		
Scotorepens orion	Eastern Broad-nosed Bat		
Falsistrellus tasmaniensis	Eastern False Pipistrelle		
Mormopterus spp.	Free-tailed Bats		
Myotis macropus	Southern Myotis	State	
Reptiles			
Lampropholis guichenoti	Garden Skink		
Chelodina longicollis	Eastern Snake-necked Turtle	State	
Drysdalia coronoides	White-lipped Snake		
Tiliqua nigrolutea	Blotched Blue-tongued Lizard		
Austrelaps superbus	Lowland Copperhead		
Lampropholis delicata	Delicate Skink		
Saproscincus mustelinus	Weasel Skink		
Tiliqua scincoides	Common Blue-tongued Lizard		
Christinus marmoratus	Marbled Gecko		
Cryptophis nigrescens	Eastern Small-eyed Snake		
Notechis scutatus	Tiger Snake		
Pseudonaja textilis	Eastern Brown Snake		
Lissolepis coventryi	Swamp Skink	State	
Pseudemoia rawlinsoni	Glossy Grass Skink	State	
Emydura macquarii	Murray River Turtle	State	
Varanus varius	Lace Monitor	State	
Anepischtos maccoyi	McCoy's Skink		
Liopholis whitii GROUP	White's Skink		
Acritoscincus duperreyi	Eastern Three-lined Skink		
Eulamprus tympanum tympanum	Southern Water Skink		
Egernia saxatilis intermedia	Black Rock Skink		
Chelodina expansa	Broad-shelled Turtle	State	
Niveoscincus metallicus	Metallic Skink		
Pseudechis porphyriacus	Red-bellied Black Snake		
Tiliqua rugosa	Stumpy-tailed Lizard		
Amphibolurus muricatus	Tree Dragon		

Appendix C Landcover classification

Table C1. Datasets used for landcover classification

Category	Land cover class	Description	Rationale	Raw data layers	Data preparation
Infrastructure	Buildings	Large structures within commercial and industrial areas which have a greater occurrence in the southern portion of the study area. High density urban areas.	Barrier to movement for some species.	Building Footprint – 2008 LiDAR (Melbourne Water)	Updated by visual API using latest imagery (2020mar16 6cm ecw) at 1:2,000 scale.
Transport	Rail	Two lines, as aligning to the highway and the other separating the NW corner from the remainder of the study area Average width of 4.7m	Barrier to movement for some species.	Vicmap – Transport (Tr_rail)	Buffered by 4.7m
	Freeway	Large multi-lane road with high traffic rates. Located in the south-west portion of the study area Average width of 35m Average speed limit 100km/hr	Barrier to movement for some species.	Road pavement layer (Council) Vicmap – Transport (Tr_road) Vicmap – Property (Road casement)	Additional roads not captured in the road pavement layer were combined from either the road casement layer or from the tr_road layer and buffered by 4m. Road classes classified by class code identified in tr_road: Freeway = 0 Highway = 1 Major Road = 2 to 4 Minor Road = 5 to 7, 9 and 12
	Highway	Large multi-lane road with high traffic rates. Travels from NE corner to western edge effectively cutting the study area in half Average width of 22m Average speed limit 60 to 80km/hr	Barrier to movement for some species.		

Category	Land cover class	Description	Rationale	Raw data layers	Data preparation
	Major road	Major roads with moderate to high traffic rates Link urban areas with scattered infrastructure dissecting the study area Average width of 12m Average speed limit 60km/hr	Barrier to movement for some species.		
	Minor road	Smaller roads with low traffic flows Average width of 6.8m Average speed limit 50km/hr	Barrier to movement for some species.		
Drainage	Channel - natural	Subjected to natural flows dominated by creeping and scrambling species some of which are now introduced	Habitat, connectivity element and/or movement barrier depending on species.	Natural drain – centreline (Melbourne Water) Vicmap – Hydro (Hy_watercourse)	Additional watercourses from Vicmap were unioned to the natural drainage line layer and all lines were buffered by 2m
	Drain - cement	Subjected to floodwater at high speed with paved groundcover	Barrier to movement for some species.	Channel drains (Melbourne Water)	Buffered by 2m and classified based on attribute 'material' field": Drain - cement = 'Conc', "Concrk' or 'Rc' Drain – grass = all other materials
	Drain - grass	Subjected to floodwater at high speed dominated by mowed grass, rock and bare earth	Connectivity element and/or barrier depending on species.		
	Waterbody	Ponds and lakes	Habitat, connectivity element and/or movement barrier depending on species.	Vicmap – Hydro (Hy_water_area) Ground-truthing survey (Nov 2020) Aerial imagery (2020mar16 6cm ecw) at 1:2,000 scale.	Waterbodies were captured by visual API using latest imagery (2020mar16 6cm ecw) at 1:2,000 scale. Existing features captured within Vicmap Hydro were crossed check against the layer to ensure no areas had been excluded. Final updates based on ground-truthing and aerial interpretation of high-resolution aerial imagery.

Category	Land cover class	Description	Rationale	Raw data layers	Data preparation
Woody Vegetation	Riparian vegetation	Woodland and forest communities associated with water i.e. flooding regime and/or proximity to permanent water	Habitat and/or connectivity element for some species.	Tree Ledger 2019 (Council) - As part of the Maroondah Vegetation Strategy 2020-2030 Council obtained foliage cover data from the Tree Ledger. The dataset identifies tree canopy cover using high-resolution aerial imagery. This product was coupled with non-vegetated land cover data and refined through aerial photographic interpretation (API) and field assessment. 1750 extent vegetation (NV_1750_EVC) Maroondah Street Tree (Council Jul 2020) Significant sites (Council) Vicmap – Hydro (Hy_water_area) Vicmap – Planning (Plan_Zone) Vicmap – Hydro (Hy_watercourse) Vicmap – Property (Road casement)	Re-alignment and removal of crowns to reflect observable extant vegetation was conducted by visual API using latest imagery (2020mar16 6cm ecw) at 1:2,000 scale. Vegetation classes were classified by the following on-screen analysis and then further refined following site assessment: Riparian vegetation – identified within NV 1750 mapping and within patches of remnant vegetation (fall within reserves and parks identified in 'significant sites' layer and on-screen visual assessment) Dry forest = identified within NV 1750 mapping and within patches of remnant vegetation (fall within reserves and parks identified in 'significant sites' layer and on-screen visual assessment) Street tree = proximity to roads (fall within road casement layer) and alignment with street tree layer Garden planting = within residential areas
	Dry forest	Woodland or forest communities consistent with relevant EVCs.	Habitat and/or connectivity element for some species.		
	Street tree	Primarily indigenous trees ranging from large, intermediate and small trees with managed understorey within a streetscape	Connectivity element for some species.		
	Garden planting	Private and public gardens supporting wide variety of vegetation of mixed origin (native and exotic)	Connectivity element for some species.		
Ground cover	Wetland complex	Unmanaged non-woody vegetation associated with standing or slow flowing water. Represents floating and littoral vegetation types associated with permanent or near-permanent wet environments.	Habitat, connectivity element and/or movement barrier depending on species.	Waterbody landcover classification Ground-truthing survey (Nov 2020) Aerial imagery (2020mar16 6cm ecw) at 1:2,000 scale.	Wetland complex - proximity to waterbody (<5m) Updated based on ground-truthing and aerial interpretation of high-resolution aerial imagery. Overlapping woody vegetation has been removed.

Category	Land cover class	Description	Rationale	Raw data layers	Data preparation
	Fringing vegetation	Unmanaged, non-woody vegetation associated with creeks and streams with consistent flows. Represents littoral vegetation along fringe of waterways.	Habitat and/or connectivity element for some species.	Natural drain – centreline (Melbourne Water)	Two-metre buffer along natural watercourses and waterbodies. Overlapping woody vegetation and wetland complex has been removed.
	Residential ground cover	Managed grassland and/or understorey within urban residential areas	Habitat, connectivity element and/or movement barrier depending on species.	Vicmap – Planning (Plan_Zone)	General, low density and neighbourhood residential zones were refined by visual API using latest imagery (2020mar16 6cm ecw) at 1:2,000 scale and field assessment
	Unmanaged grassland	Unmanaged grassland within remnant vegetation that may or may not be native	Habitat and/or connectivity element depending on species.	Vicmap – Planning (Plan_Zone) AM Council Reserves Significant sites	Public Conservation and Resource Zone unioned with veac metro open space and significant sites. Further refined by visual API using latest imagery (2020mar16 6cm ecw) at 1:2,000 scale and field assessment
	Managed grassland	Managed open spaces including parklands, roadsides, sporting fields and golf courses dominated by grassy groundcover	Habitat, connectivity element and/or movement barrier depending on species.	Vicmap – Features of Interest (FOI_Polygon) AM Council Reserves	Council reserves unioned with golf courses, sports ground, gardens, parks and reserves identified within FOI layer. Further refined by visual API using latest imagery (2020mar16 6cm ecw) at 1:2,000 scale and field assessment
	Hardstand	Pavements, bitumen and other impervious surfaces	Barrier to movement for some species.	Vicmap – Planning (Plan_Zone) Vicmap – Transport (Tr_road, class code 11 and 12)	Commercial and Industrial zones combined with walking tracks and bicycle paths (buffered by 1.5m) with additional areas captured by API using latest imagery (2020mar16 6cm ecw) at 1:2,000 scale.
	Hardcourt	Artificial semi-porus surfaces including tennis courts, netball courts and bowling greens	Barrier to movement for some species.	Vicmap – Features of Interest (FOI_Polygon)	Sporting facilities extracted and additional areas captured through API using latest imagery (2020mar16 6cm ecw) at 1:2,000 scale.

Table C2. Landcover sub-classifications for habitat types based on modelled EVCs

Landcover sub-classification	EVC Group
Dry forest (complex)	Dry Forests
	Heathlands
	Heathy Woodlands
	Herb-rich Woodlands
	Lowland Forests
	Plains Woodlands or Forests
Wet forest (complex)	Rainforests
Riparian woodlands (complex)	Riparian Scrubs or Swampy Scrubs and Woodlands
	Riverine Grassy Woodlands or Forests
Wet forest (complex)	Wet or Damp Forests

Appendix D Species parameters for connectivity modelling

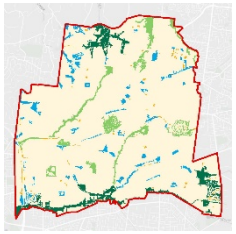
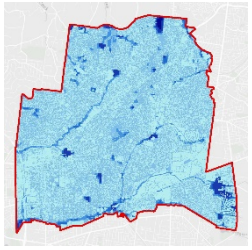
Table D1. Scenario parameters

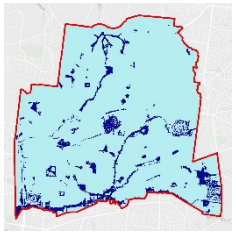
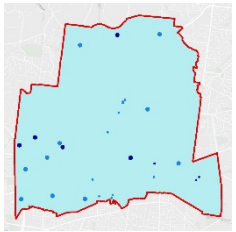
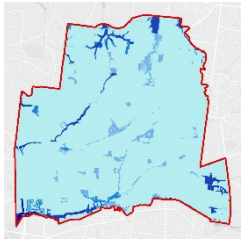
Habitat type	Forest and woodlands			Riparian			Wetlands	
Species	Superb Fairy-wren (*Malurus cyaneus*)			Rakali (*Hydromys chrysogaster*)			Marsh Frogs (*Limnodynastes* spp.)	
Scenario	1.1 (existing)	1.2 (potential)	1.3 (potential)	2.1 (existing)	2.2 (potential)	2.3 (potential)	3.1 (existing)	3.2 (potential)
Core habitat attribution	Dry forest (complex) Riparian vegetation (complex) Exotic forest (complex)	Dry forest (complex) Riparian vegetation (complex) Exotic forest (complex)	Dry forest (complex) Riparian vegetation (complex) Exotic forest (complex) **Ridgeline habitat** **Rail habitat** **Public land habitat**	Riparian vegetation (complex) within 50m of a natural waterway or waterbody	Rakali habitat *i.e. Riparian veg (complex) within 50m of waterbody or natural waterway*	**Rakali habitat V2** *i.e. Riparian veg* ***(complex and simple)*** *within* ***100m*** *of waterbody or natural waterway*	Fringing vegetation Wetlands Waterbody	Fringing vegetation Wetlands Waterbody **Reserve wetlands** **Daylighting wetlands**

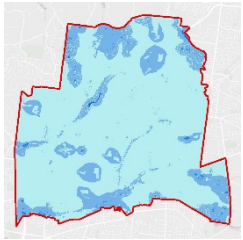
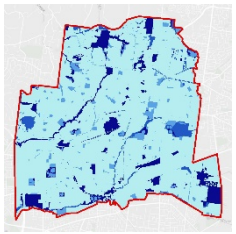
Habitat type	Forest and woodlands			Riparian			Wetlands	
Connectivity element attribution	Dry forest (complex) Riparian vegetation (complex) Exotic forest (complex) Dry forest (simple) Riparian vegetation (simple) Garden planting Street tree	Dry forest (complex) Riparian vegetation (complex) Exotic forest (complex) Dry forest (simple) Riparian vegetation (simple) Garden planting Street tree	**Ridgeline habitat** **Rail habitat** **Public land habitat** **Bayswater habitat** Dry forest (complex) Riparian vegetation (complex) Exotic forest (complex) Dry forest (simple) Riparian vegetation (simple) Garden planting Street tree	Rakali habitat Drain - Grass Waterbody Wetlands Channel - natural Dry forest (complex) Exotic forest (complex) Riparian vegetation (complex) Garden planting Unmanaged grassland	Rakali habitat Drain - Grass Waterbody Wetlands Channel - natural Dry forest (complex) Exotic forest (complex) Riparian vegetation (complex) Garden planting Unmanaged grassland	**Rakali habitat V2** Drain - Grass Waterbody Wetlands Channel - natural Dry forest (complex) Exotic forest (complex) Riparian vegetation (complex) **Riparian vegetation (simple)** Garden planting Unmanaged grassland	Fringing vegetation Wetlands Waterbody Drain - grass Dry forest (complex) Exotic forest (complex) Riparian vegetation (complex) Garden planting Unmanaged grassland	**Reserve wetlands** **Daylighting wetlands** Fringing vegetation Wetlands Waterbody Drain - grass Dry forest (complex) Exotic forest (complex) Riparian vegetation (complex) Garden planting Unmanaged grassland
Min Patch Size (ha)	2	**1.5**	2	3	3	3	0.1	0.1
Gap-crossing threshold (m)	60	**120**	60	500	**750**	500	150	150
Interpatch-crossing distance threshold (m)	500	**1000**	500	1500	**2000**	1500	1000	1000
Waterbody	1	1	1	1	1	1	1	1
Channel - natural	1	1	1	1	1	1	1	1
Drain - cement	1	1	1	2	2	2	3	3
Drain - grass	1	1	1	1.5	1.5	1.5	2	2
Wetlands	1	1	1	1	1	1	1	1
Garden plantings	1	1	1	3	1	3	2	2
Street trees	1	1	1	5	**3**	5	3	3

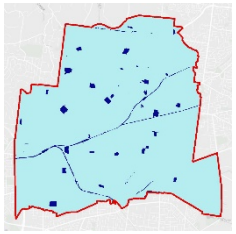
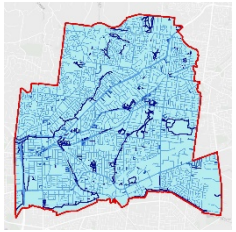
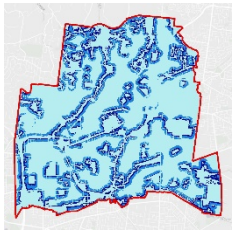
Habitat type	Forest and woodlands			Riparian			Wetlands	
Residential ground cover	1.5	1.5	1.5	4	**2**	4	3	3
Managed grassland	1	1	1	6	**3**	6	3	3
Unmanaged grassland	1	1	1	3	**1.5**	3	2	2
Hardstand	1.5	1.5	1.5	8	**3**	8	4	4
Hardcourt	1.5	1.5	1.5	8	**3**	8	4	4
Dry forest (complex)	1	1	1	2	**1.5**	2	2	2
Dry forest (simple)	1	1	1	4	**3**	4	3	3
Exotic forest (complex)	1	1	1	2	**1.5**	2	2	2
Riparian vegetation (complex)	1	1	1	1	1	1	2	2
Riparian vegetation (simple)	1	1	1	4	**3**	4	3	3
Buildings	3	3	3	Infinite	Infinite	Infinite	Infinite	Infinite
Freeway	4	4	4	20	**10**	20	20	**3**
Highway	3	3	3	16	**8**	16	10	**3**
Major Road	2	2	2	12	**6**	12	8	**3**
Minor Road	1.5	1.5	1.5	8	**4**	8	5	**3**
Rail	1.5	1.5	1.5	6	**3**	6	4	**3**
Path	1	1	1	6	**3**	6	3	3

Appendix E Data preparation and weighting for the biodiversity conservation prioritisation

Layer	Decision criteria	Rationale and description	Data layers	Values	Rank	Weighting
Biodiversity value						
	Consolidated habitat cover	The size of a patch of vegetation. A patch is defined as an area of consolidated vegetation that is separated from other patches by a mapped road or track.	Habitat landcover types identified in Maroondah Landcover (ELA 2021): • Dry forest (complex) • Riparian vegetation (complex) • Exotic forest (complex) • Dry forest (simple) • Riparian vegetation (simple) • Fringing vegetation • Wetlands • Waterbody • Drain – grass • Channel - natural	0, 25, 50, 75 or 100 100 = Regional (>50 ha) 75 = Local (10-50 ha) 50 = Small (1-10 ha) 25 = Clump (<1 ha) 0 = Non vegetation	3	x2
	Habitat quality	High quality habitat for terrestrial and aquatic species based on statewide recognized layers measuring habitat composition, structure and function. This criterion identifies the overall contribution to values for flora/fauna habitat specific to the regional context.	Native Vegetation Regulation Condition (2017) analysis ranking clipped to Cons_habitat_cover (see above) identified in Maroondah Landcover (ELA 2021). Healthy waterways Fish habitat suitability categories buffered by 10m. Other vegetation types identified in Maroondah Landcover (ELA 2021): • Garden planting • Street tree • Unmanaged grassland *Priority order as listed above.*	0, 20, 40, 60, 80 or 100 *Condition scores:* 100 = Very high (80 to 100) 80 = High (60 to 80) 60 = Moderate (40 to 60) 40 = Low (20 to 40) 20 = Very Low (1 to 20) 0 = No habitat *Fish habitat categories:* 100 = Very high 80 = High 60 = Moderate	3	x2

Layer	Decision criteria	Rationale and description	Data layers	Values	Rank	Weighting
				40 = Low 20 = Very Low 0 = No habitat *Other vegetation:* 20 = All other vegetation.		
	Threatened ecological communities	EVCs with and Endangered Bioregional Conservation Status within the region.	Endangered Bioregional Conservation Significance vegetation from NV1750_EVCBCS clipped to Cons_habitat_cover	0, 50 or 100. 100 = Endangered EVCs 0 = all other areas	1	x1
	Threatened flora and fauna	Threatened flora and fauna status under FFG Act (updated list) and EPBC Act.	Consolidated records from Victorian Biodiversity Atlas, Biodiversity in Maroondah report, Atlas of Living Australia Within 50m of a known threatened flora record or within 100m of a known threatened fauna record. *Location of threatened flora and fauna records to have a maximum accuracy of <=1000m.*	0, 50 or 100. 100 = EPBC Act listed 50 = FFG Act listed 0 = all other areas.	1	x1
			Connectivity value			
	Regional connectivity	This criterion identifies the overall contribution to habitat connectivity across the landscape and identifies fragmentation and barriers to connectivity in a regional context.	GRAPHAB Habitat Index for patches from current and potential connectivity modelling weighted by Integral Index Connectivity (0 = low importance, 0.6 = high importance) (ELA 2021). Cur_connect and Pot_connec layers Where overlap:	0, 25, 50, 75 or 100 Current connectivity: 100 = 0.2-0.6 75 = 0.05-0.02 50 = 0.01 – 0.05 25 = <0.01 0 = 0	5	x3

Layer	Decision criteria	Rationale and description	Data layers	Values	Rank	Weighting
			• Current connectivity takes precedence over potential connectivity • Use highest value	Potential connectivity: 50 = 0.2-0.6 25 = 0.05-0.02 0 = 0.01 – 0.05		
	Local connectivity	Current and potential linkages that connect localised habitats through least cost paths	Consolidated circuitscape outputs from all current and potential models (0 = low dispersal probability, 0.1 = high dispersal probability) (ELA 2021). Cur_CS and Pot_CS layers Where overlap: • Current connectivity takes precedence over potential connectivity • Use highest value	0, 25, 50, 75 or 100 Current connectivity: 100 = >0.05 75 = 0.02 – 0.05 50 = 0.01 – 0.02 25 = <0.01 0 = 0 Potential connectivity: 50 = >0.05 25 = 0.01 – 0.05 0 = <0.01	5	x3
			Connecting to nature value			
	Reserves and Sites of Biological Significance	Reserves accessible to the public with some or all of the vegetation managed for conservation purposes.	Sites of Biological Significance (Lorimer 2019) using SIGNIF attribute. Reserves (Parkres layer and AM Council reserves layer)	0, 25, 50 or 100 100 = Sites of Biological Significance (National or state significant) 75 = Sites of Biological Significance (regional or local) 50 = Other reserves 0 = all other areas.	2	x2

Layer	Decision criteria	Rationale and description	Data layers	Values	Rank	Weighting
	Public land	Other public land accessible to the public.	VIC_Map public use zones, excluding 'Reserves and Sites of Biological Significance'	0, 100 100 = public land 0 = all other areas.	1	x1
	Paths	Pathways which transport people through areas of nature	VICmap road and rail reserves, council paths and tracks layer. (Road_Rail_Buffer10m, Trail_Buffer20m, Trail_Buffer20m_Habitat).	0, 25, 50 or 100 100 = Trails through areas of habitat. 50 = Trails 25 = Road or rail 0 = other	1	x1
	Private land	Private land close to habitat areas which may be considered a priority for land management actions to support biodiversity outcomes.	VIC_plan parcels layer (private land tenures)	0, 50 or 100 100 = Adjacent to habitat patches. 50 = Within 150m of habitat patches. 0 = other	1	x1

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