



DEPARTMENT OF PLANNING, INDUSTRY & ENVIRONMENT

Mapping the natural blue grid elements of Wianamatta – South Creek

High ecological value waterways, riparian vegetation communities and other water dependent ecosystems



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Academic Citation:

Dela-Cruz J, Powell M, Tippler C, Wen L, OCock J, Spencer J and Pritchard T (2021) Mapping the natural blue grid elements of Wianamatta-South Creek: High ecological value waterways, riparian vegetation communities and water dependent ecosystems. Department of Planning, Industry and Environment, Parramatta.

Published by:

Environment, Energy and Science
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ISBN 978 1 XXXX XXX X
EES 2020/XXXX
Month 2020

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1. The most insignificant jet



'On 28 August 1826 a truly remarkable public meeting was held in Windsor Courthouse attended by notable local Aboriginal figures of the day. In this remarkable meeting it was resolved 'that the rivers be protected to the most insignificant jet', a poignant resolution still pertinent for the waters of the Wianamatta system.

Water resources have important cultural, spiritual, and practical values for First Peoples. Waterways are crucial for cultural practices and knowledge transfers as part of a healthy, flowing, connected system.

The Cannemegal and Wianamattagal peoples of the Dharug nation still care for the Country of Wianamatta and carry the stories and knowledges of that landscape. Dharug Elders describe Wianamatta as an interconnected system, formed through the Dreaming, this cultural landscape connects from beyond the mountains out to the sea. It is a particularly important place for pregnant women as the place of the mother creek – a female landscape relating to motherhood and creation.

The floodplains of Wianamatta remain a significant place for Aboriginal communities. South, Ropes, Badgerys, and Thompsons Creeks form a major part of the Aboriginal infrastructure which has provided resources such as food, medicine, and recreation over thousands of generations of people. It is imperative to respect these waterways and their dynamic movements, and to learn from their capacity to find the path of least resistance. Allowing one part to become ill through pollution, mismanagement or overuse will cause the whole system to suffer. All the waters must be protected to ensure the health of the whole system – to the most insignificant jet.'

Dr Danièle Hromek is a Budawang woman of the Yuin nation – she has spent some time yarning with the Aboriginal Elders in Wianamatta to help translate cultural values into land use planning

2. About this document

This document describes the background and methods for developing a map of the natural blue grid in the Wianamatta-South Creek catchment. The natural blue grid forms part of the essential infrastructure requirements for delivering the Western Parkland City. It is made up of waterways, riparian vegetation communities, wetlands, and other water dependent ecosystems.

This document provides examples of how the map has been used to support the strategic planning of the Western Parkland City. It is a technical document, but it is intended for strategic planners and practitioners who may require the scientific evidence base for including the map in various planning instruments and studies. There are several large appendices at the end of the document to provide more detail on the data, field work modelling and analyses used in the mapping.

3. Background

Wianamatta-South Creek is located on the Cumberland Plain in Western Sydney, Australia. It is characterised as a floodplain with a network of perennial and intermittent flowing tributaries that collectively drain into the larger Hawkesbury-Nepean River system (Fig. 1). Over the next 40 years much of the creek's catchment will be urbanised to become part of the Western Parkland City, and home to over 1.5 million people (GSC, 2018).

The Western Parkland City is one of three cities described in the Greater Sydney Commission's Region Plan (A Metropolis of Three Cities), which is currently guiding planning and investment decisions on future housing, economic development and jobs in Greater Sydney. Unlike the other two cities, the Western Parkland City will be a new city centred around a new international airport. Considerable strategic planning of the urban footprint is underway to ensure that the Greater Sydney Commission's visions for the Western Parkland City are delivered. One strong vision is for Wianamatta-South Creek (and its tributaries) to become a cool green corridor through the Western Parkland City and be the core element of liveability and amenity for the residents. This vision relies on urban planners to explicitly integrate waterways into the design of the city and residential neighbourhoods, and for the waterways and other water dependent ecosystems to be healthy so they can provide the essential services and functions expected of a cool green corridor.

Currently, the Wianamatta-South Creek catchment is described as the most degraded catchment in the Hawkesbury-Nepean River system (H-N CMA, 2007). Historical vegetation clearing and urbanisation have significantly altered the hydrological and sediment regimes of the catchment, which in turn have altered the geomorphology and ecology of the waterways. This is reflected in recent river health assessments (AUSRIVAS, River Styles), which categorise Wianamatta-South Creek and its tributaries as being significantly or severely impaired (Fig. 1). As recognised in the Greater Sydney Commission's Region Plan, urbanisation of the Wianamatta-South Creek catchment has the potential to further degrade the waterways if stormwater, wastewater, and flooding regimes are not managed upfront through an integrated ecosystems or landscape led approach. This approach requires the waterways and hydrological cycle to be central considerations in both land use and water infrastructure planning. This approach differs from current land use planning practices, which are mostly fragmented and based on *post hoc* solutions that do not consider the broader catchment context and function. As described in a growing body of international literature, and in emerging planning policy in NSW (e.g. Design and Place State Environmental Planning Policy), an integrated ecosystems or landscape led approach to urban planning will result in sustainable, resilient and liveable cities e.g. Rotterdam (Frantzeskaki and Tilie, 2014), Singapore (Rowe and Lee, 2019).

In this present study, our specific objective was to create a map showing strategic planning priorities for protecting and improving the health of high ecological value waterways, riparian vegetation, and other water dependent ecosystems in the Wianamatta-South Creek catchment. Collectively, these natural elements are recognised as part of the Blue and Green Infrastructure Framework for the Western Parkland City, and as such, have been key considerations in the design of the Aerotropolis (WSPP, 2020; WSPP 2021).

The need for the map (and hence this study) originated from two whole of government initiatives that sought to protect and restore the waterways, riparian vegetation, and other water dependent ecosystems in the Wianamatta-South Creek catchment. The purpose of the first initiative was to develop the South Creek Corridor Strategy, to meet the requirements of a sectoral review under the *Infrastructure NSW Act 2011* (INSW, 2019). The map was used to inform the Strategic Options Business Case for Stage 1 of the review, specifically addressing Infrastructure NSW's objective of 'Protect and enhance high value environmental resources (flora, fauna, habitat, waterways), with due regard to the need for environmental connectivity along South Creek and its major tributaries'.

The second initiative is as part of an overarching Marine Estate Management Strategy 2018-2028 (MEMS) for the NSW Government to co-ordinate the management of the marine estate in accordance with the objects of the *Marine Estate Management Act 2014*. Outflows from the Wianamatta-South Creek catchment to the Hawkesbury-Nepean River are the largest within the system and have been identified as a key threat to the way the local communities value and use the waterways in the area. The map has directly informed two management actions under the MEMS related to implementing the NSW Government 'Risk-based framework for considering waterway health outcomes in strategic land use planning decisions' (Dela-Cruz *et al.*, 2017) in the Wianamatta-South Creek catchment. This Risk-based Framework has been recognised in the Greater Sydney Commission's Region Plan (and supporting District Plans) as an approach to managing cumulative impacts of urban development and improving the health of catchments and waterways. The planning priorities identified in the map have since been used to inform waterway health objectives, which are needed to implement the first step of the Risk-based Framework and have guided strategic planning criteria and benchmarks for protecting and restoring the natural blue grid and reducing stormwater and wastewater impacts on Wianamatta-South Creek and its tributaries (Dela-Cruz *et al.*, *in prep*).

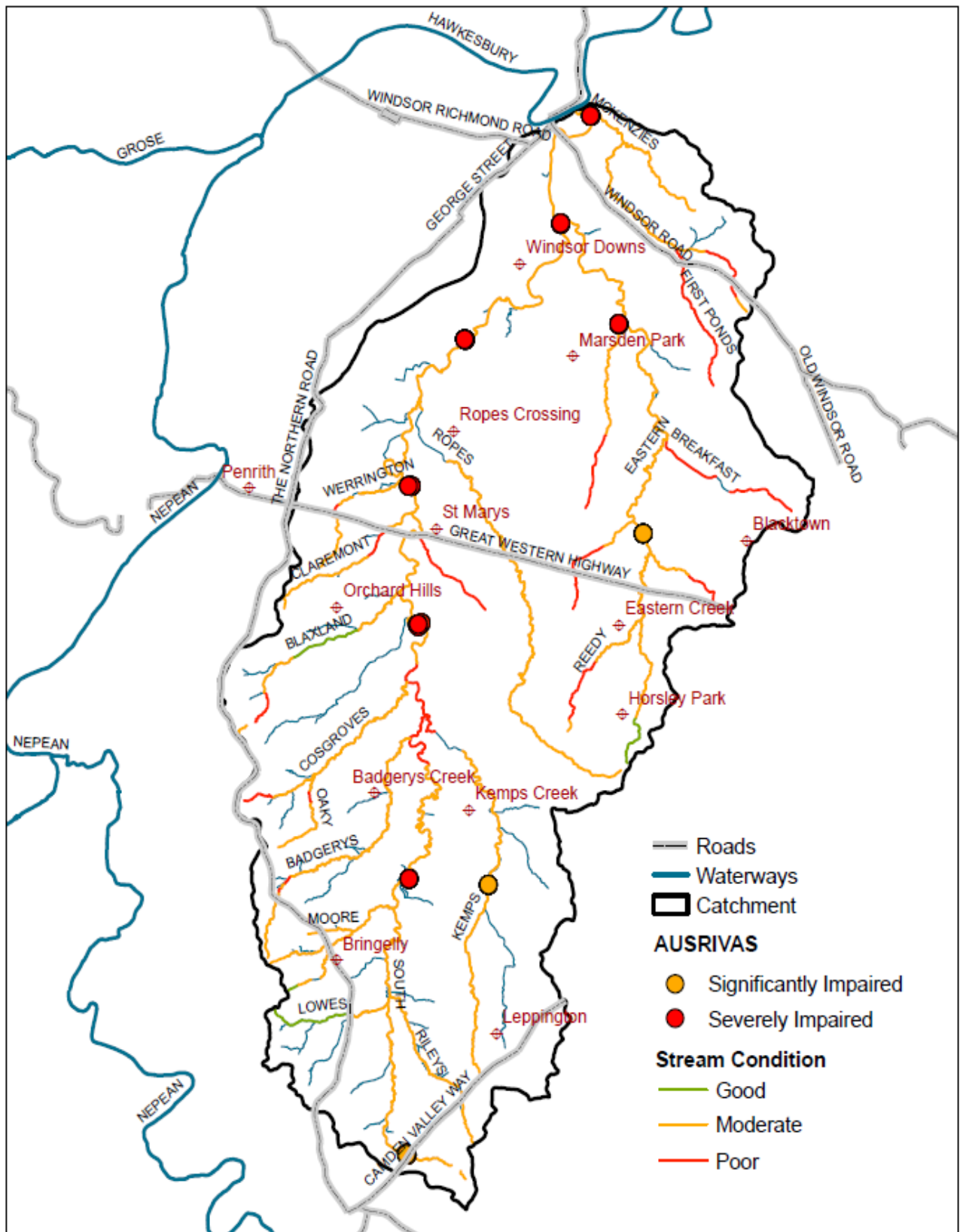


Figure 1 Wianamatta-South Creek catchment and ecological condition of major tributaries based on AUSRIVAS and River Styles assessments of stream condition

4. How was the map developed?

The general method for developing the map is summarised in Figure 2, and the following sections provide a brief description of the key steps in the method. Appendix 1 provides a summary of the dataset used to develop the map.

The rationale for the method is consistent with fundamental approaches to natural resource management, where protecting ecosystems of high ecological value and good ecological integrity is more cost-effective than retrofitting restoration activities later in the process (Keenleyside *et al.*, 2012).

Within the Wianamatta-South Creek catchment there are some waterways, riparian vegetation communities and water dependent ecosystems that are close to being in a reference or pristine state (e.g. 2018-2019 BCC Waterway Health Report Card). It is of particular significance however, that those in a degraded state, still form important habitat corridors for many species including those that are critically endangered (H-N CMA, 2007). Strategic planning priorities were therefore based on two planning goals, in which waterways, riparian corridors and other water dependent ecosystems are:

- i. protected because of their high ecological value (biodiversity, habitat) and good ecological integrity or condition
- ii. improved because they connect and help maintain the extent, cover and condition of the high ecological value waterways, riparian vegetation, and other water dependent ecosystems

4.1 Defining waterways and water dependent ecosystems

The waterways in the Wianamatta-South Creek catchment have been classified according to the Strahler Stream Classification system, which assigns waterways with an 'order' to reflect the number of tributaries associated with each waterway. For example, headwater streams are assigned an order number of 1 whereas Wianamatta-South Creek itself is assigned an order number of 6 to indicate that 5 other tributaries flow into it.

The Strahler Stream Classification system is recognised in the *Water Management Act 2000* (WM Act 2000) and *Fisheries Management Act 1994* (FM Act 1994) as it provides a system for setting riparian corridor widths or identifying aquatic habitat values (see Section 4.2). Overall, there are 540 kilometres (km) of mapped 1st order streams in the Wianamatta-South Creek catchment, 290 km of 2nd order, 138 km of 3rd order, 114 km of 4th order, 12 km of 5th order and 62 km of 6th order streams. Of these, the 3rd order streams and above are identified as being perennial, and the remaining lower order identified as intermittent or ephemeral (Fig. 3).

In addition to the waterways, the Wianamatta-South Creek catchment is characterised by three other types of water dependent ecosystems which we have classified in this study according to broad vegetation communities/groups. The riparian woodland vegetation community shown in Figure 3 covers a total area of over 30 km² in the Wianamatta-South Creek catchment. This community was considered distinct because of its dependence on waterways and shallow groundwater stores. The woody and non-woody wetland communities identified in Figure 3 are what are traditionally thought of as wetlands. They are vegetated, non-riverine or non-channel systems and include billabongs, swamps, bogs, springs, and soaks. The non-woody wetland community also includes artificial wetlands such as farm dams. Overall, there are a total 13 km² of woody and non-woody wetlands, respectively, that have been identified through a combination of existing mapping and satellite imagery (Appendices 1, 2).



Figure 2 Overview of method for developing map of strategic planning priorities for protecting or improving the natural blue-grid

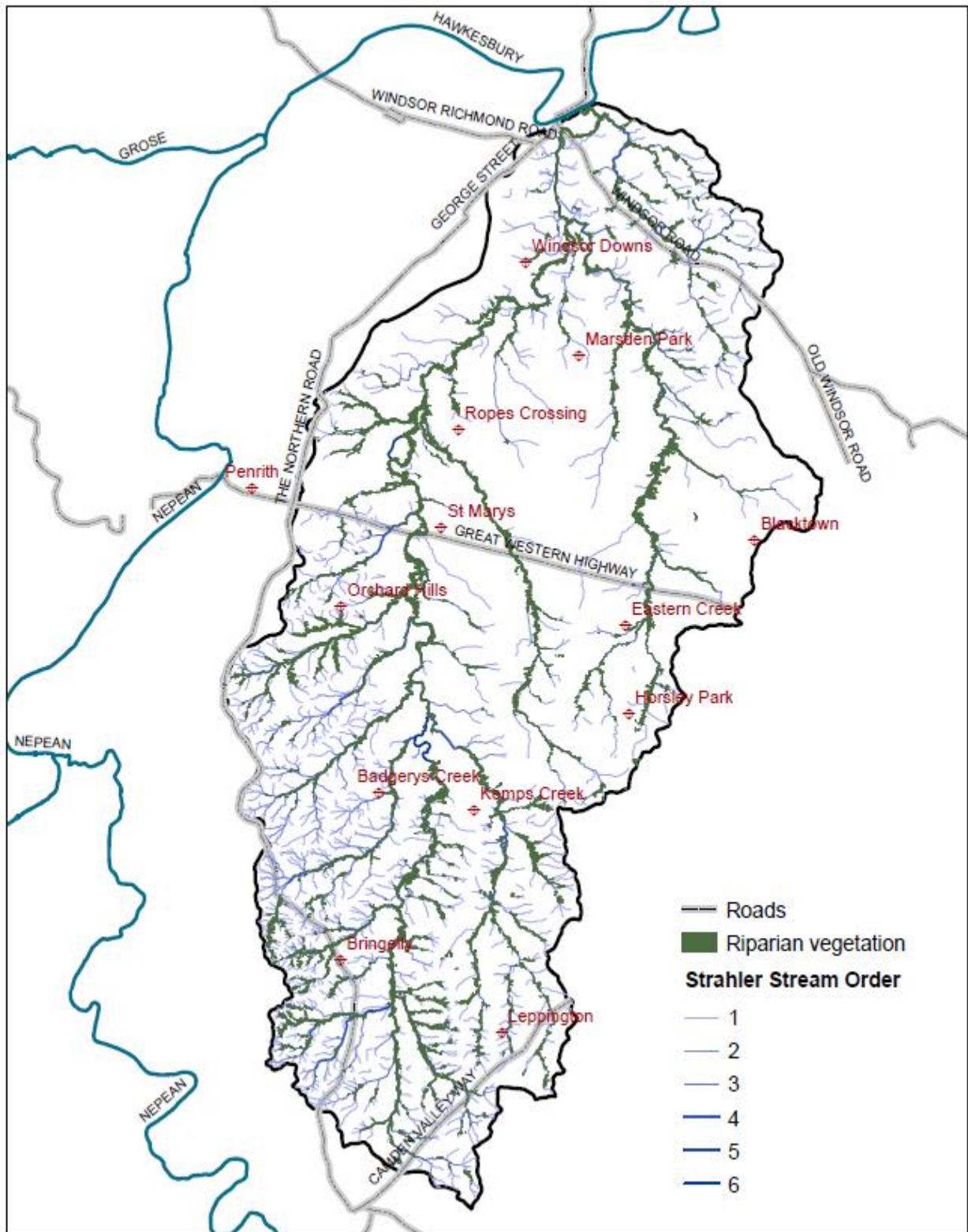


Figure 3a Waterways (Strahler Stream Order) and riparian vegetation in the Wianamatta-South Creek catchment

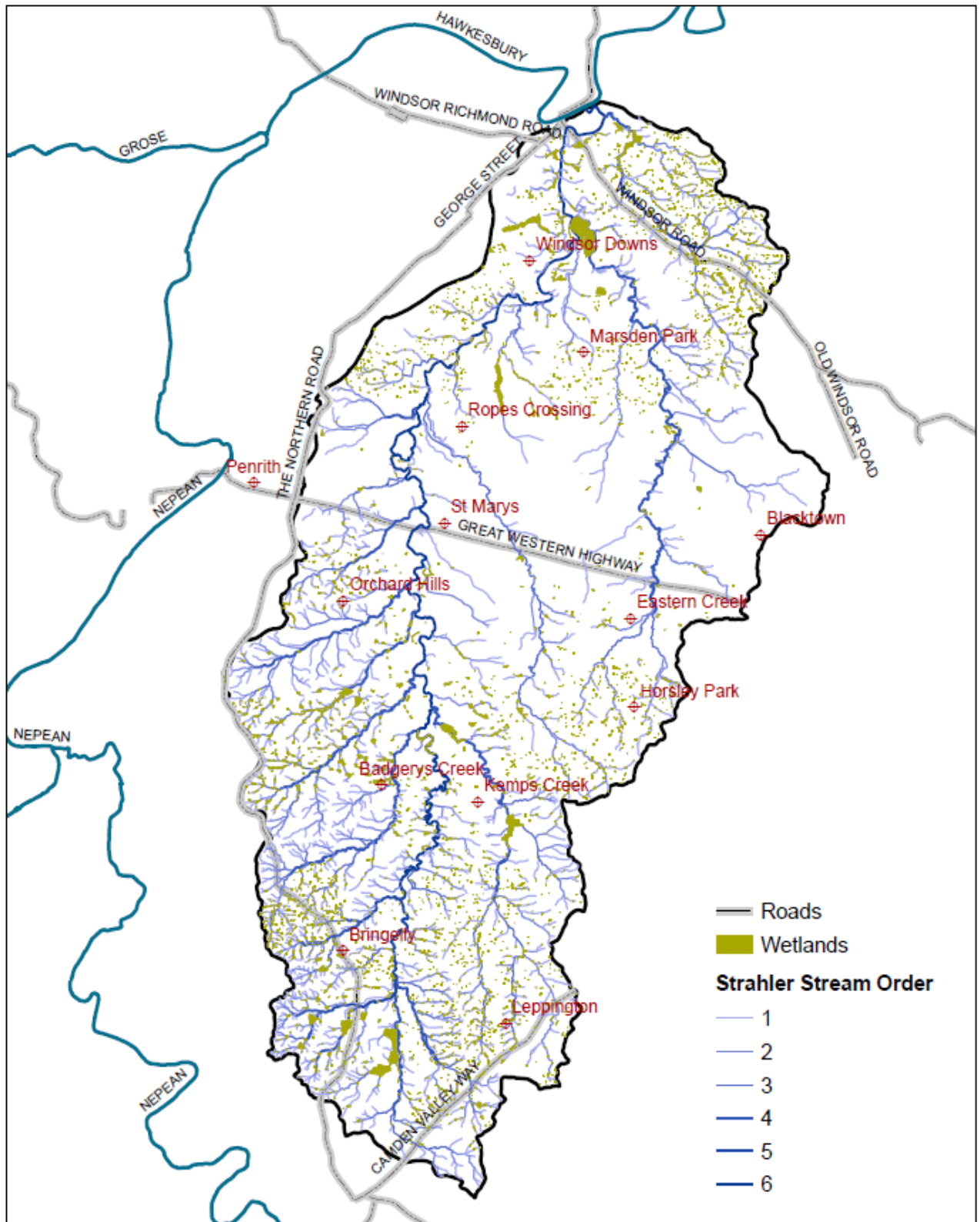


Figure 4b Waterways (Strahler Stream Order) and woody and non-woody wetlands in the Wianamatta-South Creek catchment

4.2 Defining high ecological values of the natural blue grid

Our definition for high ecological value waterways and water dependent ecosystems aligns with Commonwealth and State legislation, including the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act 1999)*, the *Biodiversity Conservation Act 2016 (BC Act 2016)*, and the *FM Act 1994*. These Acts provide schedules of endangered ecological communities and threatened species that require protection in the Wianamatta-South Creek catchment. The schedules were used as a starting point for defining the high ecological value waterways and water dependent ecosystems.

The *BC Act 2016* also specifies a Biodiversity Information Program, to assess the management of biodiversity into the future and track progress towards achieving the main objects of the Act. A list of indicators for defining biodiversity and ecological integrity is available for terrestrial ecosystems (OEH & CSIRO 2019), with work underway to develop a list for freshwater ecosystems. The preliminary list for freshwater ecosystems includes riparian vegetation and water dependent species of frogs, birds, bats, and reptiles. The extent and integrity of these preliminary indicators were mapped specifically for this study using habitat suitability models and remote sensing products (Appendix 2). The list also includes macroinvertebrates which are currently used to assess river health across the state. In this study, macroinvertebrate data were acquired to derive a biodiversity index.

To help implement the *WM Act 2000*, the Department of Primary Industries – Water developed the NSW River Condition Index to quantify long-term river health and inform water allocations and catchment planning. The index includes a mapped waterway layer defining High Ecological Value Aquatic Ecosystems (HEVAE; Appendix 1), which was used in this study to account for the requirements of the *WM Act 2000*. The HEVAE have been defined according to four key criteria, which were determined by the Commonwealth - distinctiveness, diversity, naturalness, and vital habitat. The index also relies on the River Styles Framework to map and identify river/stream types that need to be conserved because of their instream biodiversity value and good geomorphic condition.

The *Protection of Environmental Operations Act 1997 (POEO Act 1997)* is another piece of legislation relevant to this study because it requires industrial and wastewater discharges to be managed according to (protection and restoration of) the community environmental value and uses of waterways. These are what the community believes is important for a healthy ecosystem, for public benefit, welfare, safety, or health. The community environment values and uses for Wianamatta-South Creek were determined in the late '90s, as part of the Healthy Rivers Commission inquiry into the Hawkesbury-Nepean River system (Appendix 1). These are currently being reviewed as part of the delivery of the application of the Risk-based Framework under the MEMS and Aerotropolis Precinct Plan (Dela-Cruz *et al.*, *in prep*).

A summary of all blue elements/indicators to define high ecological value waterways, riparian vegetation communities and other water dependent ecosystems is provided in Table 1. The relevant legislation and policies that currently use the indicators are also provided in Table 1.

Table 1 Blue elements to define high ecological value waterways and water dependent ecosystems in Wianamatta-South Creek

ECOSYSTEM	DESCRIPTION	BLUE ELEMENT	LEGISLATION &/OR POLICY
TERRESTRIAL RESERVES	National Parks Wildlife Service and Crown Land Estate dedicated to conservation	Reserves	<i>National Parks and Wildlife Act 1974; Crown Lands Act 1989</i>
WATERWAYS	Macroinvertebrate (biodiversity)	Shannon-Weiner Index	<i>Water Management Act 2000</i>
WATERWAYS	River Biodiversity Condition Index	River Biodiversity Condition Index	<i>Water Management Act 2000</i>
WATERWAYS	High Ecological Value Aquatic Ecosystems	HEVAE	<i>Water Management Act 2000</i>
WATERWAYS	Key Fish Habitat	Key Fish Habitat	<i>Fisheries Policy - Fisheries Management Act 1994</i>
WATERWAYS	Fish nativeness of moderate or higher	Fish Nativeness	<i>Fisheries Policy - Fisheries Management Act 1994</i>
WATERWAYS	Fish condition of moderate or higher	Fish Condition	<i>Fisheries Policy - Fisheries Management Act 1994</i>
WATERWAYS	Fourth order or greater streams	Strahler	<i>Biodiversity Conservation Act, 2016</i>
WATERWAYS	Chain of Ponds as per the River Styles assessment	River Styles	<i>Water Management Act 2000</i>
WATERWAYS	Geomorphic condition as per the River Styles assessment	River Styles	<i>Water Management Act 2000</i>
WATERWAYS	Recovery potential of high or conservation as per the River Styles assessment	River Styles	<i>Water Management Act 2000</i>
WATERWAYS	Groundwater Dependant Ecosystems reliant on surface expression of groundwater	Groundwater Dependent Ecosystem	<i>Water Management Act 2000</i>
WATER DEPENDENT ECOSYSTEMS	Coastal freshwater lagoons of the Sydney Basin Bioregion and South East Corner Bioregion	Endangered Ecological Community	<i>Biodiversity Conservation Act, 2016</i>
WATER DEPENDENT ECOSYSTEMS	Forest Red Gum – Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	Endangered Ecological Community	<i>Biodiversity Conservation Act, 2016</i>
WATER DEPENDENT ECOSYSTEMS	Grey Myrtle dry rainforest of the Sydney Basin Bioregion and South East Corner Bioregion	Endangered Ecological Community	<i>Biodiversity Conservation Act, 2016</i>

ECOSYSTEM	DESCRIPTION	BLUE ELEMENT	LEGISLATION &/OR POLICY
WATER DEPENDENT ECOSYSTEMS	Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, Sydney Basin Bioregion	Endangered Ecological Community	<i>Biodiversity Conservation Act, 2016</i>
WATER DEPENDENT ECOSYSTEMS	Local Environment Plan riparian lands and watercourses	Riparian Lands and Watercourses	Standard Instrument Order 2006
WATER DEPENDENT ECOSYSTEMS	Local Environment Plan environmentally sensitive areas	Riparian Lands and Watercourses	Standard Instrument Order 2006
WATER DEPENDENT ECOSYSTEMS	Environmental Planning Instrument - wetlands	EPI-Wetlands	Standard Instrument Order 2006
WATER DEPENDENT ECOSYSTEMS	Riparian vegetation	Riparian Vegetation	<i>Biodiversity Conservation Act, 2016; NSW Wetlands Policy</i>
WATER DEPENDENT ECOSYSTEMS	Wetlands, including farm dams	Wetland	<i>Biodiversity Conservation Act, 2016; NSW Wetlands Policy</i>
WATER DEPENDENT ECOSYSTEMS	Groundwater Dependant Ecosystems reliant on sub-surface expression of groundwater	Groundwater Dependent Ecosystem	<i>Water Management Act 2000</i>
WATER DEPENDENT ECOSYSTEMS	Frog sightings (threatened, critically endangered, vulnerable)	Threatened Flora Sightings	<i>Biodiversity Conservation Act, 2016</i>
WATER DEPENDENT ECOSYSTEMS	Bird sightings (threatened, critically endangered, vulnerable)	Threatened Flora Sightings	<i>Biodiversity Conservation Act, 2016</i>
WATER DEPENDENT ECOSYSTEMS	Bat sightings (threatened, critically endangered, vulnerable)	Threatened Flora Sightings	<i>Biodiversity Conservation Act, 2016</i>
WATER DEPENDENT ECOSYSTEMS	Flora sightings (threatened, critically endangered, vulnerable)	Threatened Fauna Sightings	<i>Biodiversity Conservation Act, 2016</i>
WATER DEPENDENT ECOSYSTEMS	Important Bird Habitat	Community environmental value	Used in various environmental legislation and planning policy
WATER DEPENDENT ECOSYSTEMS	Tree Frog Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy
WATER DEPENDENT ECOSYSTEMS	Ground and Burrowing Frogs Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy

ECOSYSTEM	DESCRIPTION	BLUE ELEMENT	LEGISLATION &/OR POLICY
WATER DEPENDENT ECOSYSTEMS	Flying Fox Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy
WATER DEPENDENT ECOSYSTEMS	Microbats Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy
WATER DEPENDENT ECOSYSTEMS	Southern Myotis (Fishing Bat) Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy
WATER DEPENDENT ECOSYSTEMS	Emergent Vegetation Bird Foragers Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy
WATER DEPENDENT ECOSYSTEMS	Large Bird Waders Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy
WATER DEPENDENT ECOSYSTEMS	Small Bird Waders Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy
WATER DEPENDENT ECOSYSTEMS	Open Water Bird Foragers Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy
WATER DEPENDENT ECOSYSTEMS	Riparian Vegetation Bird Foragers Potential Habitat	Community environmental value	Used in various environmental legislation and planning policy

4.3 Datasets

A range of existing spatial datasets (digital maps) and local field measurements were collated from state and local government agencies and utilities to inform/quantify the elements of the natural blue grid listed in Table 1. Some datasets were directly usable, while others required additional analysis such as spatial extrapolation to ensure the dataset represented the entire Wianamatta-South Creek catchment. A summary of all datasets and how they were used and analysed is provided in Appendix 1.

4.4 Prioritisation criteria

The principles of systematic conservation planning (Margules and Pressey, 2000) were used to prioritise which waterways, riparian vegetation communities and other water dependent ecosystems should be protected or improved. These principles ensure that protected areas are comprehensive, representative, adequate, efficient, flexible, irreplaceable, and complementary. The first three principles are collectively known as the CAR principle, and have been adopted by the Commonwealth and all state and territory governments to define key criteria for developing national reserve systems (National Reserve System). The CAR principle has been used as criteria for identifying priority conservation lands (for investment) in the Cumberland Plain, and is also reflected in a range of mandatory requirements for establishing biodiversity offsets under the *BC Act 2016* (OEH, 2018). A general definition of the CAR principle, and the other related principles, is summarised in Kukkala and Moilanen (2013).

To operationalise the systematic conservation planning principles, a range of spatial prioritisation tools have been developed to assist decisions on areas for protection. Marxan (www.uq.edu.au/marxan) is the most used widely tool for systematic conservation planning globally. It allows users to explicitly integrate many of the principles described above as criteria for prioritisation. Marxan was used to underpin the rezoning of the Great Barrier Reef Marine Park (Lewis et al., 2003) and has been used to inform management areas for water allocations of floodplains in the Murray-Darling Basin of the *WM Act 2000* (e.g. DPIE, 2020). Marxan was used in this study to create a single integrated map of strategic planning priorities for protection or improvement of the high ecological value waterways, riparian vegetation, and other water dependent ecosystems. Appendix 3 provides the details of how Marxan was used, including the scale of application, the criteria for prioritisation and additional datasets to account for the CAR principle. Of significance, are numerical management targets, which are needed in Marxan to quantify the extent to which each blue element (listed in Table 1) should be protected. Past efforts to set targets for the Cumberland Plain have been fraught with difficulties due to competing land uses, high land values, high management costs and the continued threat of land clearing and fragmentation. A 15% conservation target for extant endangered ecological communities in the Cumberland Plain was in place prior to the *BC Act 2016*. This target has now been increased to 30% of the original (pre-1750) extents of endangered ecological communities to directly align with the targets recommended in the International Union for Conservation of Nature (IUCN) World Parks Congress. Other targets currently in place for the Cumberland Plain include the Aichi Biodiversity Target 11, which recommends 17% of inland waterways be conserved, particularly those important for biodiversity and ecosystem services (OEH, 2008; OEH, 2018). A 100% conservation target for the rarest and most intact stream types has also been recommended to recognise the confinement of these stream types to the Cumberland Plain (H-N CMA, 2007). Adoption of this latter target would help to ensure that prioritised areas for protection are representative.

Table 2 provides a summary of the management targets used in this study. The appropriateness of these specific targets for informing the South Creek Corridor Strategy and waterway objectives for Wianamatta-South Creek (to implement the Risk-based

Framework required under the MEMS) was agreed in a stakeholder workshop attended by Infrastructure NSW, Sydney Water, the former Office of Environment Heritage, NSW EPA and an independent reviewer with recognised expertise in defining the ecological values of waterways in the Wianamatta-South Creek catchment. The targets were also presented to the Department of Primary Industries – Fisheries in a separate workshop. In both workshops, the stakeholders were provided with three scenarios to demonstrate the sensitivity of outcomes to the management targets. All stakeholders agreed that the most pragmatic approach was to select the management targets shown in Table 2 since they align with targets being used to prioritise land investments under the Biodiversity Offset Scheme of the *BC Act 2016*.

Table 2 Management targets to quantify the extent of high ecological value waterways and water dependent ecosystems to protect in the Wianamatta-South Creek catchment.

ECOSYSTEM	BLUE ELEMENT	MANAGEMENT TARGET
WATERWAYS	River Styles	100%
	Macroinvertebrates diversity	17%
	River Biodiversity Condition Index	17%
	Key Fish Habitats, and other fish measures	17%
	Strahler	17%
	High Ecological Value Aquatic Ecosystems	17%
WATER DEPENDENT ECOSYSTEMS	Endangered Ecological Communities	30%
	Riparian vegetation	30%
	Woody and non-woody wetlands	30%
	Groundwater Dependent Ecosystems	17%
	Frog, bird, and bat habitats	17%
	Threatened Species sightings	100%

4.5 Ground-truthing

A range of validation datasets were collected to assess the accuracy of the map. The datasets include field survey data, independent desktop analyses of sites, and the use of existing field survey datasets collated from the [BioNet Vegetation Survey database](#), Blacktown City Council and the Conservation and Sustainability Branch of DPIE.

A total 330 new field survey sites were assessed across the Wianamatta-South Creek catchment, specifically for this study, between March and August 2019 (Appendix 4). The new field survey sites were combined with 66 field survey sites from previous studies, bringing the total number of validation sites to 396.

The accuracy assessment was based on the amount of agreement between the validation datasets and the mapped values (Stehman and Czaplewski, 1998). The results are expressed as overall accuracy (number of agreements) and Kappa statistics, which quantifies the agreement due to chance. In addition, confusion matrices were used to identify the sources of error.

The results show that the map has an overall accuracy of greater than 80%, which is typically deemed acceptable for maps to support natural resource planning (Stahman and Czaplewski, 1998). The accuracy of the individual datasets varied with some showing greater agreement with the validation datasets than others. In general, the validation datasets showed a greater number and extent of indicators than is currently mapped (i.e. greater ecological value).

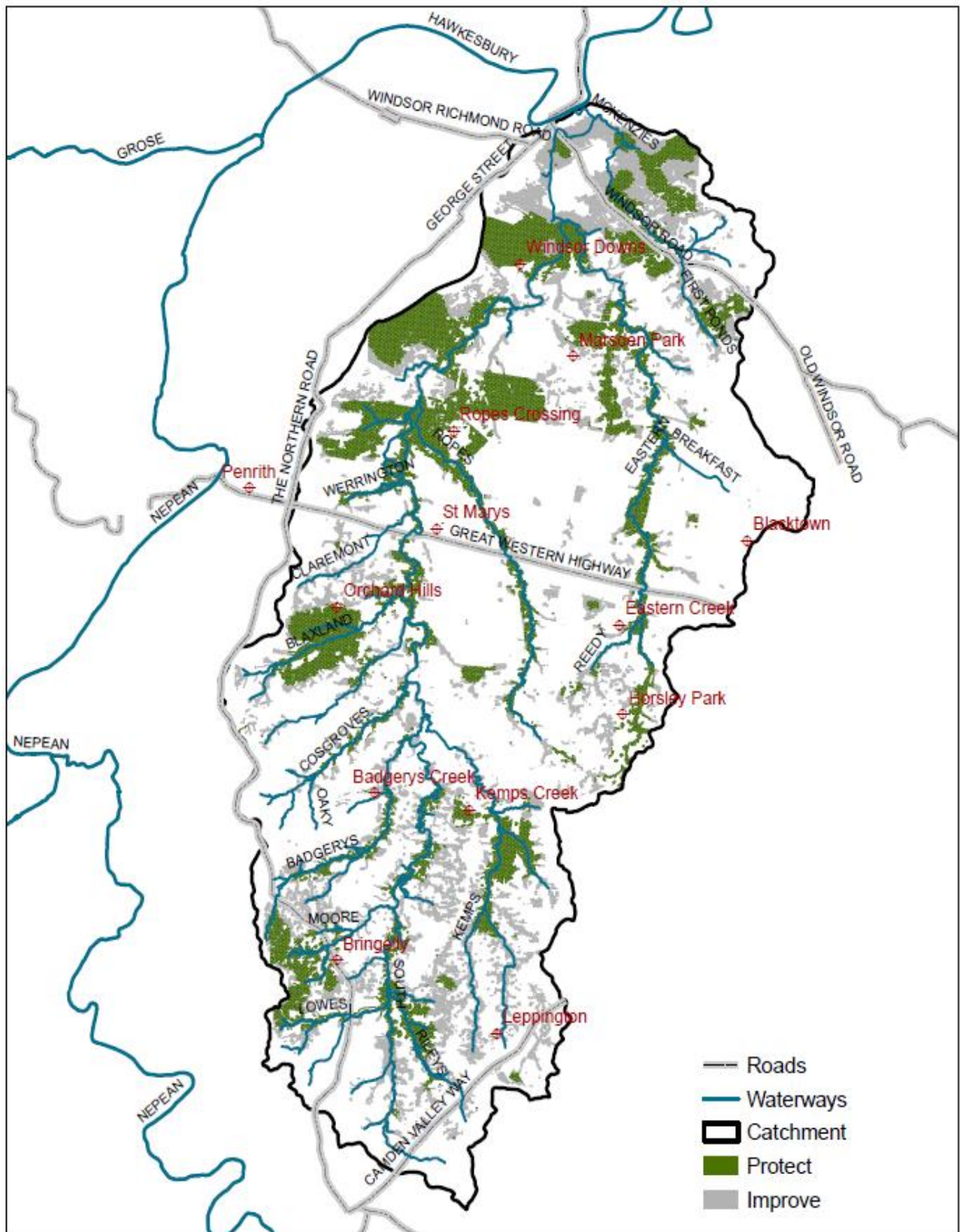


Figure 5 Strategic planning priorities for protecting or improving the natural blue-grid in the Wianamatta-South Creek catchment

5. What does the map show?

The map shown in Figure 4 brings together datasets used by the Commonwealth, State and Local Governments to implement various legislation and policies for managing waterways and (water) biodiversity in NSW (Appendices 5, 6). It should not replace the intent of the original datasets or mapping but rather used as a diagnostic tool to identify strategic planning priorities, as has been done in this study and in the applications described below.

The map consists of two planning goals that can be aligned with the objectives of the Environment and Recreation Zone of the State Environmental Planning Policy (Western Sydney Aerotropolis) 2020.

The planning goal identified as 'protect' aligns with zone objectives to:

- protect, manage and restore areas of high ecological, scientific, cultural or aesthetic values
- protect and conserve the environment, including threatened and other species of native fauna and flora and their habitats, areas of high biodiversity significance and ecological communities

The planning goal identified as 'improve' aligns with zone objectives to:

- protect the ecological, scenic and recreation values of waterways, including Wianamatta–South Creek and its tributaries
- provide a range of recreational settings and activities and compatible land uses

The map identifies a total of 102 km² of 'protect' areas, of which 12.5% lie within the established reserves and parks of the Wianamatta-South Creek catchment and 23% in areas of Existing Native Vegetation (ENV) designated to be protected (on non-certified land) in accordance with the Order to confer biodiversity certification under the State Environmental Planning Policy (Sydney Region Growth Centres) 2006. The remaining 64.5% of protect areas are located around large stands of remnant Cumberland Plain vegetation (Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion) that are water dependent. Figure 5 provides a series of photographs showing the natural character of the 'protect' areas. The photograph shown in Figure 5a was taken from the Little Creek tributary, which is located within a predominantly naturally vegetated catchment. The structure of the riparian vegetation is intact with obvious ground cover, mid-story and canopy cover sections. The vegetation buffer is extensive and dominated by native grassland. The surrounding native trees are classed as Groundwater Dependent Ecosystems. The photograph shown in Figure 5b was taken at South Creek above the Richmond Road bridge. It is characteristic of a highly sensitive Key Fish Habitat (Type 1), that contains in-stream gravel beds, rocks greater than 500 mm in two dimensions, snags greater than 300 mm in diameter or 3 metres in length and the presence of native aquatic plants. The photograph shown in Figure 5c depicts a remnant *Eucalyptus tereticornis* which has developed hollows. The hollows are essential habitat for a variety of birds and mammals in the catchment. The photograph shown in Figure 5d shows a small wetland branching off from Badgerys Creek. The wetland has an abundance of native macrophytes and riparian vegetation. Entry to the wetland is shallow, falling to a maximum depth of approximately 30 cm in the centre. These characterises are conducive to supporting a diverse frog community.

The 'improve' areas also include important habitats but not to the same extent and are in poorer condition. Figure 6a represents a reach in an altered state/relatively poorer condition, however there are significant opportunities for ecological improvement. The biodiversity is low with vegetation consisting mainly of pasture grasses with a narrow fringe of *Casuarina cunninghamiana*. However due to the wide riparian buffer (> 500m), there is an opportunity to re-vegetate to improve the ecological condition of the reach and provide habitat through

nest boxes which mimic natural hollows. Under the Key Fish Habitat classification, the reach shown in the photograph is classed as Type 3, Class 3 with low/sporadic flows and low instream habitat complexity. Field measurements, however, show a good potential for improvement through enhancement of the existing overhanging vegetation and instream woody debris.

Areas that have not been attributed with a planning priority of 'protect' or 'improve' are those in the most degraded state (Figure 6b). These areas have low vegetation coverage, usually dominated by invasive species. The areas are typically susceptible to illegal dumping and can have a high volume of litter. Owing to their disturbed state, these areas have low habitat value and support limited biodiversity. Streams in these areas are degraded, with poor water quality and altered hydrology. Accordingly, Key Fish Habitat scores are typically low, indicating streams are unlikely to support diverse aquatic life.

a) Riparian vegetation



b) Key Fish Habitat



c) Habitat for birds and mammals



c) Habitat for frogs



Figure 6 Characteristic features of waterways and water dependent ecosystems in the 'protect' areas of the map of the natural blue grid

a) improve



b) degraded



Figure 7 Characteristic features of waterways and water dependent ecosystems in the 'improve' areas of the map of the natural blue grid or in areas that have not been recognised in the map due their degraded state

6. How has the map been used?

As an urban parkland, the South Creek Corridor Strategy was designed to respond to its climatic and landscape settings, with areas of higher density and high-quality public spaces orientated towards (cooler) waterways. The map was used to inform the key environmental indicators and associated extent of beneficial costs for the economic appraisal of Infrastructure NSW Strategic Options Business Case for the South Creek Corridor Strategy (INSW, 2019). The net benefits of protecting and improving the natural blue grid were estimated to be over \$1 billion and include benefits for communities both within the South Creek Corridor (e.g. bass fishing) and downstream in the Nepean River and out towards the ocean. Since this work, the map has been used to inform the Western Sydney Place Infrastructure Compact (GSC, 2020a), Aerotropolis Precinct Plan (WSPP 2021, Sydney Water 2021a, b), priorities for the place-based delivery strategy for the Wianamatta South Creek precinct (DPIE, 2021a), and the Liverpool City Council Vegetation Strategy for Riparian Lands (CTENVIRONMENTAL, 2020). The following sections provide an overview of the first two applications listed.

6.1 Western Sydney Place Infrastructure Compact

The Place Infrastructure Compact (PIC) is a new model, developed by the Greater Sydney Commission, to identify the most effective way of sequencing infrastructure for urban growth over time. The model is evidence and outcomes focussed and looks at a place holistically by identifying both city building infrastructure such as roads, public transport and water services, and city making infrastructure underpinned by environmental and social needs.

The PIC for Western Sydney considered up to 28 precincts within the Aerotropolis and Greater Penrith and Eastern Creek urban growth areas. The map was used to identify, locate and cost natural blue infrastructure projects, specifically for waterway management ($\geq 2^{\text{nd}}$ Order streams) and revegetation of riparian corridors as required under the NSW Office of Water specifications for vegetated riparian zones (DPI – Office of Water, 2012). The costs for the ‘protect’ areas were lower than costs for ‘improve’ areas, on the assumption that ‘protect’ areas are in relatively good condition (integrity) and therefore only need to be enhanced through revegetation and weeding. Costs for ‘improve’ areas included stabilisation of stream banks, through both revegetation and armouring. Costs were assigned to all extant waterways and riparian corridors, and hence, represented the largest proportion (37.5%) of the total land area required for infrastructure within the PIC. However, the total cost of the natural blue infrastructure projects was only 16.4% of all capital costs, with unit costs relatively lower than those for city building infrastructure.

The individual blue elements making up the map were used as the basis for monitoring against the Greater Sydney Commission’s place outcome ‘Scenic productive and resilient landscapes: a city in its landscape’. For example, a metric to monitor the benefits of investments for enhancing extant water dependent vegetation through revegetation and weeding was based on field assessments of vegetation integrity, following the requirements under the Biodiversity Assessment Method (OEH, 2018). The baseline assessment for this metric indicated that the proportion of water dependent vegetation in the PIC area in excellent condition is 18.4%, in good condition 11.3%, fair condition 21.3%, poor condition 31.3%, and very poor condition 17.8%. For waterways, the baseline assessment indicated that the water quality at representative sites was predominantly (98%) poor. Note that these metrics are directly related to the extent of impermeable (i.e. hard) surfaces, which has been used by the Greater Sydney Commission as a measure for ‘water in the landscape’ and reducing urban heat (see GSC 2020b, Chirgwin and Dela-Cruz 2021).

6.2 Aerotropolis Precinct Plan – Riparian Corridors Assessment and Stormwater and Water Cycle Management

Requirements for protecting and restoring waterways and riparian vegetation are identified in almost all planning elements of the Aerotropolis Precinct Plan, from Aboriginal heritage and the Blue and Green Infrastructure Framework to tree canopy cover, linear parks and urban typologies. The Western Sydney Aerotropolis (Initial Precincts) Riparian Corridors Assessment (WSARCA – Sydney Water, 2021a) effectively operationalises the waterway management and riparian corridor revegetation projects identified in the Western Sydney PIC. The WSARCA used the ‘protect’ and ‘improve’ areas of the map to develop guiding principles for identifying the specific waterways and associated riparian corridors that will be retained in the priority precincts of the Aerotropolis.

Similar to the Western Sydney PIC, the WSARCA has used the ‘protect’ and ‘improve’ areas of the adapted map to assign indicative costs for revegetation, weed control and bank stabilisation of waterways. Assumptions for costings in the Western Sydney PIC were validated in the WSARCA using the field survey data collected in this study (Appendix 4). This validation confirmed that ‘protect’ areas had relatively greater native vegetation extent and lower weed cover compared to the ‘improve’ areas. Under the WSARCA, it was further assumed that waterways and riparian corridors outside of the ‘protect’ and ‘improve’ areas were of poorest condition and likely to require greater capital input to improve.

The map has also guided the locations of wetlands, stormwater detention basins and water sensitive urban design in the Aerotropolis (Sydney Water, 2021b). This infrastructure has been placed mostly around the periphery of the map, so as to work as closely as possible with the landscape but providing enough storage of stormwater to minimise changes to the stream hydrology and minimise streambank and bed erosion.

6.3 Aerotropolis Precinct Plan – Performance outcomes for protecting and restoring the natural blue grid and managing stormwater

Performance outcomes for protecting and restoring the natural blue grid and managing stormwater in the Aerotropolis are described in a companion study (Dela-Cruz *et al.*, *in prep*). They were based on the habitat, water quality and flow related requirements of the individual blue elements making up the map. Table 2 provides an example for one blue element of the map, which was used to represent the high ecological value of fish in the Wianamatta-South Creek catchment. In this example, the presence of Key Fish Habitat ‘switched on’ requirements under the *FM Act 1994*, and the NSW Department of Primary Industry – Fisheries Policy and Guidelines for Fish Conservation and Management (DPI-Fisheries, 2013). Three types of Key Fish Habitats have been defined in NSW depending on their sensitivity to land use activities, including urban development. The field surveys, which were undertaken to ground truth the map, showed that all three types of Key Fish Habitat are present in the Wianamatta-South Creek catchment (Appendix 5). The dominant combination of Key Fish Habitat in the Aerotropolis is Type 2 Class 2, and as shown in Table 2, existing policy and guidelines can then be used to inform the type of habitat restoration and the extent of stormwater quantity and quality required to protect this specific ecological value.

The ‘classification for fish passage’ can be used to inform the timing and duration of stormwater discharges from development sites in the Aerotropolis (Dela-Cruz *et al.*, *in prep*). Similarly, the water quality requirements of fish can be used to inform the quality of stormwater discharges from development sites. Generally, the NSW Department of Primary

Industry – Fisheries requires no net impact of land based pollutants on Key Fish Habitats, and as default, specify ambient concentrations of nutrients, sediments and other water quality parameters described in the Australia and New Zealand Environment Conservation Council Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ, 2000).

Table 3 Basis for water quality and flow related objectives for protecting Key Fish Habitat in the Aerotropolis – adapted from DPI – Fisheries, 2013

BLUE ELEMENT	TYPE AND SENSITIVITY CLASSIFICATION	CLASSIFICATION FOR FISH PASSAGE	WATER QUALITY
Key Fish Habitat	Type 1 – highly sensitive Type 2 – moderately sensitive Type 3 – minimally sensitive e.g. Type 2, relevant to Wianamatta Freshwater habitats and brackish wetlands, lakes and lagoons other than those defined in Type 1, and Weir pools and dams up to full supply level where the weir or dam is across a natural waterway	Class 1 – major Class 2 – moderate Class 3 – minimal Class 4 – unlikely e.g. Class 2 Non-permanently flowing (intermittent) stream, creek or waterway (generally named) with clearly defined bed and banks with semi-permanent to permanent waters in pools or in connected wetland areas. Freshwater aquatic vegetation is present. Type 1 and 2 habitats present.	Nutrients, Dissolved Oxygen, pH, turbidity, temperature, salinity chemical contaminants – as required for breeding, feeding and maintaining quality of habitat. Default is Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 ('ANZECC guidelines')

6.4 Strategic Alignment with the Greener Places Design Guide

The planning goals outlined in this study to 'protect' or 'improve' waterways and water dependent ecosystems supports the design principles of the NSW Government Architect's Greener Places Design Guide, which is a key component of the Design and Place State Environment Planning Policy. This guide provides principles for designing urban ecosystems and explicitly recognises the role of waterways in shaping our urban environment and supporting natural biodiversity. The 'protect' areas in our map of the natural blue grid in Wianamatta-South Creek directly align with the 'protect and enhance' strategy of the Green Places Design Guide. This strategy specifies that the design process should start with protecting what's already there, specifically enhancing and restoring the health of the existing remnant ecosystems to prevent further habitat and biodiversity loss. The 'improve' areas in our map of the natural blue grid directly align with the 'improve and create' strategy of the guide. This strategy specifies that the design process should improve areas to a new urban condition where the area cannot be restored, and to create habitat linkages within a riparian corridor to support connectivity.

An example of how the 'protect' and 'improve' areas of the map have been used to design the indicative layout plan for the Aerotropolis Core Precinct in the Aerotropolis is shown at Appendix 3, Figure 10.

7. Natural blue grid mapping for Greater Sydney

As a result of this study, the Environment Energy and Science Group of DPIE developed a new series of natural blue grid maps for each Local Government Area in the Greater Sydney Region and for the Wilton and Greater Macarthur Growth Areas located south of the Wianamatta-South Creek catchment (Dela-Cruz *et al.*, 2021). This new series of maps were designed to support delivery of Strategies 25.1 and 25.4 of the Greater Sydney Region Plan (GSC, 2018), which are to protect environmentally sensitive waterways and the coastal environment and reinstate more natural conditions in highly modified urban waterways, respectively.

Similar to what was produced in this study, this new series of natural blue green maps brings together the blue elements (indicators) that are recognised as high ecological value in each area. The new series of maps do not identify 'protect' and 'improve' areas, because these need to be delineated through specific criteria relevant to the area and to the intended use of the map. However, the new series of maps includes a map attribute titled 'TVALUE' to help with priority setting. The TVALUE was developed as a relative heuristic measure of the ecological value of an area. It simply represents the total number (value) of blue elements present within a one hectare planning grid, with the assumption that the greater the TVALUE the greater number of blue elements present and hence greater ecological value of the area. Examples of how this new series of map can be used in strategic planning are available in the Land Use and Infrastructure Implementation Plan for Wilton and Greater Macarthur (DPE 2018a,b), the Macquarie Park Place Strategy and accompanying Strategic Infrastructure and Service Assessment (DPIE, 2021b; GSC, 2021), and the Northern Beaches Council Local Strategic Planning Statement (NBC, 2020).

7.1 Access the maps from SEED

SEED is the NSW Government's central resource for Sharing and Enabling Environmental Data. It was developed for the NSW community in a collaborative effort between government agencies to provide an accessible and reliable platform for environmental data.

In SEED, we have released:

- natural blue grid for the Wianamatta-South Creek ([add link](#))
- new series of natural blue grid mapping for the Greater Sydney Region ([High Ecological Value Waterways and Water Dependent Ecosystems – Greater Sydney Region](#))

In all cases, the maps are provided as a shapefiles and are accompanied by a table summarising the blue elements (or indicators) that make up the map.

8. Acknowledgments

We are very grateful to the many contributors of data to inform and/or validate our map of high ecological value waterways and water dependent ecosystems in the Wianamatta-South Creek catchment:

- Blacktown City Council (Keysha Milenkovic, Tahina Ahmed), Liverpool City Council (Maruf Hossain), Penrith City Council and Camden Council (Aditi Verma) provided field survey data from their long-term monitoring of water quality, riparian health and/or iconic species such as bats.
- Department of Primary Industry – Fisheries provided in kind support to collect new field survey data on Key Fish Habitat and developed new spatial datasets to inform the map. We thank Chris Walsh and Karen Danaher for training our monitoring team and collecting the fish samples, and Marcus Riches for developing spatial datasets for the map.
- Department of Primary Industry – Water provided access to their HEVAE and River Styles datasets. We thank Allan Raine and Fergus Hancock for providing early access to the new datasets.
- Sydney Water for providing datasets on water quality and macroinvertebrates.
- Water, Wetlands and Coastal Science Branch of DPIE for collecting the field validation datasets. We thank Uthpala Pinto, Daniel Svozil, Colin Johnson, Emily Rayner, Adam Wethered, Dominic Lawler, Joanne Ling and Aaron Wright.
- Metrics and Forecasting Team of DPIE, especially Jamie Love and Eren Turak, for providing the datasets on ecological carrying capacity of native vegetation and habitats of water dragons in the Wianamatta-South Creek catchment, respectively
- CTENVIRONMENTAL for collecting data on vegetation integrity and training the Water Wetlands and Coastal Science Branch on vegetation identification and assessments on the condition of native vegetation. We especially thank Ben Green for his input into the preparation of this report, including sourcing and describing the photographs for the protect and improve areas
- Streamology for collecting data on the geomorphic condition of the catchment and training the Water Wetlands and Coastal Science Branch on LiDAR analysis and geomorphic field assessments.
- University of Newcastle and Salients Consulting for developing a spatial dataset on the water quality in catchment, especially Vincent Rao, Troy Gaston and David Wainright.

We are also very grateful to our subject matter reviewers – Darren James from DAJ Environmental and Professor Peter Davies from Macquarie University. Richard McManus and Brigitte Kuhn at Infrastructure NSW provided oversight on the project needs, as did Giselle Howard and Paul Wearne at the NSW Environment Protection Authority. Simon Hunter at the Water, Wetlands and Coastal Science Branch of DPIE provided invaluable advice on systematic conservation mapping tools and datasets.

This project was funded by the NSW Government under the Marine Estate Management Strategy 2018-2028. The ten-year Strategy was developed by the NSW Marine Estate Management Authority to coordinate the management of the marine estate.

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10. Appendix 1 - Datasets

This Appendix provides a summary of key datasets considered and/or used in the creation of the single thematic map of high ecological value waterways and water dependent ecosystems (viz. natural blue grid). The first section (Section 10.1) summarises datasets for waterways, the second section (Section 10.2) summarises datasets for water dependent ecosystems, and the last section (Section 10.3) summarises datasets for identifying strategic planning priorities in Marxan.

Some datasets were not explicitly included in this study because their intent was captured in other datasets that were directly used. Specifically, the datasets for Commonwealth listed Critically Endangered Ecological Communities and Species of National Significance were not included because the communities and species were captured in certified datasets (used in the *Biodiversity Conservation Act 2016*) on Endangered Ecological Communities and threatened species sightings in NSW. Datasets (mapping) contained in Local Environment Plans showing environmentally sensitive areas, wetlands, riparian lands, watercourses, wildlife corridors or high ecological value areas were captured by the respective vegetation and wetland datasets used directly in this study.

Note that maps of the datasets, which were used for the Marxan analysis, are provided in a separate Appendix (5) towards the end of this document. The maps are cross referenced to the respective sections below.

10.1 Datasets for waterways

10.1.1 Macroinvertebrates

Macroinvertebrate data were sourced directly from the Environment, Energy and Science Group of DPIE and Councils within the Wianamatta-South Creek catchment. Raw data were scored against the Australian River Assessment System on the health of freshwater ecosystems - AUSRIVAS (<https://ausrivas.ewater.org.au/>). AUSRIVAS was developed under the National River Health Program (NRHP) funded by the Federal Government in 1994, in response to growing concern in Australia for maintaining the ecological values of our rivers. AusRivAS has two streams, biological and physical assessment. These correspond with the biological assessment protocols and the geomorphic, physical and chemical assessment protocols, respectively.

10.1.2 River Biodiversity Condition Index

<https://www.industry.nsw.gov.au/water/science/surface-water/monitoring/river-health/river-condition-index>

The River Condition Index (Appendix 5, Fig. 11) is the primary long-term reporting tool for assessing change in riverine condition. The index is used in state of the environment reporting.

The index was developed using the Framework Assessment of River and Wetland Health (FARWH) approach. This approach is based on a hierarchical model of river function. The FARWH recognises the effects of catchment disturbance, physical form of the landscape, hydrologic regime, water quality, fringing zone and aquatic biota as measures of river health. The FARWH method uses existing data collection activities across Australia. It converts them into a standardised and nationally comparable representation of river health.

A component of the River Condition Index is the River Biodiversity Condition Index, which is calculated using the Aquatic Biodiversity Forecaster Tool (Turak *et al.*, 2011) and based on

macroinvertebrates assemblages. Macroinvertebrates are used surrogate measure of instream biota and many taxa have been shown to be responsive to broad scale landscape attributes alteration to natural flow regimes and water quality.

10.1.3 Shannon-Weiner Diversity

In addition to the River Biodiversity Condition Index, we calculated the Shannon-Weiner Diversity index (Appendix 5, Fig. 12) from the local field collections of macroinvertebrate assemblages. The resulting Shannon-Weiner Diversity Index at the field sites were then extrapolated to all 3rd order streams using the spatial statistical modelling technique described in Appendix 2. This approach produced a data layer that more closely reflected the spatial trends in the local field data.

10.1.4 High Ecological Value Aquatic Ecosystems

<https://www.environment.gov.au/water/cewo/monitoring/aquatic-ecosystems-toolkit>

The Aquatic Ecosystems Toolkit is a nationally agreed framework that provides a set of good practice tools for mapping, classifying and assessing the condition of aquatic ecosystems, and provides guidance to identify high ecological value aquatic ecosystems – HEVAE (Appendix 5, Fig. 13). The toolkit has been developed to complement existing assessment tools and is flexible in its application. The toolkit includes five modules: Aquatic Ecosystems Toolkit Guidance Paper, Interim Australian National Aquatic Ecosystems (ANAE) Classification Framework, Guidelines for Identifying High Ecological Value Aquatic Ecosystems (HEVAE), Aquatic Ecosystem Delineation and Description Guidelines, Integrated Ecological Condition Assessment Framework (IECA). The toolkit was used to develop the HEVAE subindex in the NSW River Condition Index spatial data layer, which was sourced directly from the NSW Department of Primary Industries (see next).

10.1.5 Key Fish Habitat

www.dpi.nsw.gov.au/fishing/habitat/publications/pubs/key-fish-habitat-maps

Key Fish Habitats (KFH) include all marine and estuarine habitats up to highest astronomical tide level (that reached by 'king' tides) and most permanent and semi-permanent freshwater habitats including rivers, creeks, lakes, lagoons, billabongs, weir pools and impoundments up to the top of the bank (Appendix 5, Fig. 14). Small headwater creeks and gullies (known as first and second order streams), that only flow for a short period after rain are generally excluded, as are farm dams constructed on such systems. Wholly artificial waterbodies such as irrigation channels, urban drains and ponds, salt and evaporation ponds are also excluded except where they are known to support populations of threatened fish or invertebrates. Maps were compiled on the basis of local government areas and were sourced directly from the NSW Department of Primary Industries-Fisheries.

10.1.6 Fish Condition and Nativeness

<https://www.dpi.nsw.gov.au/fishing/habitat/your-catchment/condition-of-fish-communities-in-nsw>

The condition of fish communities in NSW is derived from the three condition indicators of Expectedness, Nativeness and Recruitment built from a number of field datasets owned by the NSW Department of Primary Industries-Fisheries.

The indicators and the overall fish condition metric have been produced from sampled reaches using a suite of environmental variables extracted from the National Hydrological Geospatial Fabric Version 2 environmental attribute tables (NHGFV 2).

Outcomes rate the condition of fish communities as Very Good, Good, Moderate, Poor or Very Poor. The nativeness and condition of fish communities (Appendix 5, Fig. 15 and Fig. 16) rated as moderate or higher were used as an input to Marxan in this study to develop the single thematic map of high ecological value waterways and water dependent ecosystems (viz. natural blue grid).

10.1.7 Strahler Stream Order

The RivEX tool was used to generate a state-wide layer of Strahler Stream Order (Appendix 5, Fig. 17) using the 2012 Land and Property Information topographic map. RivEX implements a fast-recursive algorithm to calculate Strahler stream order, stream segments and can deal with multi-channelled networks.

The Strahler system is based on the confluence (joining) of streams of the same order. A 1st order stream has no other streams flowing into it. When two streams with different orders join, the resulting stream has the same order as the highest order of the two joining streams. For example, when a first and second order stream join, the resulting stream is second order. When two streams with the same order join, the resulting stream has the next highest order than the joining streams. For example, when two second order streams join, the resulting stream is third order. A stream may separate and then converge—this is called a ‘braided stream’. A braided stream retains the same stream order throughout the braid, as though it were a single stream. A lake may be located on a stream. The occurrence of a lake does not change the stream order of a stream. Further information is available from https://www.industry.nsw.gov.au/data/assets/pdf_file/0020/172091/Determining-Strahler-stream-order-fact-sheet.pdf

10.1.8 River Styles (Chain of Ponds, Geomorphic Condition, Recovery Potential)

<https://riverstyles.com/river-styles-framework/>

The River Styles Framework is an approach to the geomorphic analysis of river systems, developed at Macquarie University. Use of all four stages of the Framework provides coherent, scaffolded baseline information for use in river management practice. Stage 1 is used to identify river types (Styles e.g. *Chain of Ponds*) and interpret their forms, processes, behaviour, patterns in catchments and controls on their character and behaviour (Appendix 5, Fig. 18). Stage 2 is used to interpret *geomorphic condition* in the context of river evolution (Appendix 5, Fig. 19). The data can be used to describe the extent to which the river has been altered relative to an expected reference condition and to identify causes of deterioration or improvement. Stage 3 places each reach within its catchment context to analyse river *recovery potential*, based on the connectivity of reaches within that catchment (Appendix 5, Fig. 20). The data can be used to identify trajectories of geomorphic recovery and likely timeframes for recovery. Stage 4 provides an approach to vision-setting and conservation first and recovery-based prioritisation for river management.

10.1.9 Groundwater Dependent Ecosystems, reliant on surface expression of groundwater

<http://asdd.ga.gov.au/asdd/profileinfo/anzlic-theme.xml#anzlic-theme>

The dataset expresses the potential for groundwater interaction/use for river/spring/wetland ecosystems across Australia (Appendix 5, Fig. 21). It shows the ecosystems that rely on groundwater that has been discharged to the surface, such as baseflow or spring flow. The dataset was created by analysing all river/spring/wetland polygons contained in existing maps, and the outcome of the analysis identified which of those polygons were potentially

interacting with groundwater. All river/spring/wetland polygons are considered to be accessing a source of water in addition to rainfall, and hence, they are all IDEs. The river/spring/wetland ecosystems were analysed to determine whether the additional water source was likely to be groundwater, water in the unsaturated zone or surface water. Where this additional information enabled a conclusion to be made on the potential of each river/spring/wetland ecosystem to be interacting with groundwater, the ecosystem was included in the GDE layer ('Reliant on surface expression of groundwater') and categorised as having either a high, moderate or low potential for groundwater interaction.

10.1.10 Community environmental values and uses of waterways

Spatial datasets identifying the environment values of the waterways in South Creek were obtained from the Healthy Rivers Commission report for the Hawkesbury-Nepean River system. The report shows that there are 8 environmental values designated to the waterways in the South Creek catchment depending on the surrounding catchment land use. Those that apply to all waterways include Protection of Aquatic Ecosystems, Secondary Contact Recreation and Visual Amenity. In this study, we focussed on Protection of Aquatic Ecosystems, on the assumption that this environmental value will remain a community expectation into the future as the South Creek catchment is urbanised. This assumption is reflected in the visions for the Western Parkland City and in recent community surveys conducted by the Environment Energy and Science Group of DPIE (Dela-Cruz *et al.*, *in prep*). The ANZECC & ARMCANZ (2000) guidelines indicate that Protection of Aquatic Ecosystems requires 'maintaining or improving the ecological condition of water bodies and their riparian zones', and that protecting aquatic ecosystems also protects the other environmental values and uses. Typically, the NSW Environment Protection Authority rely on water quality data to determine if the Protection of Aquatic Ecosystems is being achieved in the waterway before setting point source (industrial) discharge limits.

10.1.11 Water Quality

For this study, we collated all available water quality datasets from state and local government monitoring programs and from Sydney Water, who are required to monitor water quality for their Environmental Protection Licenses. Datasets were mostly available for waterways on the eastern side of the catchment. To provide an objective representation of water quality across the South Creek catchment, we extrapolated the field observations to all 3rd order (perennial) streams via a spatial statistical modelling technique developed by researchers at the Commonwealth Scientific Industrial Research Organisation (CSIRO) and the National Oceanic and Atmospheric Association (Appendix 2, Section 11.4). This modelling technique is specific to stream networks because the models account for patterns of spatial autocorrelation among locations (see Appendix 2).

10.2 Datasets for water dependent ecosystems

10.2.12 Environment Protection and Biodiversity Conservation Act 1999 listed threatened species and ecological communities

<https://www.environment.gov.au/epbc/what-is-protected/threatened-species-ecological-communities>

The *Environment Protection and Biodiversity Conservation Act 1999* provides for the listing of nationally threatened native species and ecological communities, native migratory species and marine species. The lists are provided on the website, and spatial data layers showing endangered ecological communities or known occurrences of listed ecological communities (Appendix 5, Fig. 22) were obtained from the Environment, Energy and Science Group of the Department Planning, Industry and Environment.

10.2.13 Local Environment Plan – riparian lands and watercourses

<https://www.planningportal.nsw.gov.au/opendata/dataset/epi-riparian-lands-watercourses>

This spatial dataset identifies land where development implications exist to reduce impacts in riparian lands and watercourses, as designated by a NSW environmental planning instrument. Riparian lands are a transition zone between the land and the watercourse that is important for maintaining or improving the shape, stability and ecological functions of a watercourse.

10.2.14 Local Environment Plan – Environmentally Sensitive Lands

<https://www.planningportal.nsw.gov.au/opendata/dataset/epi-environmental-plan-environmentally-sensitive-land>

This spatial dataset identifies environmentally sensitive lands that are subject to 'Additional Local Provisions' found in Part 6 (or Part 7) of the Local Environment Plan. Local provisions help to augment existing zoning in order to ensure that special environmental features are considered.

10.2.15 Environmental Planning Instrument - Wetlands

<https://www.planningportal.nsw.gov.au/opendata/dataset/epi-wetlands>

This spatial dataset identifies land where development implications exist due to the presence of wetlands, as designated by the relevant NSW environmental planning instrument. The NSW Wetlands Policy promotes the sustainable conservation, management and use of the state's wetlands.

10.2.16 Riparian Vegetation and Wetlands (including Farm Dams)

The riparian vegetation and wetland datasets (see Figure 3) were developed by initially combining the following three datasets using a hierarchy of decision rules and then checking against 2017-2018 aerial imagery to account for any unmapped wetlands:

- i. Remnant Vegetation of the western Cumberland subregion, 2013 Update VIS 4207. This dataset provides detailed information on the native vegetation communities, including a fine level of floristic classification detail for plant communities. The dataset does not identify areas of open water (otherwise known as non-vegetated wetlands)

- ii. NSW Structure Compilation V2p0, see specifically Native Vegetation of the Sydney Metropolitan Area - Version 3.1 (OEH, 2016) VIS ID 4489. This dataset provides a fine level of linework (delineation of polygon boundaries) and is more up to date with respect to clearing and regrowth of native vegetation extent. However, at the time of this study, the dataset only described broad structural vegetation classes.
- iii. NSW Hydro Area Dataset

A summary of methods for developing the datasets is provided in Appendix 2. Note that the final step in developing the datasets involved manually reconciling against 2017-2018 aerial imagery and satellite imagery to account for recent clearing of vegetation and urban development. The satellite imagery was based on the Sentinel 2 satellite imagery (10m true colour) with an image observation date 31/01/2018. The image was downloaded from the Copernicus Open Access Hub.

10.2.17 Groundwater Dependent Ecosystems, reliant on sub-surface expression of groundwater

<http://asdd.ga.gov.au/asdd/profileinfo/anzlic-theme.xml#anzlic-theme>

The dataset expresses the potential for groundwater interaction/use of vegetation ecosystems across Australia (Appendix 5, Fig. 21). It shows the ecosystems that use groundwater from beneath the water table or in the capillary zone. The dataset was created by analysing all vegetation polygons contained in existing maps, and the outcome of the analysis identified which of those polygons were potentially interacting with groundwater. The analysis initially identified vegetation polygons that were using another water source in addition to rainfall using remote sensing (MODIS and Landsat) data. These ecosystems are known as IDEs. The IDEs were then analysed further to determine whether the additional water source was likely to be groundwater, soil water or surface water. Where this additional information enabled a conclusion to be made on the potential of each vegetation IDE to be using groundwater, the ecosystem was included in the GDE layer ('Reliant on subsurface groundwater') and categorised as having either a high, moderate or low potential for groundwater interaction.

10.2.18 Water Dependent Vegetation

www.bionet.nsw.gov.au;

<https://www.environment.nsw.gov.au/research/Visclassification.htm>

The Department of Planning, Industry and Environment maintains the NSW BioNet, which is the repository for biodiversity data in NSW. It has with two core applications - BioNet Atlas and BioNet Vegetation Classification. The BioNet Vegetation Classification includes spatial datasets on Plant Community Types (PCTs), which is the master community-level typology used in NSW's planning and assessment tools and vegetation mapping programs.

Two specific vegetation datasets were used this study (Appendix 5, Fig. 22) – the Pre 1750 Veg - Sydney Urban Bushland Biodiversity 1997 and the Southeast NSW Native Vegetation Classification and Mapping – SCIVI (VIS ID 2230).

10.2.19 Species Sightings – Flora and Fauna

www.bionet.nsw.gov.au;

https://www.environment.nsw.gov.au/atlaspublicapp/UI_Modules/ATLAS_/AtlasSearch.aspx

The Department of Planning, Industry and Environment (DPIE) maintains the NSW BioNet, which is the repository for biodiversity data in NSW. It has two core applications - BioNet Atlas and BioNet Vegetation Classification. The BioNet Atlas contains records of observations of plants, mammals, birds, reptiles, amphibians, and some fish, invertebrates and fungi (Appendix 5, Fig. 23). Each record contains various details, including geographic coordinates, information regarding the source and accuracy of the record and the time period within which a species was recorded at a particular location. Sightings of fauna and flora are constantly submitted for entry into the Atlas, and so the dataset will never be complete.

10.2.20 Atlas of Living Australia

<https://www.ala.org.au/>

A collaboration between Commonwealth Scientific Industrial Research Organisation (CSIRO), Australia's museums and herbaria, universities, and the Australian Government established the Atlas of Living Australia (ALA); a national project focused on making biodiversity information accessible and usable. The ALA contains more than 85 million occurrence records, based on specimens from natural history collections, field observations and surveys (Appendix 5, Fig. 23).

10.2.21 Important Bird Areas

birdlife.org.au/projects/important-bird-areas/iba-maps

The Important Bird and Biodiversity Areas (IBA) program is an international non-governmental conservation scheme led by BirdLife International Partners such as BirdLife Australia. IBAs are sites of international importance for bird conservation. They are small enough to be practical targets for conservation management but large enough to meet the global IBA criteria. Three hundred and fourteen IBAs have been identified across Australia. A spatial data layer of IBAs was sourced from the Environment, Energy and Science group of DPIE (Appendix 5, Fig. 23).

10.2.22 Iconic species habitat mapping (part of community environmental values and uses)

Spatial datasets on the habitats of frogs, birds, bats and reptiles (Appendix 5, Fig. 24 to Fig. 33) were derived from local species sightings acquired from the NSW BioNet and the Atlas of Living Australia. The sightings were quality checked by subject matter experts at the former Office of Environment and Heritage and their associated networks, including those at the Australian Museum and universities. Sightings of species that were incorrectly identified were excluded (e.g. cane toad, *Rhinella marina*), as were sightings in locations that were unlikely habitats (e.g. along the roadside). The sightings for individual species were sorted into functional groups based on their habitat and water requirements. The requirements were then used to inform habitat cost benefit models that predict the extent of suitable habitat for each functional group in the Wianamatta-South Creek catchment (Appendix 2).

10.3 Datasets for Marxan

10.3.23 Hard Urban Surfaces

Recent urban developments in the Wianamatta-South Creek catchment have meant that some mapped habitats and species sightings no longer exist. To ensure that our spatial datasets were current at the time of the study, we developed a spatial dataset of hard urban surfaces (Appendix 5, Fig. 34) and assumed that any mapped habitats and species sightings in these urban areas no longer existed. Any habitats and species sightings within the footprint of the new airport were also removed, based on advice from Infrastructure NSW.

The spatial dataset of was developed by combining the following datasets and associated attributes:

- NSW Landuse 2013

All polygons classified as 'urban' under the major land use category were selected and then filtered to exclude any urban areas with greenspace i.e. urban recreation, sewage ponds, golf courses, tourist development, universities and research facilities.

Building and other surfaced areas from agricultural areas were selected from the detailed land use category. These included abattoirs, buildings associated with horticultural industry (winery, packing shed), farm infrastructure (house, machinery & storage sheds and garden areas), intensive animal production, intensive animal production - beef feedlot, intensive animal production - dairy shed, intensive animal production - piggery, intensive animal production - poultry, shade house or glass house (includes hydroponic use).

- NSW Roads dataset, sourced from the Department of Planning, Industry and Environment

The NSW Roads dataset is made up of mapped lines categorised into specific road classes. The following classes were selected as they represent surfaced/paved roads: motor way, primary road, Sub-arterial Road, Distributor Road, and Local Road. The resulting lines were superimposed on the high-resolution imagery (see below) to assess road width, which was estimated to be 7m. An additional buffer of 3.5m was applied to generate polygons representing the surfaced roads.

- High resolution (10cm) imagery provided by NSW Spatial Services Department of Finance, Services and Innovation.

The most recent imagery available for the Wianamatta-South Creek catchment at the time of study was collected from 24/2/2016 to 03/05/2016.

- Sentinel-2 multispectral image (January 2018) 10m cloud free image collected on 30th January 2018, available from the Copernicus Open Access Hub.

A final step was to add in urban surfaces that had recently been developed, and not already captured in the NSW Landuse 2013 or NSW Road datasets. This was achieved by generating a vegetation index (NDVI, or Normalised Difference Vegetation Index) from the Sentinel Imagery ($NDVI = (NIR - R)/(NIR + R)$). Areas with no vegetation cover were identified using the criteria $NDVI = 0$. These areas were reclassified from the NDVI raster

and exported to an interim 'bare surfaces' polygon layer. The bare surfaces polygon layer was then superimposed on the high-resolution imagery (see above) and a true colour composite (RGB) from the Sentinel 2 (January 2018) 10m imagery. Where polygons in the bare surfaces layer corresponded to urban surfaces in the high-resolution imagery or the Sentinel image, these were selected manually selected and included in the final hard urban surfaces dataset.

10.3.24 NSW National Parks and Wildlife Service (NPWS) Estate

<https://datasets.seed.nsw.gov.au/dataset/nsw-national-parks-and-wildlife-service-npws-estate3f9e7>

The NSW National Parks and Wildlife Service (NPWS) Estate database provides information on areas (Appendix 5, Fig. 35) reserved under the *National Park & Wildlife Act 1974*. Areas include National Parks, Nature Reserves, Regional Parks, State Conservation Areas, Aboriginal Areas, Historic Sites and Karst Conservation Reserves.

10.3.25 Crown Reserve Estate

<https://www.industry.nsw.gov.au/lands/what-we-do/find-crown-land-on-a-map>

Crown reserves are land set aside on behalf of the community for a wide range of public purposes including environmental and heritage protection, recreation and sport, open space, community halls, special events and government services.

New South Wales has more than 34,000 Crown reserves. The reserve management system enables the NSW Government, local councils and members of the community to work together to provide care, control and management over Crown reserves.

10.3.26 Ecological Carrying Capacity

<https://datasets.seed.nsw.gov.au/dataset/ecological-carrying-capacity-of-terrestrial-habitat>

This dataset accounts for the quality of terrestrial habitats supporting biodiversity and the connectivity of the habitats based on biological movement such as foraging, dispersal and migration (Appendix 5, Fig. 36). It is used in the NSW Government Biodiversity Indicator Program, as required under the *Biodiversity Conservation Act 2016*. The dataset accounts for the carrying capacity of a landscape to support its original complement of biodiversity and ecosystems. It is part of a family of measures on the condition and connectivity of habitat, including its capacity to support the needs of native plants, animals and ecosystems in NSW, as a proportion relative to that in the pre-industrial era.

11. Appendix 2 - Developing spatial datasets

This Appendix provides a summary of spatial datasets that were specifically developed in this study to fill the known gaps on mapping of high ecological value waterways and water dependent ecosystems in the Wianamatta-South Creek catchment.

Section 11.1 of this Appendix describes the development of the riparian and woody wetland vegetation datasets. Section 11.2 describes the development of the non-woody wetlands dataset. Section 11.3 describes the development of datasets on the habitats of iconic water dependent species. Section 11.4 describes the spatial datasets for water quality and the Shannon-Weiner Index which were derived from the local field monitoring sites.

Maps of the final datasets that were used in the Marxan analysis are provided in Figure 3 or Appendix 5, and tables of species lists, habitat requirements of iconic water dependent species, and datasets used to develop the maps are provided in Appendix 6. The last Appendix (7) of this document provides a list of the literature reviewed to develop the maps of habitats of iconic water dependent species.

11.1 Riparian and Woody Wetland Vegetation

The riparian and woody wetland vegetation datasets (Figure 3) were developed by combining two existing vegetation datasets available for Wianamatta-South Creek, according to the following decision rules:

- (1) Polygons mapped as native vegetation in the NSW Structure Compilation V2p0 dataset were assigned a Plant Community Type from the Remnant Vegetation of the western Cumberland subregion, 2013 Update VIS 4207 (hereafter termed '2013 dataset') dataset using a majority rule in which the Plant Community Type from the 2013 dataset occupying the majority of the polygon by area was assigned to the polygon.
- (2) Polygons were mapped as 'non-native' in the NSW Structure Compilation V2p0 dataset the vegetation community, were retained as 'non-native'.
- (3) If polygons were mapped as 'Riparian woodland' or 'Non-woody wetland' in the NSW Structure Compilation V2p0 dataset but were to be assigned to a non-wetland or non-riparian vegetation Plant Community Type at Decision Rule (1), then they were retained as 'Riparian woodland' or 'Non-woody wetland'. This step was implemented to retain riparian and wetland polygons that were too small to be delineated in the coarser resolution 2013 dataset.
- (4) A reclassification was then applied to the output from Decision Rule (3) to categorise Plant Community Types adopted from the 2013 dataset to riparian and wetland map units, according to the following:
 - a) Coastal freshwater lagoons of the Sydney Basin Bioregion and South East Corner Bioregion to 'non-woody wetlands'
 - b) Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion to 'riparian woodland'
 - c) Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, Sydney Basin Bioregion to 'woody wetland'
 - d) All other Plant Community Types to 'other native vegetation'

Decision Rule (4) was guided by a review of the NSW Native Vegetation Classification to identify vegetation communities with surface water dependencies. A plant community type was identified to have surface water dependency if it was described as a 'wetland' or 'riparian' vegetation community in the BioNet Vegetation Classification database. A summary of map units, vegetation classes, Endangered Ecological Communities and water dependencies is provided in Table 7 at Appendix 6.

11.2 Non-Woody Wetlands, including Farm Dams

Areas of open water including natural and modified water storage areas, farm dams, and non-vegetated natural waterbodies (Figure 3) were not delineated in the NSW Structure Compilation V2p0 dataset or the Remnant Vegetation of the western Cumberland subregion, 2013 Update VIS 4207. To develop this dataset, the output of Decision Rule (1), was superimposed on high resolution aerial imagery collected in 2017-18, and polygons corresponding to larger areas of open water but mapped as 'non-native' were identified and reclassified to the non-woody wetland dataset. Small farm dams were identified from the NSW Hydro Area Dataset and also added to the non-woody wetland dataset. A final set of farm dams that were not already identified were digitised from the high-resolution aerial imagery and added to the non-woody wetland dataset.

11.3 Habitats of Iconic Water Dependent Species

Maps of suitable habitats for iconic species of frogs, waterbirds and water dependent bats were developed using a cost benefit mapping method, which combines measures of habitat suitability and connectivity to prioritise habitat (Drielsma *et al.*, 2007). The method assumes a species will occupy and move across a landscape according to the shortest path or cost based on the species' requirements for foraging, breeding and shelter. An advantage of this method is that connectivity between waterways and other habitats (e.g. terrestrial vegetation) is included as a measure of habitat suitability. The method consists of a sequence of 4 steps, as outlined below (Sections 11.3.1 to 11.3.4). We applied the 4 steps of method to produce maps of habitats for species within the same habitat groups (i.e. functional groups).

Limitations of the method are that it relies on scientific understanding and/or expert opinion of species habitat requirements. In many cases, species habitat requirements are not well documented, especially for the sites of interest in this study. Where species habitat requirements are known, the spatial datasets matching the requirement may be unavailable or limited in accuracy or currency. Many species are known to use fallen timber, for example, but mapping of fallen timber is not available for the Wianamatta-South Creek catchment. Similarly, many species require shallow water for foraging (waterbirds) or breeding (frogs), but datasets identifying water sources do not provide information on water depth. To address this limitation, we undertook an extensive review of the literature (Appendix 7, Section 16.2) and consulted with subject matter experts from the former Office of Environment and Heritage and their associated networks such as those at the Australian Museum and universities.

11.3.1 Step 1: Identify habitat requirements of iconic species through a review of the literature

Species lists for birds, frogs and water dependent bats were developed from sighting records held in the Atlas of Living Australia, BioNet Atlas, local data collected by Blacktown City Council (bats) and schedules of threatened species under the *Biodiversity Conservation Act*

2016 and *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*. These lists were checked and refined by subject experts to remove errors associated with misidentification of species and accuracy of the sightings data. The species were categorised into habitat groups according to their (similar) water and other habitat requirements.

A summary of the species identified (and sightings), their habitat requirements, and the assigned habitat use group is shown in Tables 8 to 11 at Appendix 6.

11.3.2 Step 2: Collate and prepare spatial datasets that characterise habitat requirements of iconic species

Several spatial datasets were collated to use as inputs for the 'water source' and 'landscape features' datasets (Appendix 6, Table 12). The water source dataset brings together the sources of water in the landscape, and the landscape features dataset brings together more terrestrial features of the landscape that iconic species of frogs, birds and water dependent frogs use for foraging, breeding and shelter. Note that the latter dataset is used to define the shortest path or cost of species moving and/or connecting the water sources.

11.3.3 Step 3: Create integrated 'water source' and 'cost' datasets for each habitat group

Integrated 'water source' and cost datasets were generated for each habitat group (Appendix 6, Table 13), using combinations of data selected from the spatial datasets listed in Table 12 at Appendix 6. The only exception was for the fishing bat, Southern Myotis, where sufficient information was available to create a dataset specifically for this species (as opposed to habitat groups). Table 14 at Appendix 6 provide a list of additional datasets that were available for generating habitat datasets for the bats.

All datasets identified in Table 12 at Appendix 6 were snapped to a 5 m Digital Elevation Model to provide a common grid for data preparation and spatial analysis. The datasets describing the landscape features were weighted with a cost to reflect the suitability of the landscape feature. Weightings (Appendix 6, Table 13) were based assigned heuristically using information on from a review of the literature (Appendix 7, Section 16.2). Lower weightings (i.e. lower 'costs') are assigned to the landscape features that provide the most suitable habitat, and the highest weights assigned to unsuitable habitats.

11.3.4 Step 4: Develop habitat group maps for input to Marxan

Each habitat map was developed using a standard Cost Distance Tool in ArcGIS 10.4. The Cost Distance tool calculates the least accumulative distance for each raster cell/grid of the cost dataset to the nearest water source. Figure 7 demonstrates how cost distance is calculated from the water source dataset and cost dataset developed for the Southern Myotis. The cost distance dataset was further refined by selecting the only those areas where the cost distance equalled 1 to create the final habitat suitability map for input to Marxan.

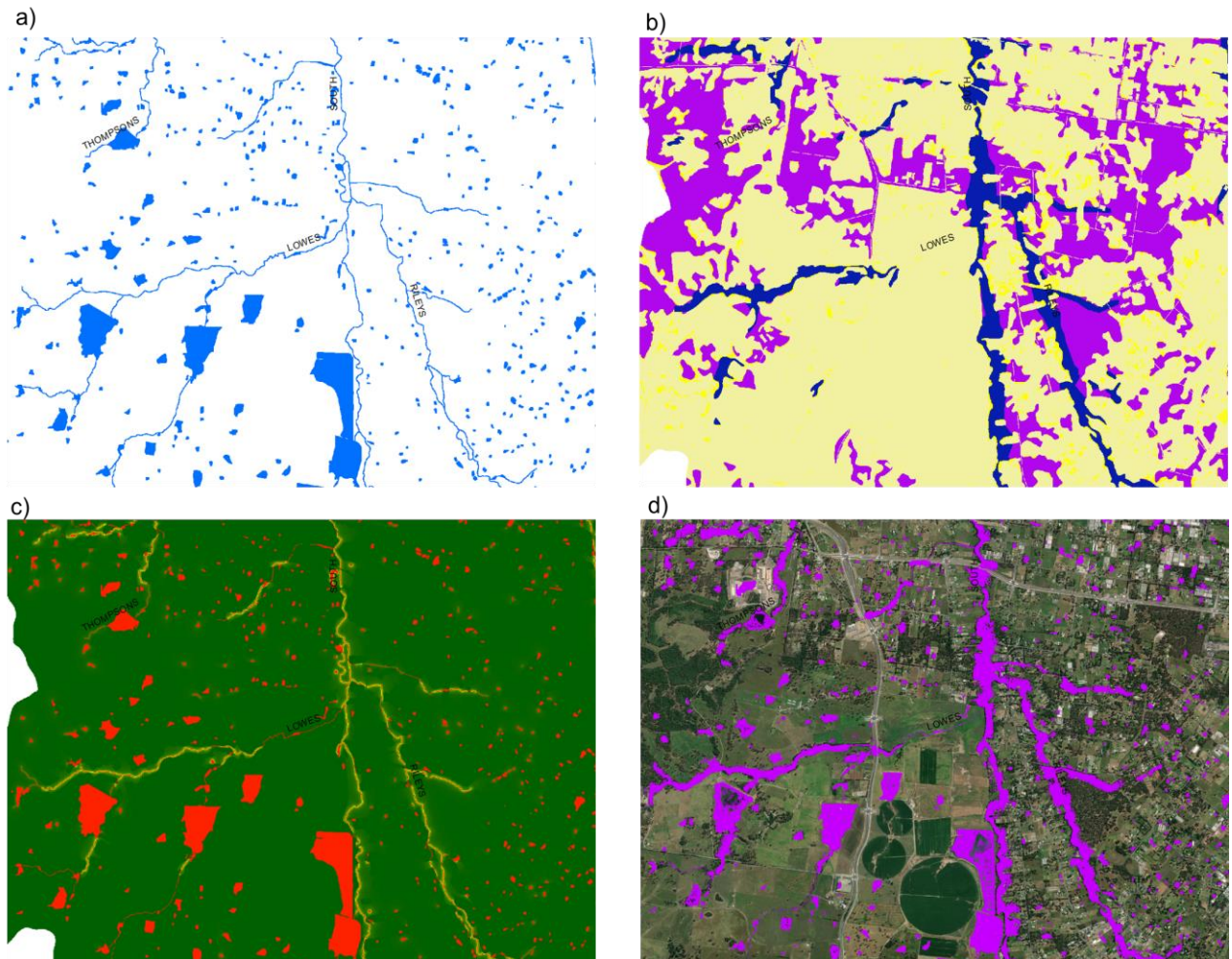


Figure 8 Integration of the (a) water source and (b) cost (blue least cost, yellow most cost) datasets to generate a range of (c) suitable habitats (red most suitable, green least) for Southern Myotis. Only the most (d) suitable habitats (purple) for Southern Myotis were used in the Marxan analysis.

11.4 Water quality and Shannon-Weiner Index

Local field measures of water quality and the derived Shannon-Weiner Index were extrapolated to $\geq 3^{\text{rd}}$ order streams in the Wianamatta-South Creek catchment using two spatial modelling tools developed by Commonwealth Scientific Industrial Research Organisation and National Oceanic and Atmospheric Administration for the United States Department of Agriculture. The first is a Spatial Tool for the Analysis of River Systems (STARS, version 2.0.4), which is needed to generate and format data to align with the stream network for the (second tool) Spatial Sream Network (SSN) tool. This second tool specifically extrapolates the local field measures via a series of steps:

- i. calculate pair-wise distances and spatial weights of the local field measures based on the stream network
- ii. check for autocorrelation that may be related to upstream and downstream influences
- iii. estimate (generalised linear) relationships between field measures and predictor variables to create the spatial datasets of water quality and Shannon-Weiner Index

Note only the Shannon-Weiner Index dataset (Appendix 5, Fig. 12) was used as an input to Marxan.

11.4.5 Data for STARS and SSN

Over 2200 local field measurements were available for extrapolation. The field measurements were collected between 2005 to 2017, from 54 monitoring sites in the Wianamatta-South Creek catchment. The median, 20th and 80th percentiles of the field measurements were calculated and then used as inputs to STARS and the SSN tool. Table 4 provides a list of spatial datasets that were used as predictor variables in the SSN tool to extrapolate the field measurements to all 3rd order streams in the Wianamatta-South Creek catchment. The list is aligned with the corresponding field measure that was extrapolated. For example, the land use, perennial nature of the streams and the condition of streams were predictor variables for the Shannon-Weiner Index.

Extrapolations were successfully produced for the Shannon Weiner Index, Chlorophyll a, Dissolved Oxygen, Temperature, Turbidity, Ammonia, Total Nitrogen and Total Phosphorus. Extrapolations for field measures of pH and conductivity could not be produced due to the variability in the data. The predictor variables that were often strongly related to the water quality and Shannon-Weiner Index were land use and the riparian vegetation condition.

Table 4 Datasets (and sources) used as predictor variables to extrapolate local field measurements to 3rd order streams in Wianamatta-South Creek

FIELD MEASURE	PREDICTOR VARIABLE	DATA SOURCE
Shannon-Weiner Index	Land use	NSW Landuse 2013
	Perennial streams	Stream Strahler Order
	Stream reach condition	Ecological Carry Capacity
Chlorophyll a	Land use	NSW Landuse 2013
	Total nitrogen export to streams	NSW Estuary Health Risk Dataset
Dissolved Oxygen	Annual air temperature	Bureau of Meteorology
	Water erosion hazard	Land and Soil Capability Mapping for NSW
	Perennial streams	Stream Strahler Order
	Stream reach condition	Ecological Carry Capacity
Temperature	Land use	NSW Landuse 2013
	Water erosion hazard	Land and Soil Capability Mapping for NSW
	Perennial streams	Stream Strahler Order
	Stream reach condition	Ecological Carry Capacity
Turbidity	Land use	NSW Landuse 2013
	Water erosion hazard	Land and Soil Capability Mapping for NSW
Ammonia	Land use	NSW Landuse 2013
	Annual air temperature	Bureau of Meteorology
	Water erosion hazard	Land and Soil Capability Mapping for NSW
	Perennial streams	Stream Strahler Order
Total Kjeldahl Nitrogen	Land use	NSW Landuse 2013
	Total nitrogen export to streams	NSW Estuary Health Risk Dataset
	Total phosphorus export to streams	Land and Soil Capability Mapping for NSW
	Water erosion hazard	
Total Nitrogen	Land use	NSW Landuse 2013
	Water erosion hazard	Land and Soil Capability Mapping for NSW
	Stream reach condition	Ecological Carry Capacity
Total Phosphorus	Land use	NSW Landuse 2013
	Water erosion hazard	Land and Soil Capability Mapping for NSW
	Stream reach condition	Ecological Carry Capacity

12. Appendix 3 – Marxan

Marxan software is freely available from <https://marxansolutions.org/>. An older version of Marxan (version 2.43) was used as this version was the most recent at the time of this study.

Marxan addresses the general problem of how to meet user-defined ‘management targets’ (Section 4.4, Table 2) for the minimum ‘cost’. Targets are the amount of each feature that the program is instructed to select (e.g. 30% of riparian vegetation). Costs are flexible, and can be defined in terms of land value, resource harvest value, cultural value, spiritual value, cumulative impact and so on. High costs are applied to areas that should be avoided for protection. Other options that Marxan provides include the ability to determine the degree of compactness of selected areas (i.e. creating few large or many small areas for protection).

Marxan relies upon a mathematical equation (not a model) to meet constraints with a number of good solutions. The algorithm answers the minimum set problem, which captures a minimum representation of features for the least cost. The objective is to minimize the total cost of the protect and improve areas and their total boundary, while meeting all management targets. The equation that Marxan uses is:

$$\text{Score} = \text{Efficiency} + \text{BLM} \times \text{Clumping} + \text{SPF} \times \text{Target Shortfall}$$

where:

- Efficiency is the combined planning cost
- BML is the Boundary Length Modifier
- Clumping is the combined boundary length
- SPF is the Specifies Penalty Factor
- (Combined) target shortfall is a penalty for not achieving conservation targets

The solution with the lowest score is the one that Marxan selects as the ‘best’ solution – see below Section 12.2, which describes the Marxan results.

12.1 Setting up Marxan

To set up Marxan, the study area needs to be broken down into planning units, which are small geographic parcels of regular or irregular shapes such as hexagons, squares or hydrological drainage areas. In this study, we chose hexagons because they are more efficient than squares and hydrological drainage areas in producing compact/small protected areas. We also chose a hexagon size of 1 ha to correspond with the typical lot sizes of urban developments. Applying this configuration of planning units to the entire Wianmatta-South Creek catchment resulted in 63710 planning units.

Each 1 ha hexagon was attributed area, length or occurrences of each of the blue elements listed in Table 1 (see Section 4.2) for defining high ecological value waterways and water dependent ecosystems. An example is shown for the Lowes Creek tributary in Figure 8, where the planning units coloured in red are attributed with an area of 1 ha riparian vegetation because the spatial extent of the riparian vegetation covered (e.g. 9261 m²) almost the entire planning unit. By comparison, the planning units coloured in dark green have less area riparian vegetation (e.g. 7 m²).

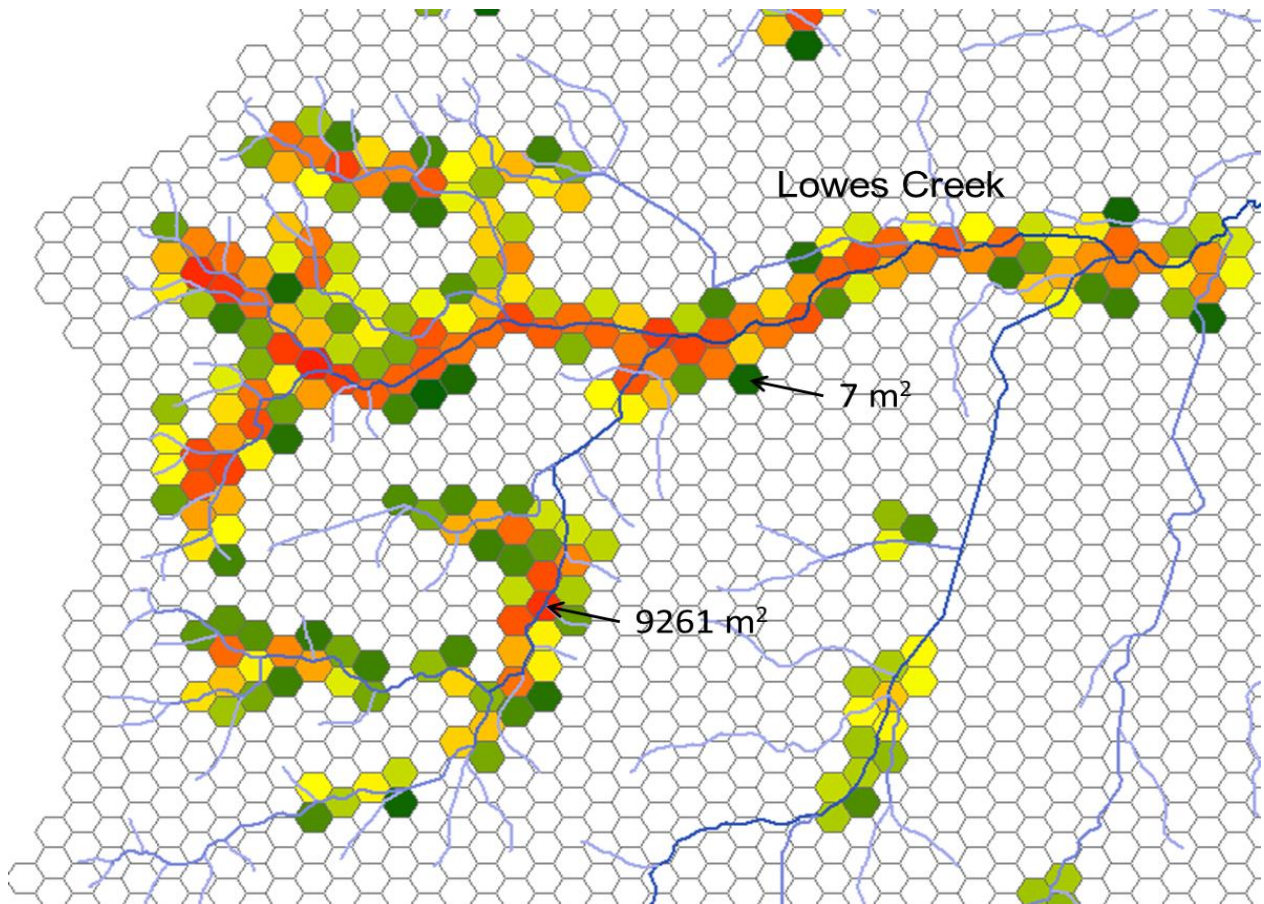


Figure 9 Lowes Creek tributary and surrounding catchment disaggregated into 1 ha hexagon planning units for use in Marxan

Datasets representing prioritisation criteria were also attributed to each 1 ha hexagon. These included the boundaries of the existing and acquired National Parks Estate in the Wianamatta-South Creek catchment, and the ecological carrying capacity of native vegetation (Appendix 1, Section 10.3). The National Parks Estate was used as a basis for determining complementarity, so that planning units selected outside of the existing protected areas complement those that are already protected. Planning units complement each other well if the species and habitats differ, so their selection provides a combination of planning units, which combined, achieve the goal of comprehensiveness in the most efficient manner.

The ecological carrying capacity of native vegetation was developed as an indicator of ecological integrity for the Biodiversity Information Program (OEH & CSIRO, 2019), required under the *Biodiversity Conservation Act 2016*. It was used in this study to ensure the principle of efficiency is met through relatively good condition and well-connected ecosystems. These two prioritisation criteria were particularly important given the general degraded state of the Wianamatta-South Creek catchment. Prioritising corridors that connect healthy ecosystems will allow populations to interbreed (and hence improve long-term genetic viability), provide access to larger habitats which ensures a wider range of food sources and shelter, and provide an avenue for fauna to move or shelter in times of stress (e.g. resilience to climate change impacts). In this study, we used the ecological carrying capacity to quantify the 'cost' parameter in Marxan. This parameter literally defines the cost of including a planning unit in your final set of priority areas for protection. The lower the cost the more likely the planning unit will be included.

12.2 Explanation of Marxan outputs

Marxan produces two outputs – a best solution and a summed solution, which indicate how many and which specific planning units should be prioritised, respectively. The best solution can be interpreted as the 'best' solution for priority areas for protection when comparing all solutions determined from a specified number of times Marxan is run. In this study we ran Marxan 100 times, meaning that our best solution was determined from 100 possible solutions. We chose 100 because this number of runs provides adequate repetition while minimising the overall run time when using large and complex datasets. In Marxan, the best solution is determined by a score that is calculated for each planning unit. The score is indicative of the extent to which the management target for each indicator and other conservation principles (e.g. complementarity) is met while minimising costs (i.e. ecological carrying capacity). The lower the score for each planning unit, the better. The algorithms in Marxan will compare the 100 combinations of planning units arising from the 100 runs and determine the best solution from the combination resulting in the overall lowest score.

The summed solution shows how often each planning unit is selected for inclusion in protected areas. The outputs are percentages based on selection frequency. For example, if a planning unit was selected 50 times out of the 100 runs, then the frequency of selection is 50%. Planning units that are rarely selected can be ignored because they do not meet all the management targets and other conservation principles. The selection frequency cut-off is usually 50% (see below).

12.3 Priority areas for protection and priority areas for improvement

In this study we used the selection frequency to define our cut-offs for priority areas for protection and priority areas for improvements. The plot provided in Figure 9 compares the selection frequency and the proportional extent (area or length) of each indicator for waterways and water dependent ecosystems. The proportional extent of each indicator markedly decreases, at a selection frequency cut-off of around 80%. The next marked decrease occurs at a selection frequency cut-off of 50%. Intuitively, we identified priority areas for protection based on the 80% cut-off, and priority areas for improvement based on the 50% cut-off.

Figure 10 provides a close-up of our priority areas for protection or improvement around the Badgerys Creek and Thompsons Lowes Creek tributaries and their connection to Wianamatta-South Creek itself. All of Badgerys Creek has been prioritised for protection, as have the upper reaches of Thompsons Creek. Smaller tributaries and stands of groundwater dependent ecosystems (vegetation) lie between the two creeks and these have been prioritised for improvement. Much of the lower parts of Thompsons Creek itself has been prioritised for improvement and will provide the important connection to Wianamatta-South Creek. Within the areas for improvement are potential habitats for water birds, frogs and water dependent bats.

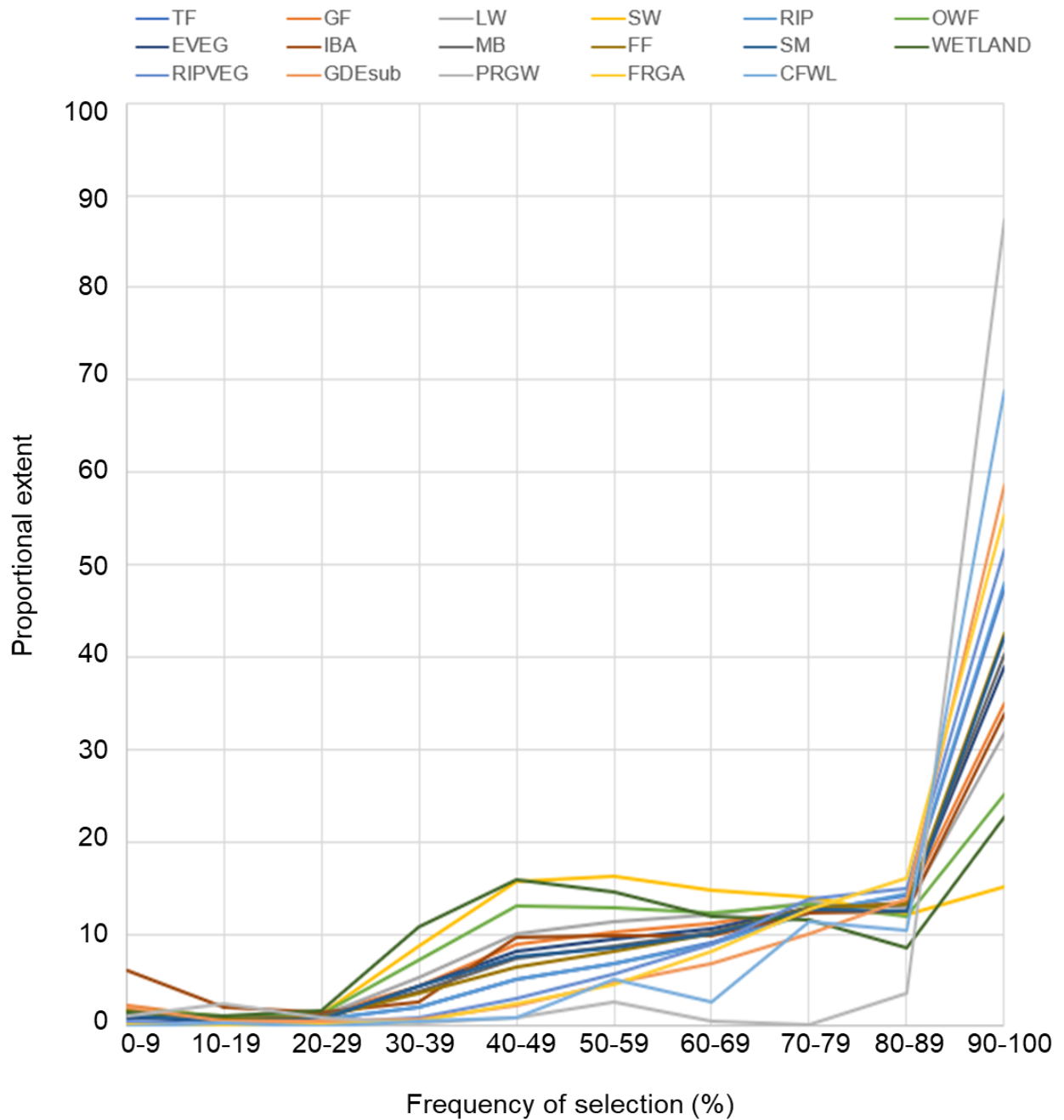


Figure 10 Thresholds used to define protect and improve areas in the map, based on the proportional extent of each blue element in a planning unit and the frequency of selection of the planning unit. NOTE: TF = tree frogs, GF = ground dwelling frogs, LW = large wader birds, SW = small wader birds, RIP = water birds dependent on riparian vegetation, OWF = open water bird foragers, EVEG = emergent vegetation bird forages, IBA = important bird habitat, MB = microbats, FF = flying fox, SM = Southern Myotis, WETLAND = woody and non-woody wetlands, RIPVEG = riparian vegetation, GDEsub = groundwater dependent ecosystems (accessing aquifers), PRGW = Parramatta River Red Gum, FRGA = Forest Red Gum, CFWL = Coastal Freshwater Lagoons

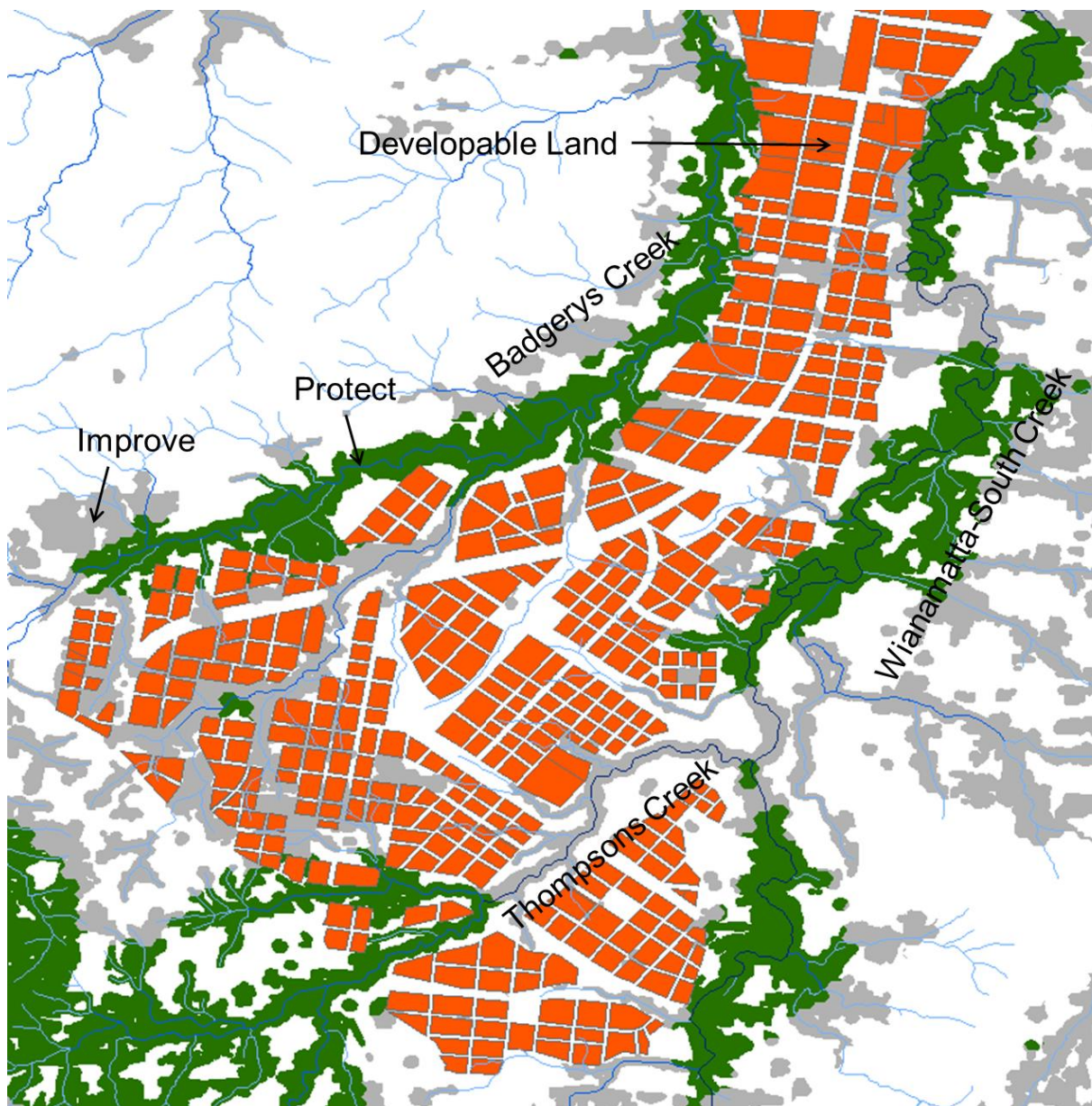


Figure 11 Map of the Aerotropolis Core Precinct showing the connection between the protect and improve areas of high ecological value waterways and water dependent ecosystems.

13. Appendix 4 – Ground truthing

The map of high ecological value waterways and water dependent ecosystems was ground truthed (otherwise known as map accuracy assessment) by comparing independent field measurements with the map attributes at the same locations. The amount of agreement between the attributes and field measurements were evaluated using confusion matrices and the Kappa Statistic. This accuracy assessment is a standard method, and follows the methods outlined by Stehman and Czaplewski (1998). The following sections describe the selection of field measurement locations, and detailed descriptions of the accuracy of the overall map and individual datasets making up the map.

13.1 Locations for ground truthing

The locations of field measurements were determined initially through desktop assessment, which involved selecting a subset of the 1 ha hexagons (planning units) that make up the planning grid structure of the map (Appendix 3, Figure 8). The selection was via a stratified random sampling approach to ensure that field measurements are obtained from areas mapped as high ecological value and those that fall outside of the map because they have no or relatively little ecological value. An initial screening of the 1 ha hexagons was undertaken to rapidly assessing whether the map accurately captured areas of no or low ecological value. The screening was done through air photo interpretation, in which the selected 1 ha hexagon was superimposed on very high-resolution aerial imagery collected in 2017 and 2018 by NSW Spatial Services at the Department of Finance Services and Innovation

(https://maps.six.nsw.gov.au/arcgis/rest/services/public/NSW_Imagery/MapServer). The 1 ha hexagon was classed as no or low ecological value if were the area contained sporting fields, buildings, car parks and/or streets. If the 1 ha hexagon could not be classified, it was selected as part of the subset of 1 ha hexagons requiring a field/ on-ground measurement. The final subset of 1 ha hexagons was then constrained by (safe) accessibility to the locations on ground and permissions by landholders to access their properties.

The locations of the final subset of 1 ha hexagons were provided to field staff to assess the presence or absence of the individual map attributes (see Section 13.2). The field staff were not informed of whether the location fell within an area attributed as high ecological value or not on the map, to ensure that the field measurements were as independent as possible.

13.2 Field measurements

The field measurements were completed by subject matter experts and field practitioners:

- Presence of absence of Key Fish Habitat was determined by Fisheries Officers at the Department of Planning and Industry – Fisheries and specialist aquatic ecologists at the Environment, Energy and Science Group of DPIE
- Assessments of the River Styles Recovery Potential, Geomorphic Condition, and River Style Type were undertaken by geomorphologists, who conducted preliminary surveys to familiarise themselves with the catchment and then used desktop assessments including air photo interpretation, terrain modelling and stream sinuosity measures to complete the analyses
- Vegetation assessments were undertaken by accredited vegetation ecologists. Rapid vegetation surveys were used to determine the presence or absence of native vegetation. If one or more native vegetation communities were present, a 20 x 20 m

vegetation survey plot was placed within the 1 ha hexagon to determine Plant Community Type according to the NSW BioNet Vegetation Classification database.

Additional vegetation datasets were sourced and adopted into the accuracy assessment, in cases where the data was found to be independently collected (i.e. unrelated to the vegetation mapping projects) and consistent with the accredited survey plot sampling method. These additional vegetation datasets included:

- 1) Vegetation survey plots from the NSW BioNet Systematic Flora Survey database
- 2) Recently collected vegetation survey data provided by the Conservation and Sustainability Branch of DPIE

In cases where the vegetation plot data provided complete coverage of the 1 ha hexagon, the data was included into the overall map accuracy assessment (see Section 13.3). All vegetation survey plot data were included to assess the accuracy of the relevant individual spatial datasets making up the map such as the riparian vegetation and woody wetland datasets (Section 13.4).

A total of 396 field and desktop measures were used for the accuracy assessment (Table 5). These fell within a total of 161 1ha hexagons.

Table 5 Number of field measures (sampling sites) used for assessing the accuracy of datasets underpinning the map of high ecological value waterways and water dependent ecosystems

ATTRIBUTE	METHOD	NEW FIELD MEASURES	EXISTING FIELD MEASURES	TOTAL NUMBER OF FIELD MEASURES
Key Fish Habitat	Field	60	0	60
River Styles	Field and Desktop	68	0	68
Vegetation Plots	Field	136	66	202
Attribution of 1 ha hexagons as having high ecological value or not	Desktop	66	0	66
Grand total number of field measures used in accuracy assessment		330	66	396
Grand total number of 1 ha hexagons used in accuracy assessment				*161

* Multiple vegetation plots used to assess the accuracy of a single 1 ha hexagon, and the different totals for the number of field measures.

13.3 Overall accuracy of the map

The overall accuracy of the map was high according to the % of agreement between the field measurements and mapped attributes (93.2%), and the Kappa Statistic (0.86 ± 0.04). Only a small number of 1 ha hexagons were incorrectly attributed as having no or little ecological value, indicating a very low omission error (Table 6). Commission error was even lower, with only two 1 ha hexagons incorrectly attributed as having high ecological value. The majority of the 1 ha hexagons that were attributed as having ecological value, were correctly classified into the protect areas of the map. Field measurements also confirmed that the 1 ha hexagons classified as improve areas in the map still contained ecological value but to a lesser degree.

Table 6 Overall accuracy of the map of high ecological value waterways and water dependent ecosystems and attributes

MAP AND ATTRIBUTES	OVERALL ACCURACY (%)	KAPPA STATISTIC (\pm standard error)
High ecological value waterways and water dependent ecosystems - overall	93.2	0.86 ± 0.04
Key Fish Habitat	84.9	0.06 ± 0.06
River Styles – Geomorphic Condition	55.6	0.04 ± 0.09
River Styles – Recovery Potential	38.3	0.11 ± 0.07
River Styles – Type	51.1	0.08 ± 0.07
Endangered Ecological Communities (Plant Community Types)	67.5	0.54 ± 0.04
Riparian vegetation and wetlands	84.3	0.63 ± 0.05

13.4 Accuracy of the individual map attributes

The accuracy of the individual datasets that make up the map were also assessed, as they provide an indication of the sources of error. It is important note, however, that many of the individual datasets have been produced by other agencies for specific purposes. This means that the accuracies presented below are relevant only to the interpretation of the map of high ecological value waterways and water dependent ecosystems.

13.4.1 Key Fish Habitat

A total of 126 1 ha hexagons were independently assessed for the presence or absence of Key Fish Habitat. There was good agreement between the field measurements and the mapped Key Fish Habitat, with an accuracy of 84.9% (Kappa Statistic = 0.69 ± 0.06).

13.4.2 River Styles

Many streams in the Wianamatta-South Creek Catchment were not mapped in the River Styles dataset. While assessment was therefore limited to mapped streams, it still showed low agreement between the field measurements and the River Styles areas was found to have low agreement with the mapped River Styles Type (51%, Kappa Statistic = 0.08 ± 0.07), Geomorphic Condition (38%, Kappa Statistic = 0.11 ± 0.07) and Recovery Potential (38%, Kappa Statistic = 0.11 ± 0.07). This is primarily due to incorrect ‘absences’ of the River Style attribute. For example, the most important River Style Type in the Wianamatta-South catchment requiring protection is the ‘Chain of Ponds’. Very few Chain of Ponds are

identified in the River Styles map compared to the number observed in the field. It is worth noting however that the location of the mapped Chain of Ponds were accurately confirmed and that other attributes in our map of high ecological value waterways and water dependent ecosystems ensured that the locations of the unmapped Chain of Ponds were included in the protect areas anyway.

13.4.3 Endangered Ecological Communities (water dependent vegetation)

The accuracy of the individual Plant Community Types in the vegetation dataset (see Appendix 1) was assessed as these correspond to the Endangered Ecological Communities, which were included in the map of high ecological value waterways and water dependent ecosystems. A full list of the Plant Community Types and their name codes, corresponding map unit, and dependencies on water is shown in Table 15 of Appendix 6.

A comparison between the field measurements and mapped Plant Community Types indicates a moderate accuracy of 67.5% (and Kappa Statistic = 0.54 ± 0.04). The largest source of error occurred in areas that were mapped as non-native but were assessed as native in the field. Some of this omission error is likely to be a result of small patches of native vegetation not being large enough to be identified for inclusion in the vegetation dataset.

13.4.4 Riparian vegetation and wetlands

Field measurements from the vegetation plots within the 1 ha hexagons were grouped into either water dependent (riparian and wetland) and not water dependent and compared to the mapped riparian vegetation and wetland datasets developed for this study. The results suggest good agreement, with an accuracy of 84.3% (and Kappa Statistic = 0.63 ± 0.05).

14. Appendix 5 – Maps of datasets

This Appendix provides maps of the final datasets that were used in Marxan. Descriptions of the datasets and their sources are provided in Appendix 1. The datasets are presented in the same order as they are described in Appendix 1.

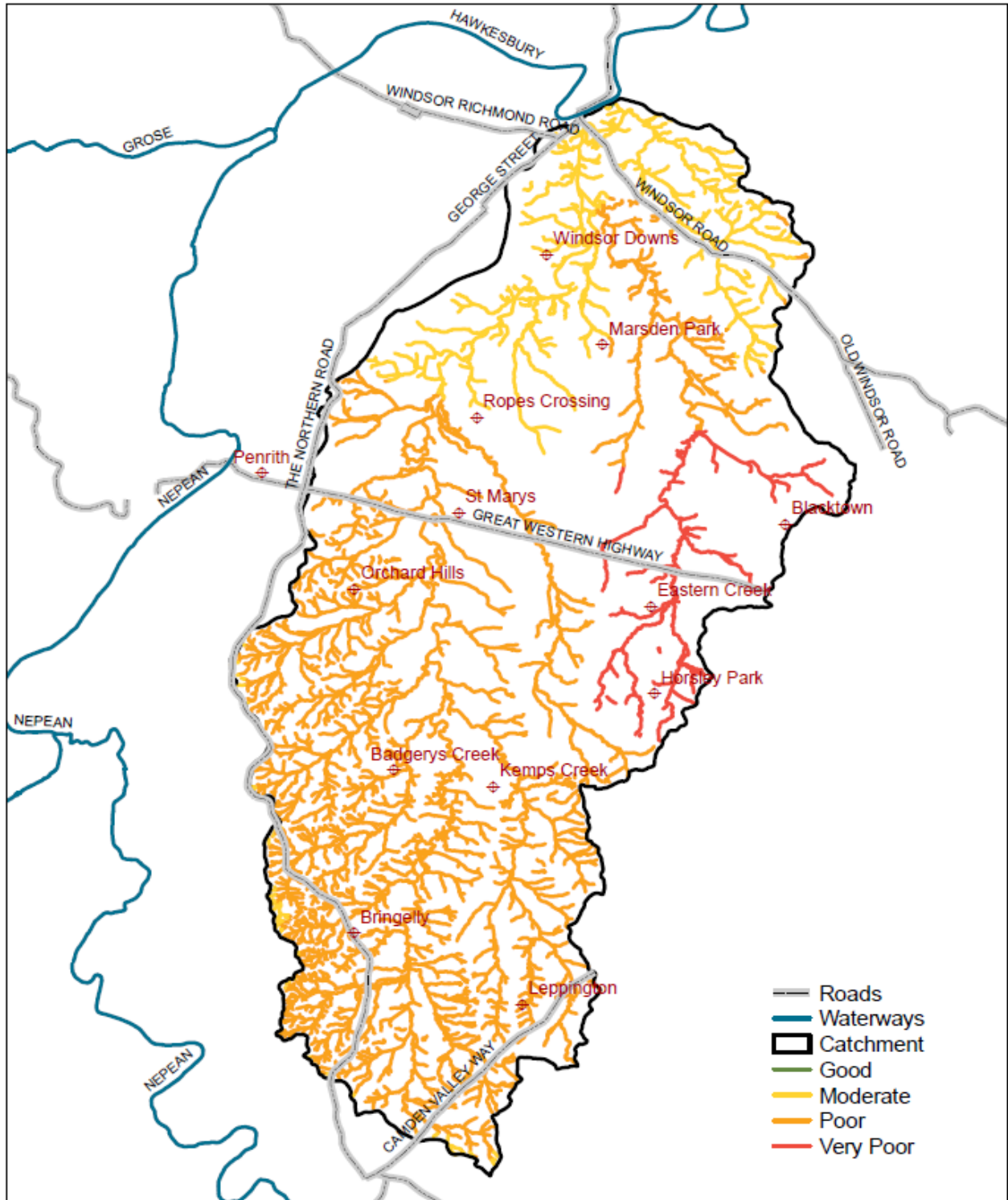


Figure 12 River Biodiversity Condition Index

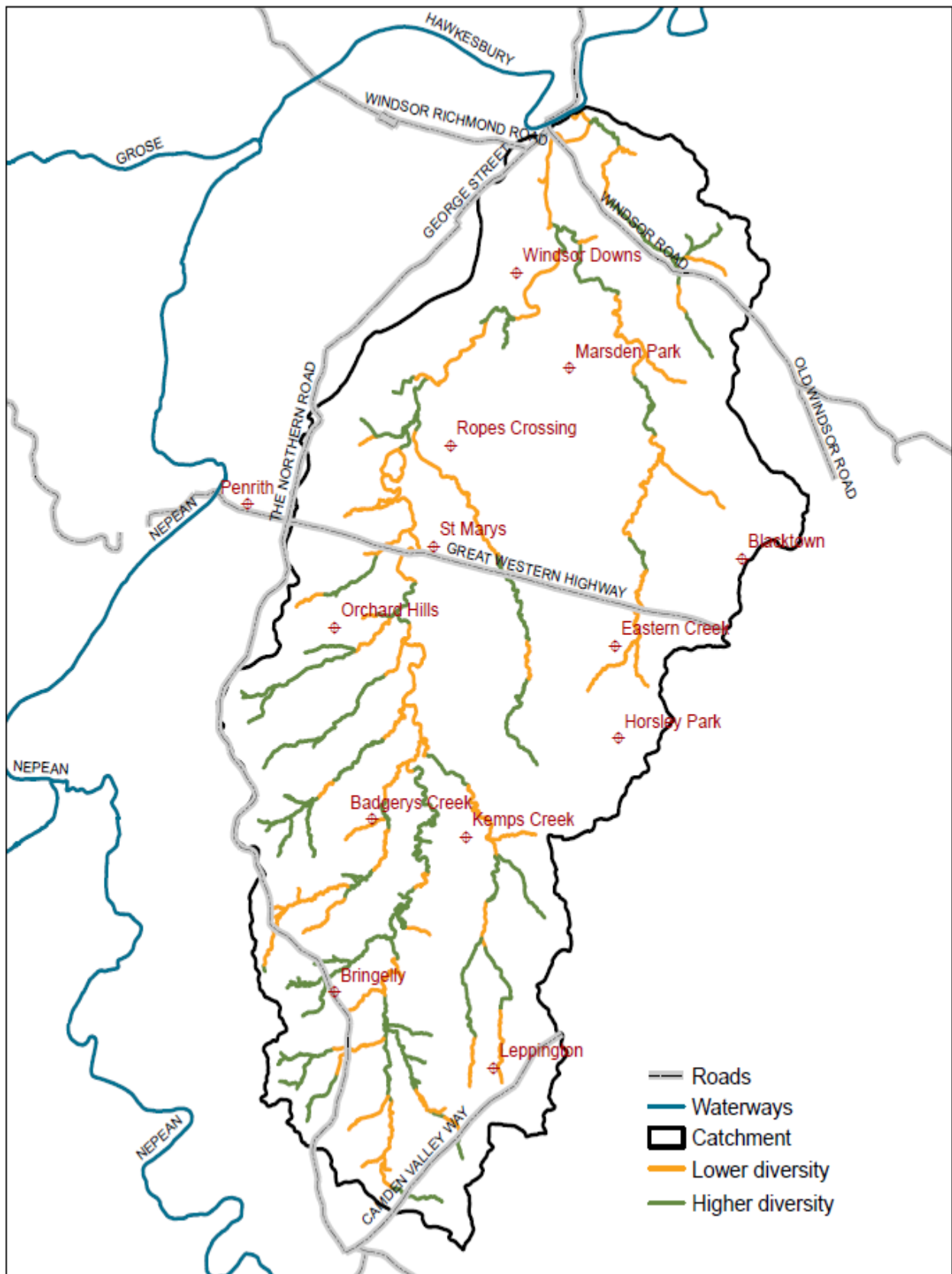


Figure 13 Shannon-Weiner Index.

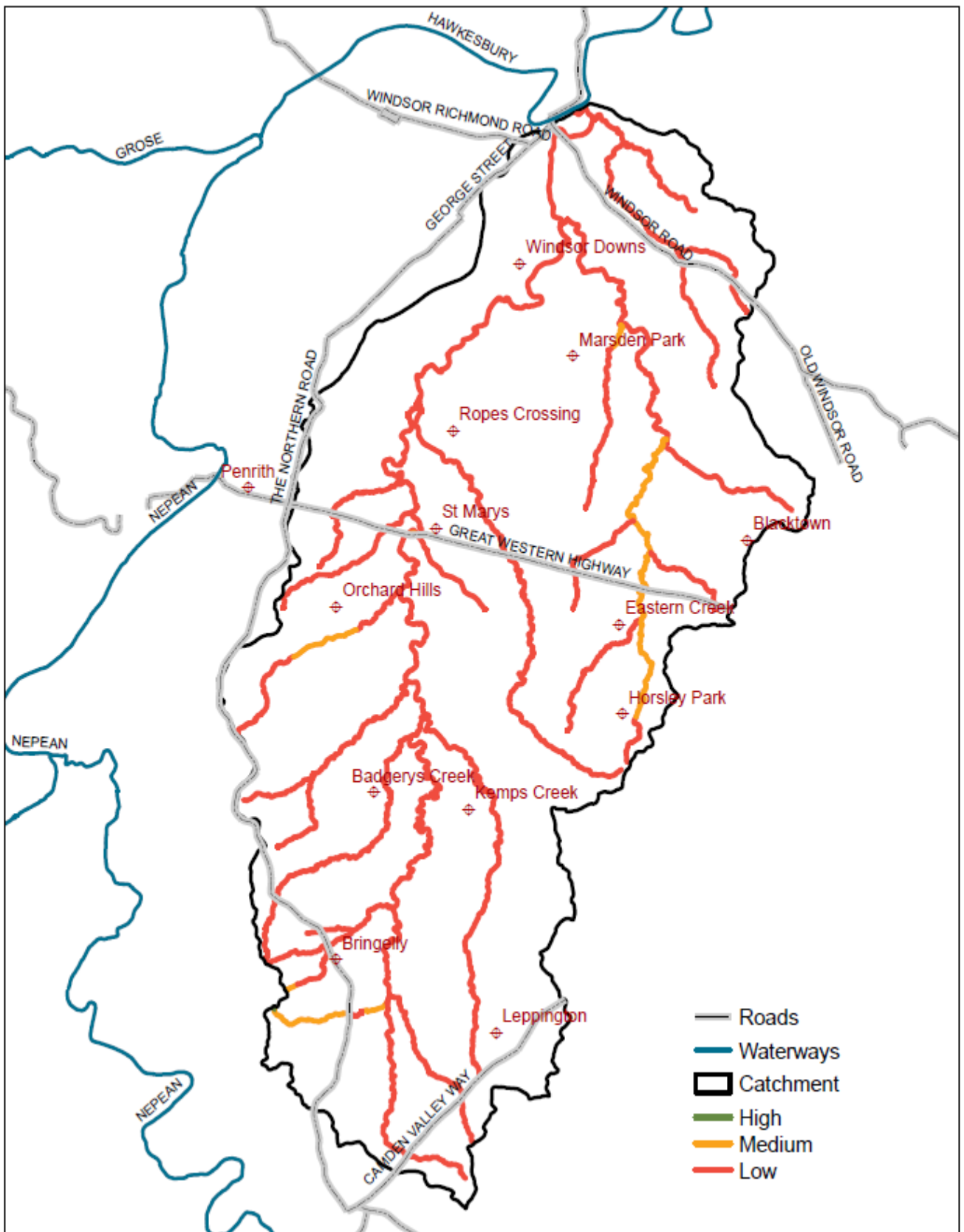


Figure 14 High Ecological Value Aquatic Ecosystems.

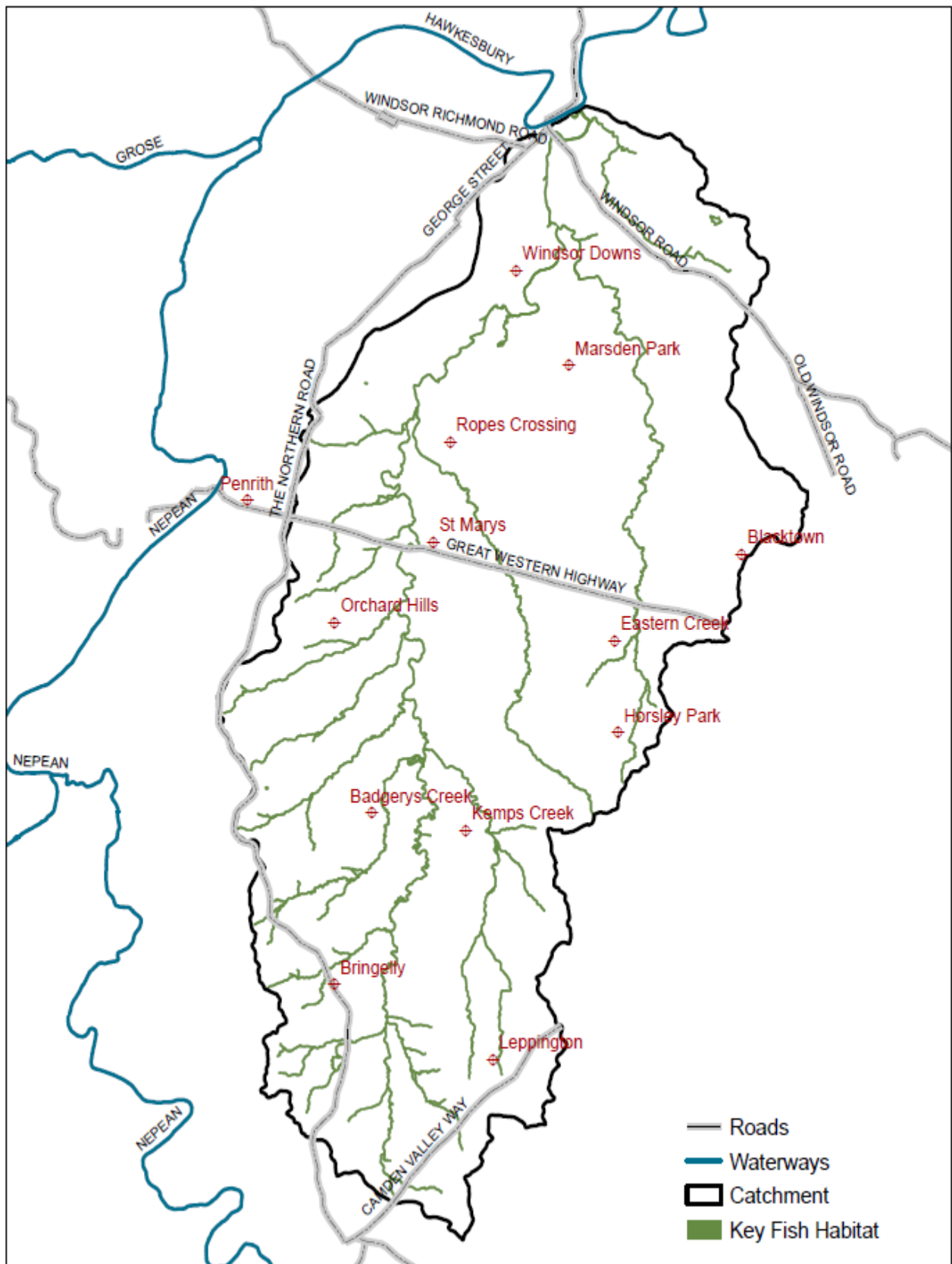


Figure 15 Key Fish Habitat.

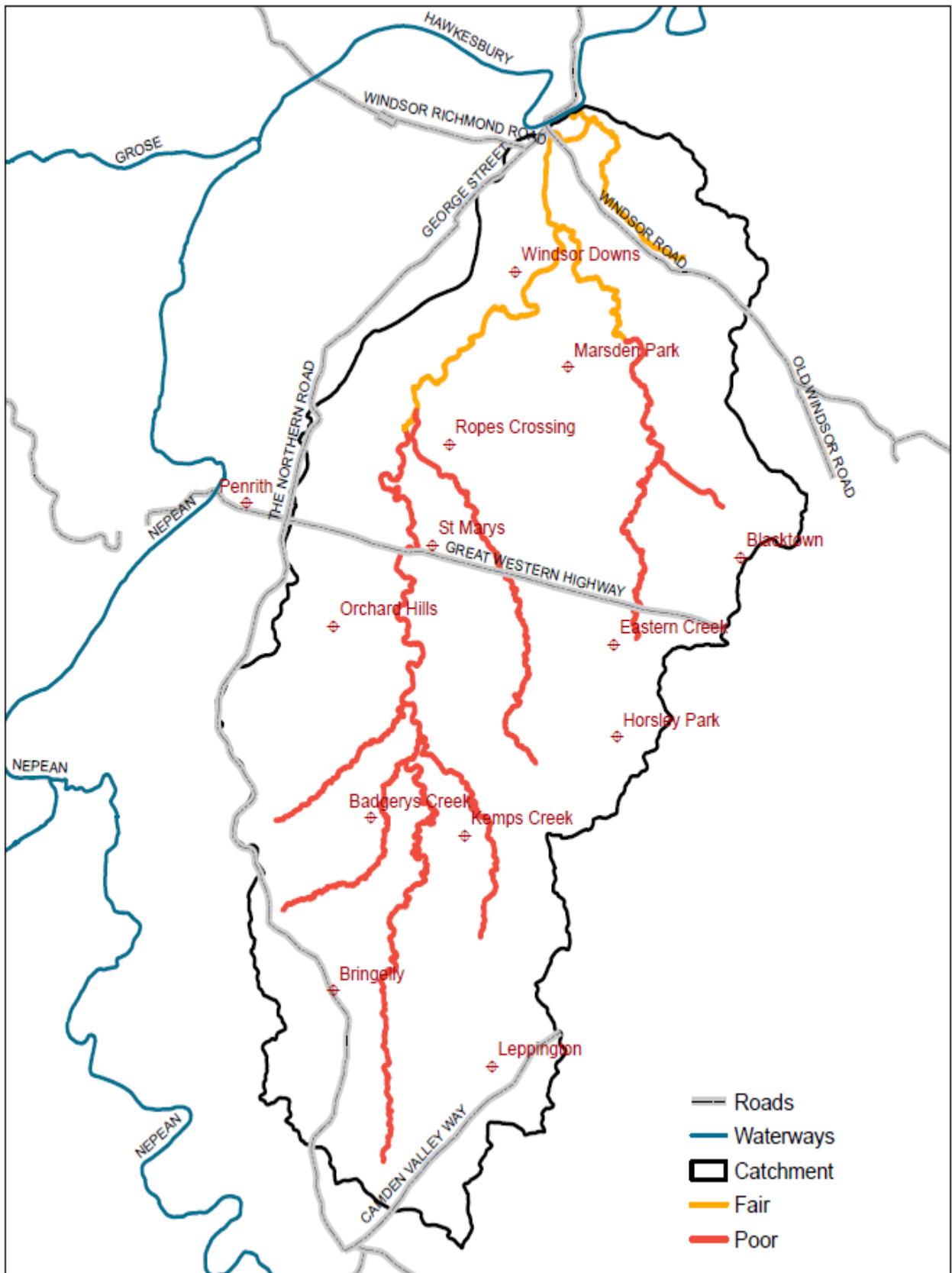


Figure 16 Fish Condition.

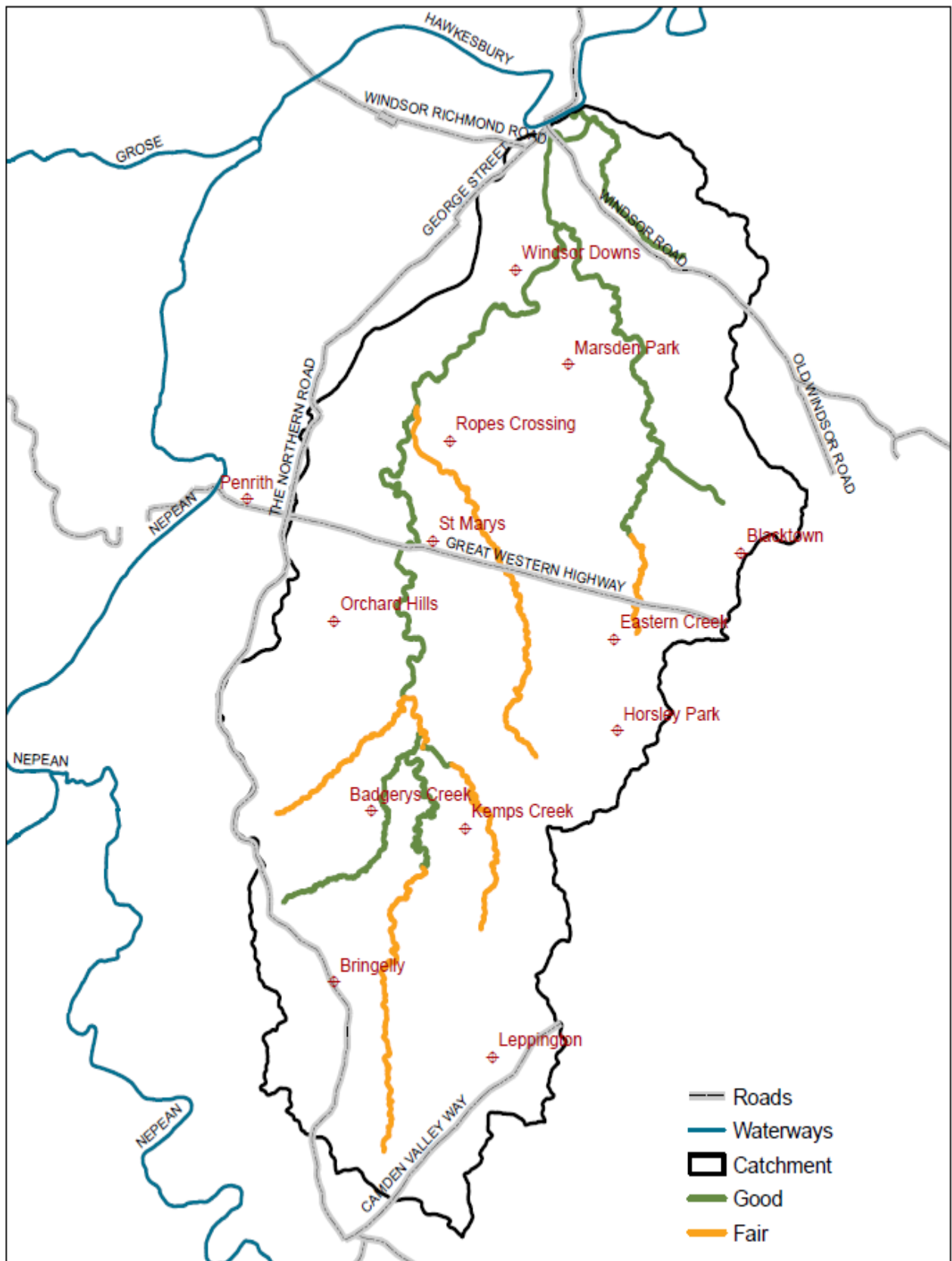


Figure 17 Fish Nativeness.

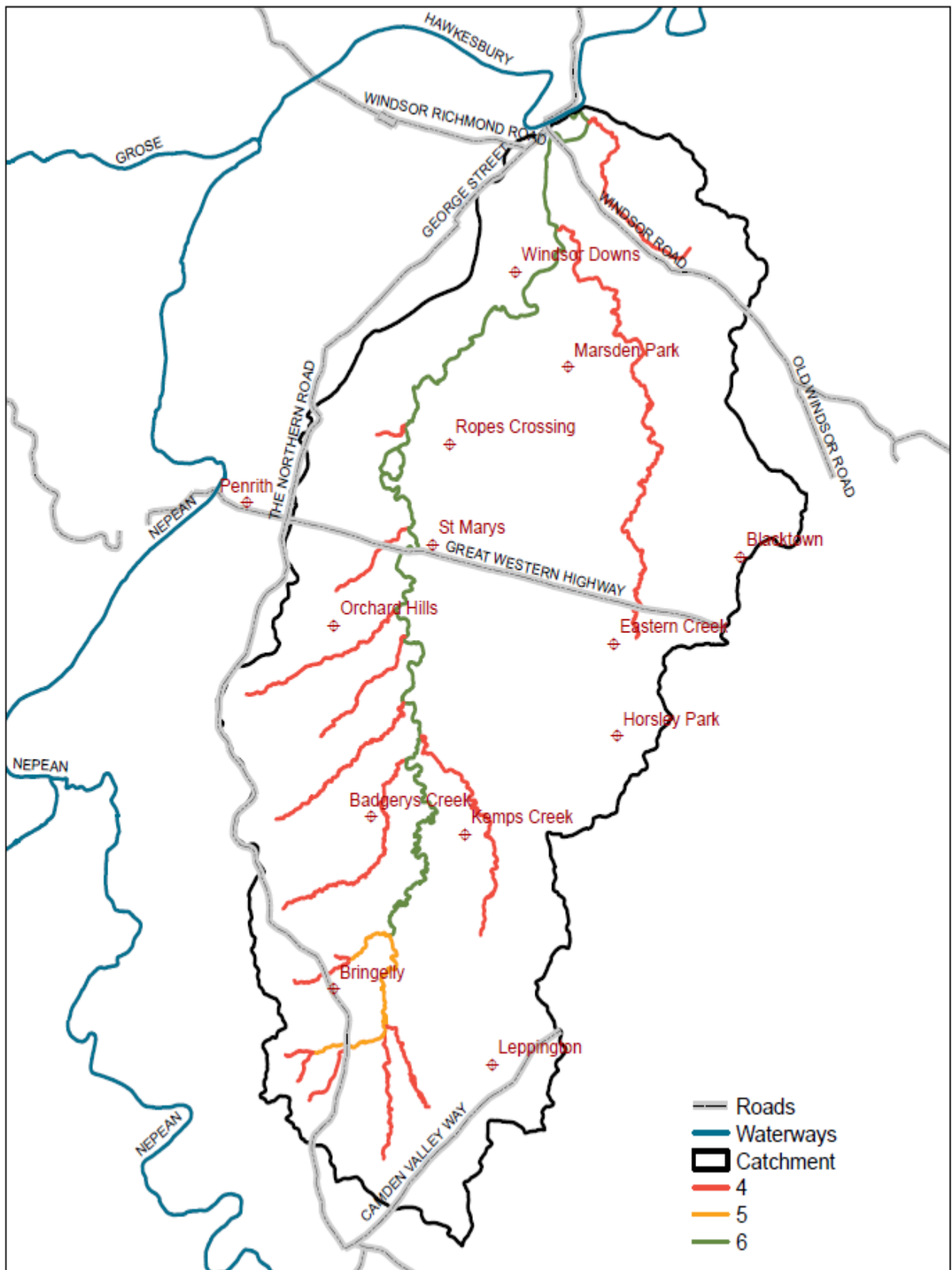


Figure 18 Strahler Stream Order, greater than or equal to 4th Order Streams.

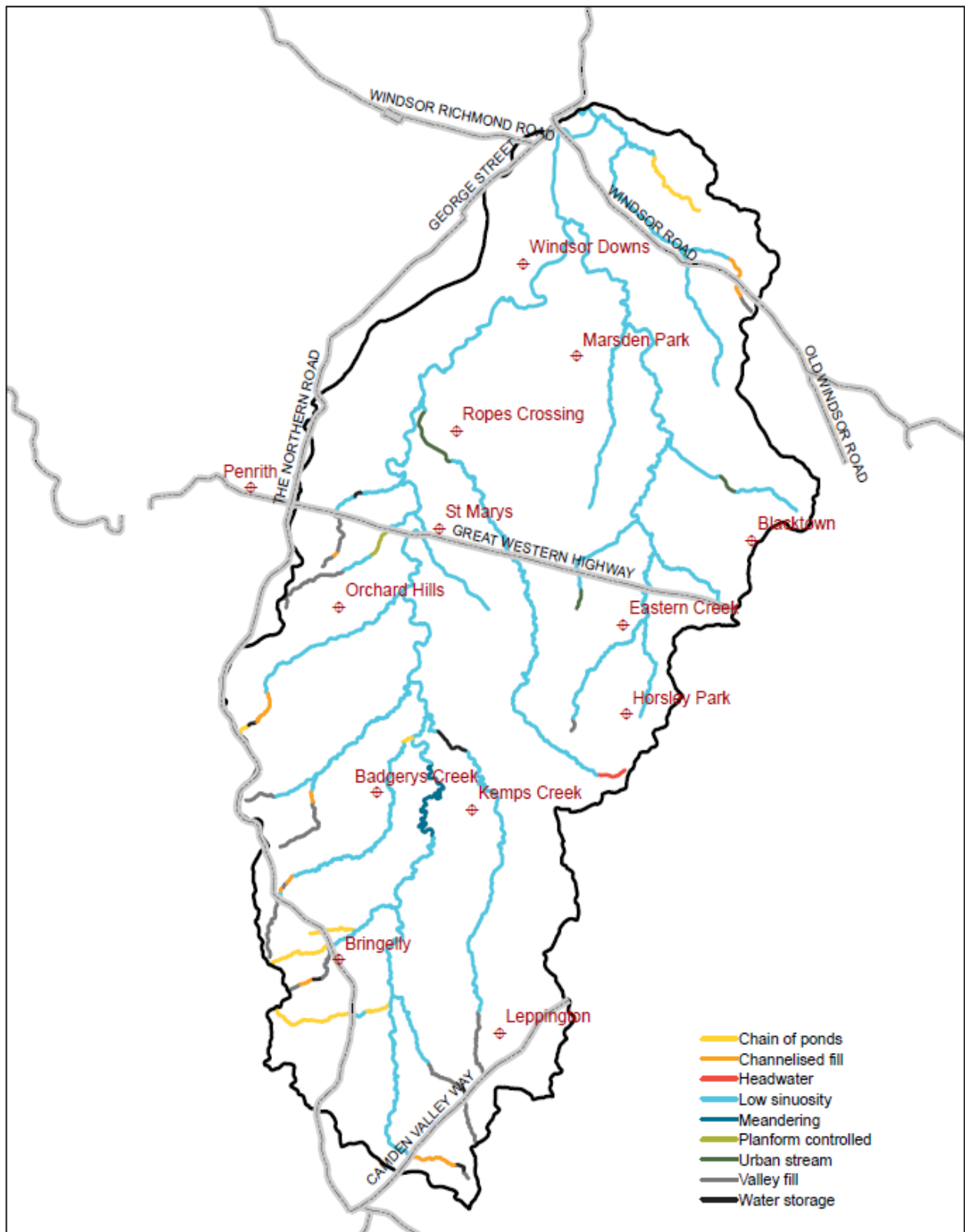


Figure 19 River Styles Type.

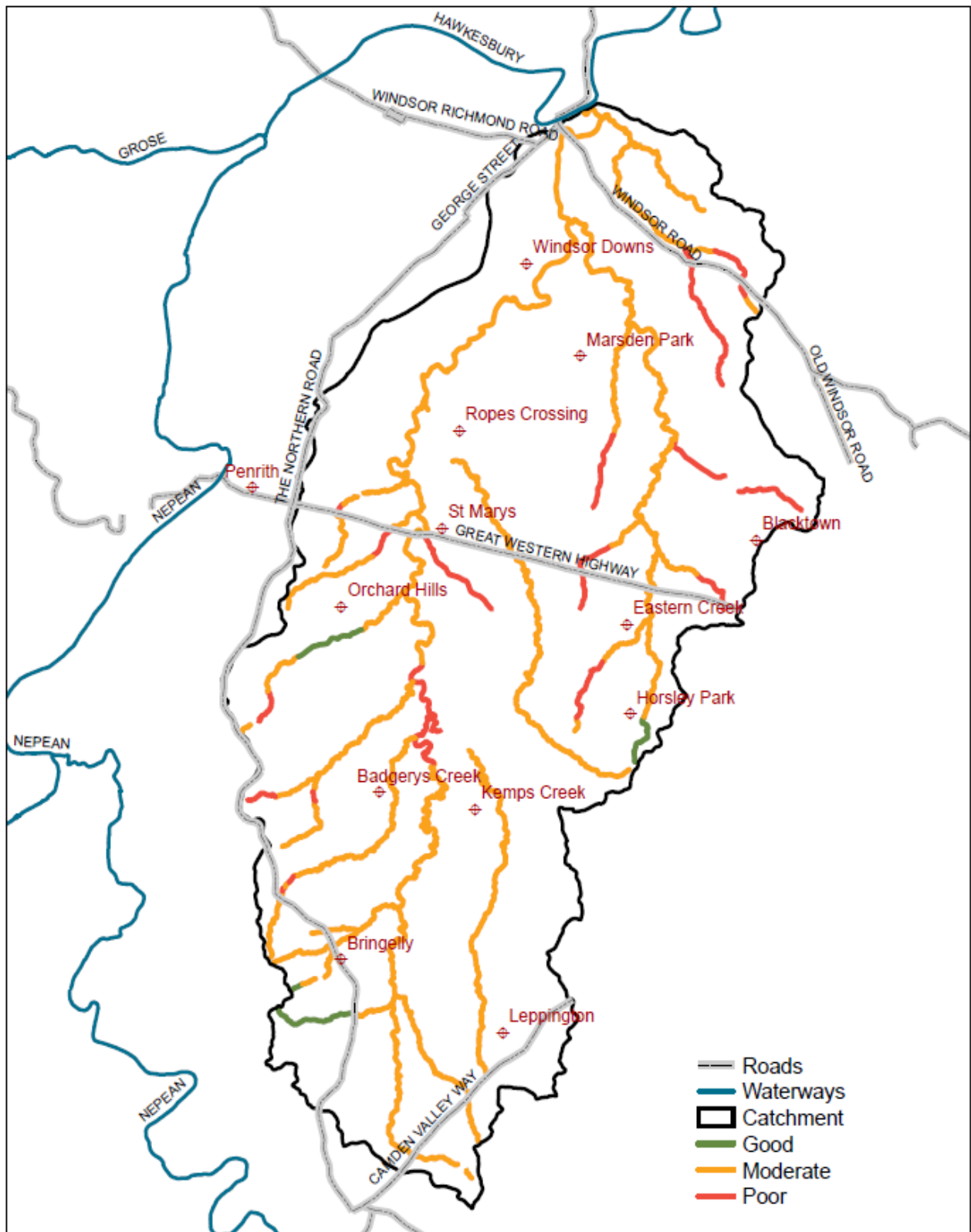


Figure 20 River Styles Geomorphic Condition.

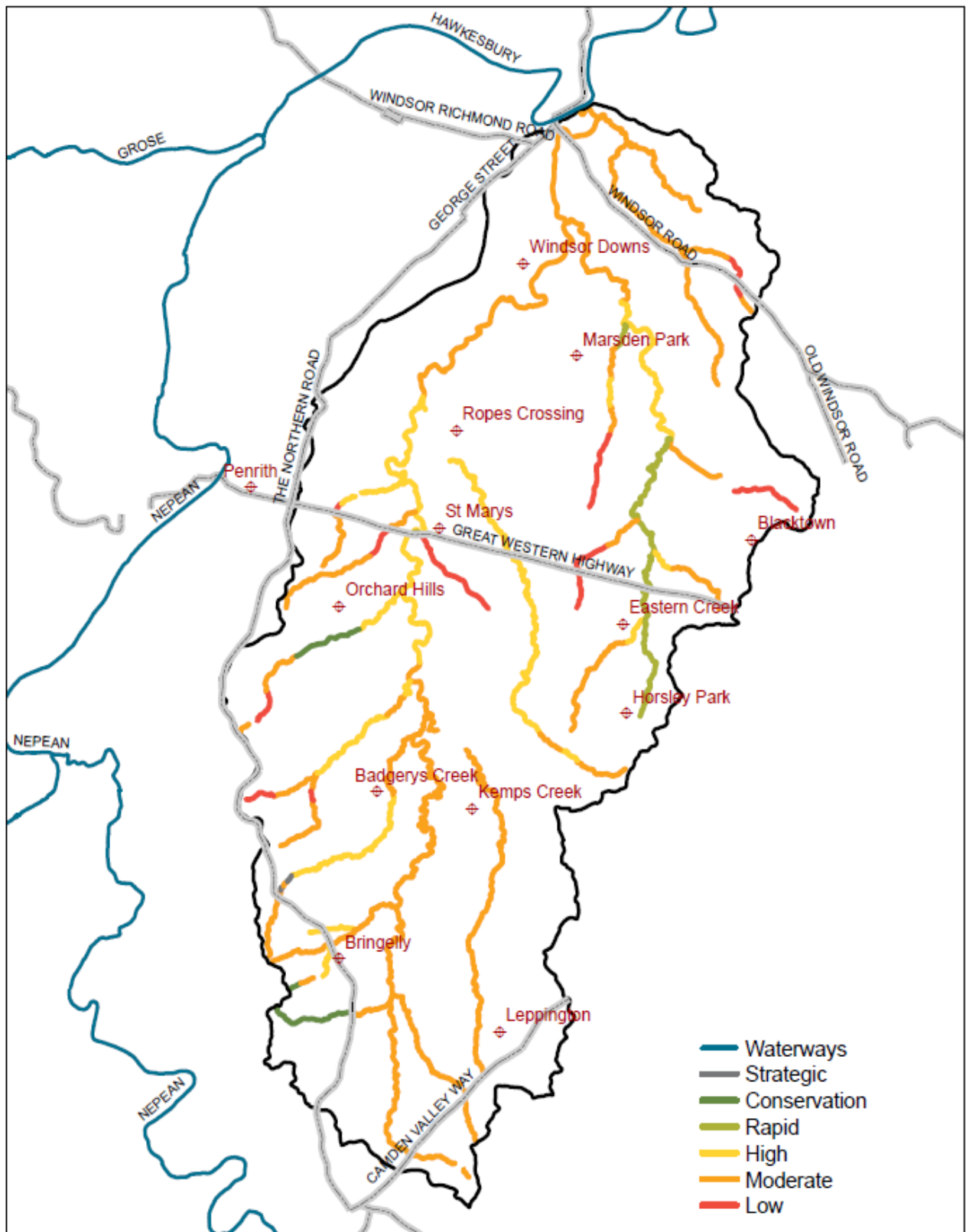


Figure 21 River Styles Recovery Potential.

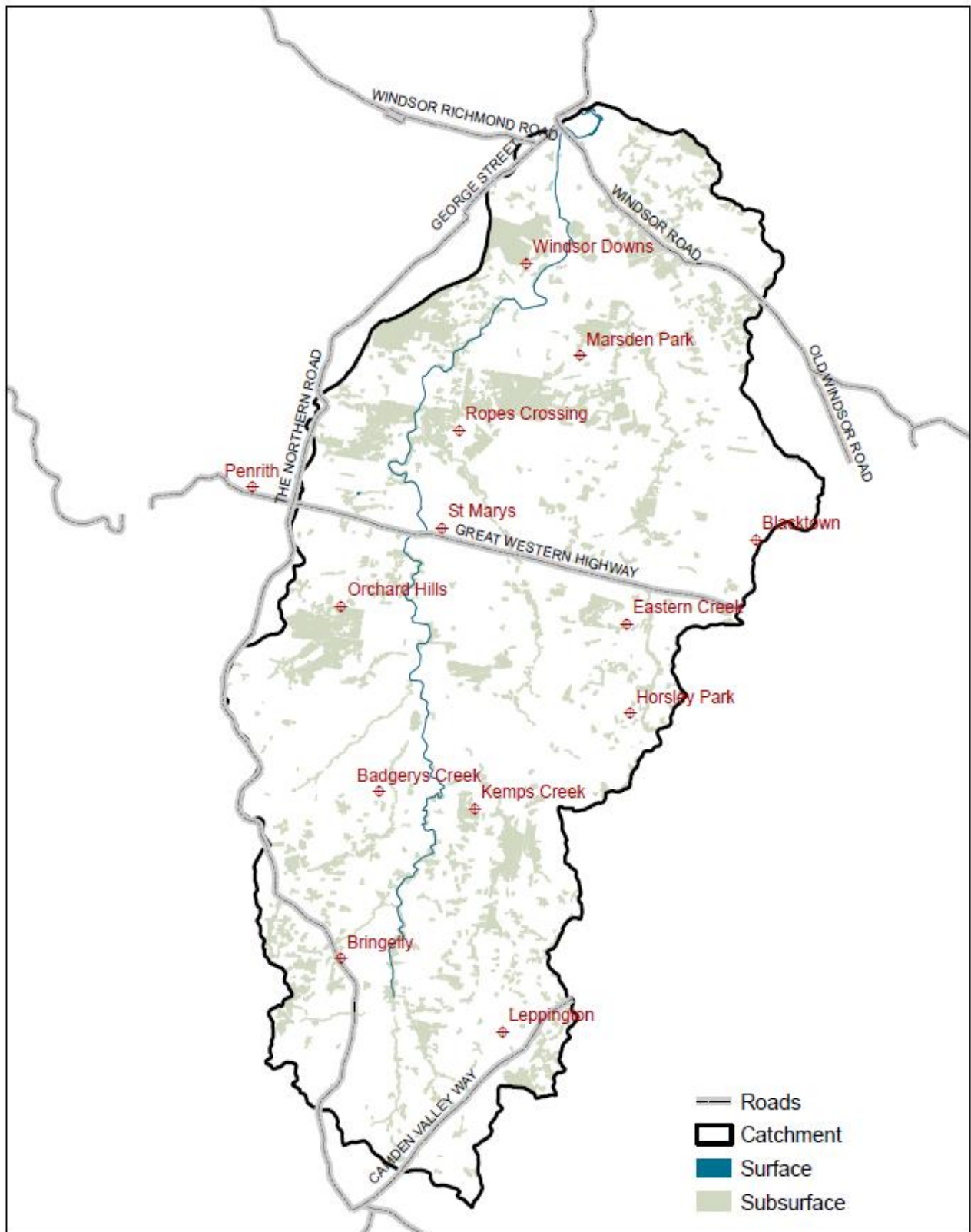


Figure 22 Groundwater Dependent Ecosystems.

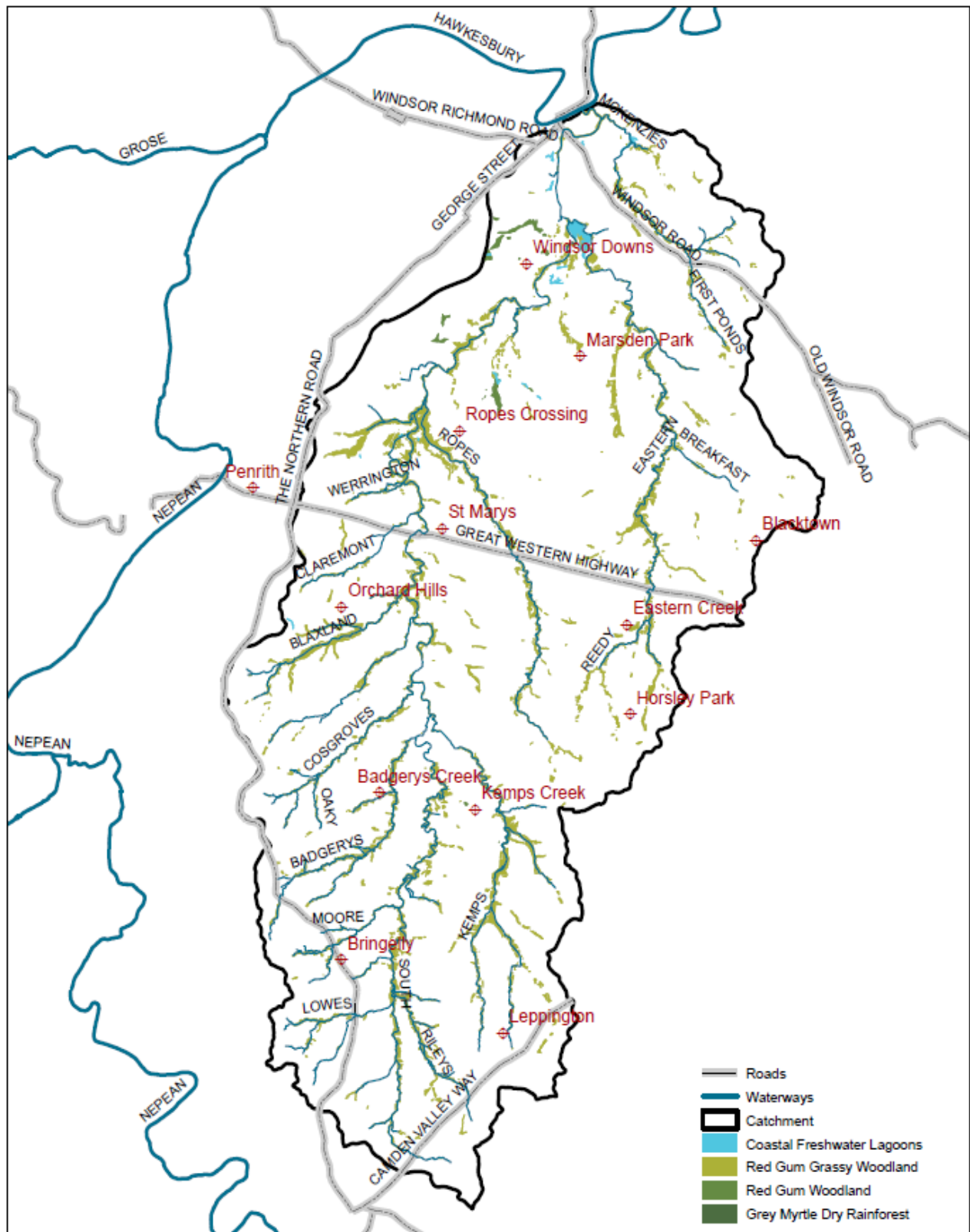


Figure 23 Endangered Ecological Communities.

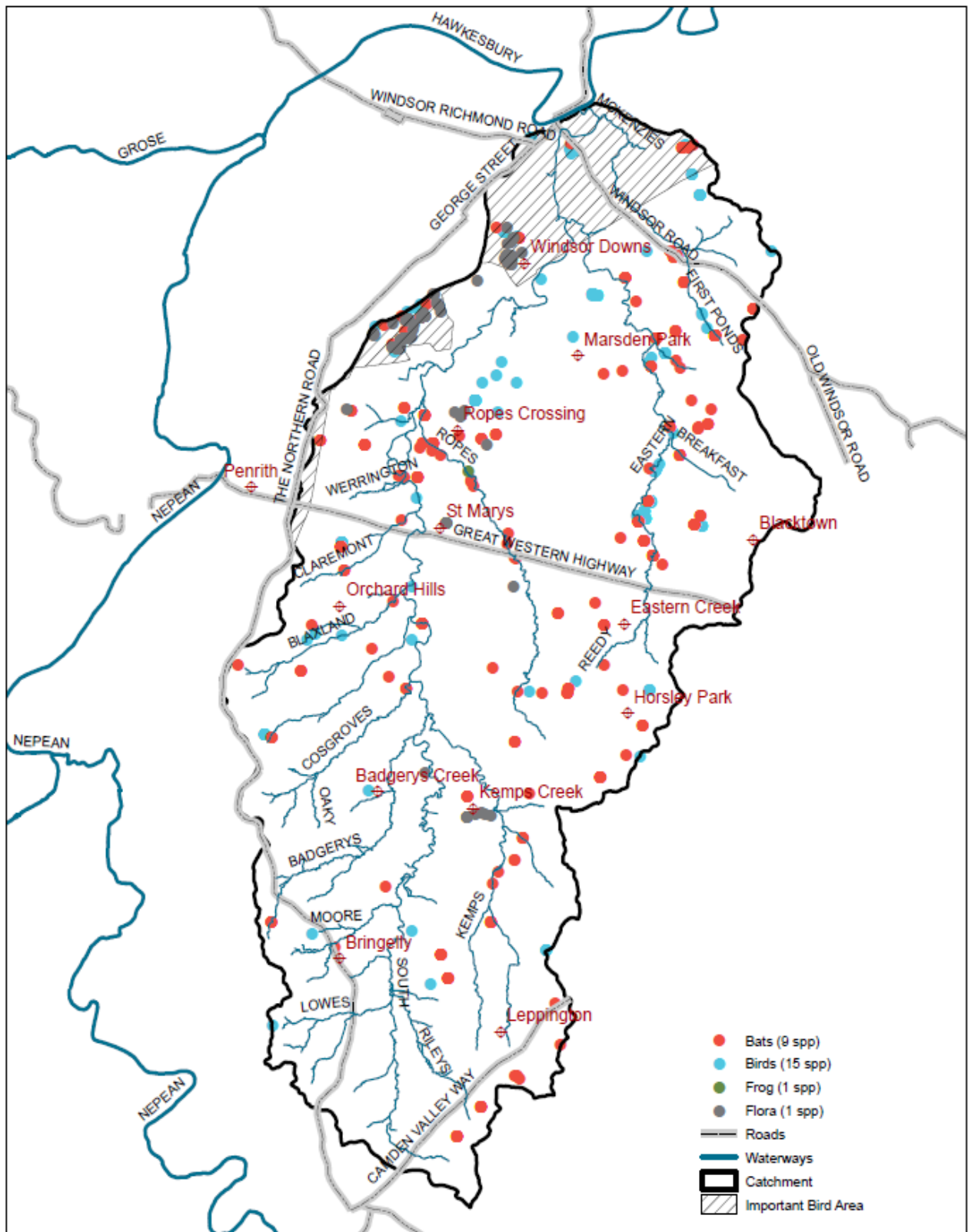


Figure 24 Important Bird Areas and species sightings.

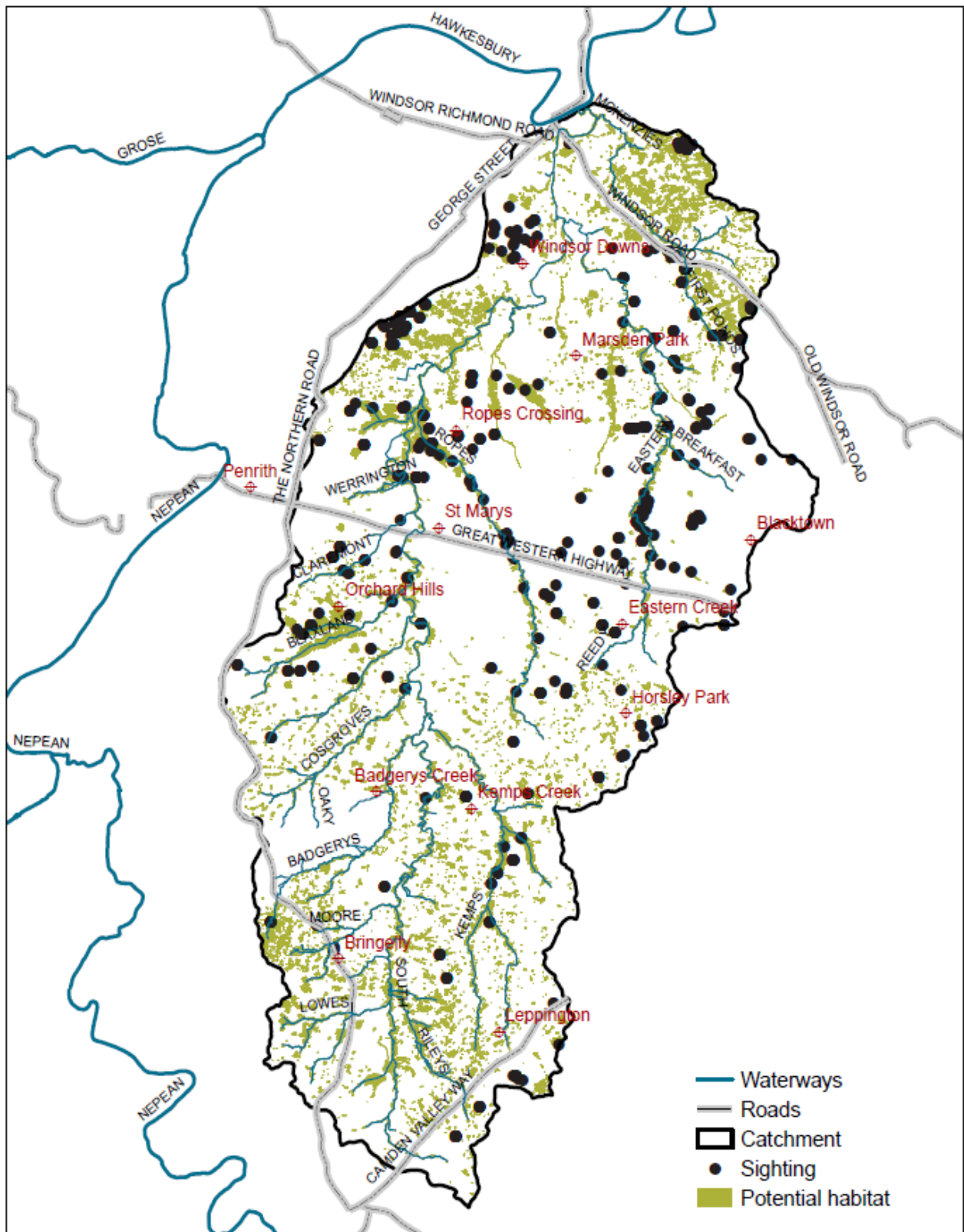


Figure 25 Water dependent Flying Fox habitat and sightings.

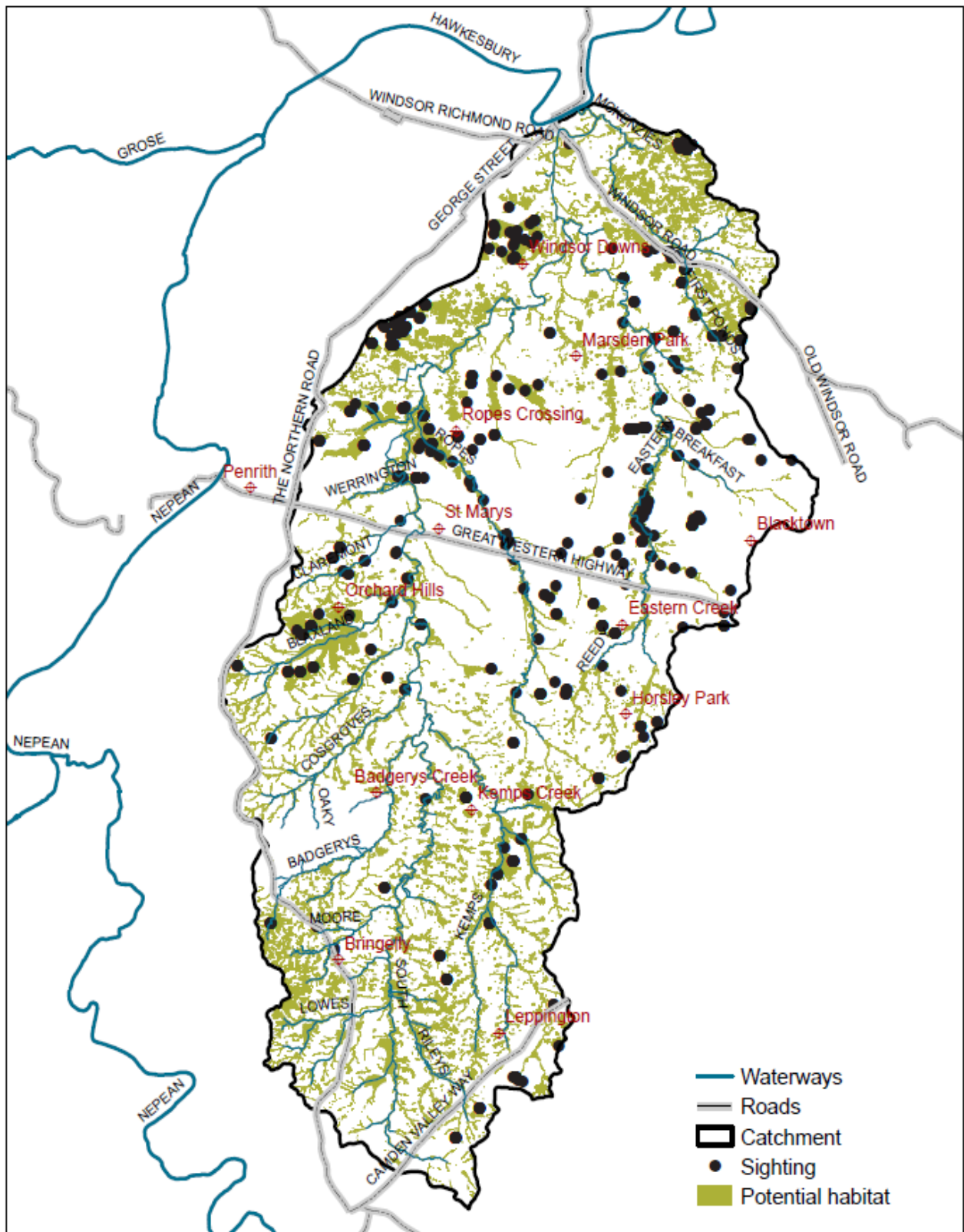


Figure 26 Water dependent Microbat habitat and sightings.

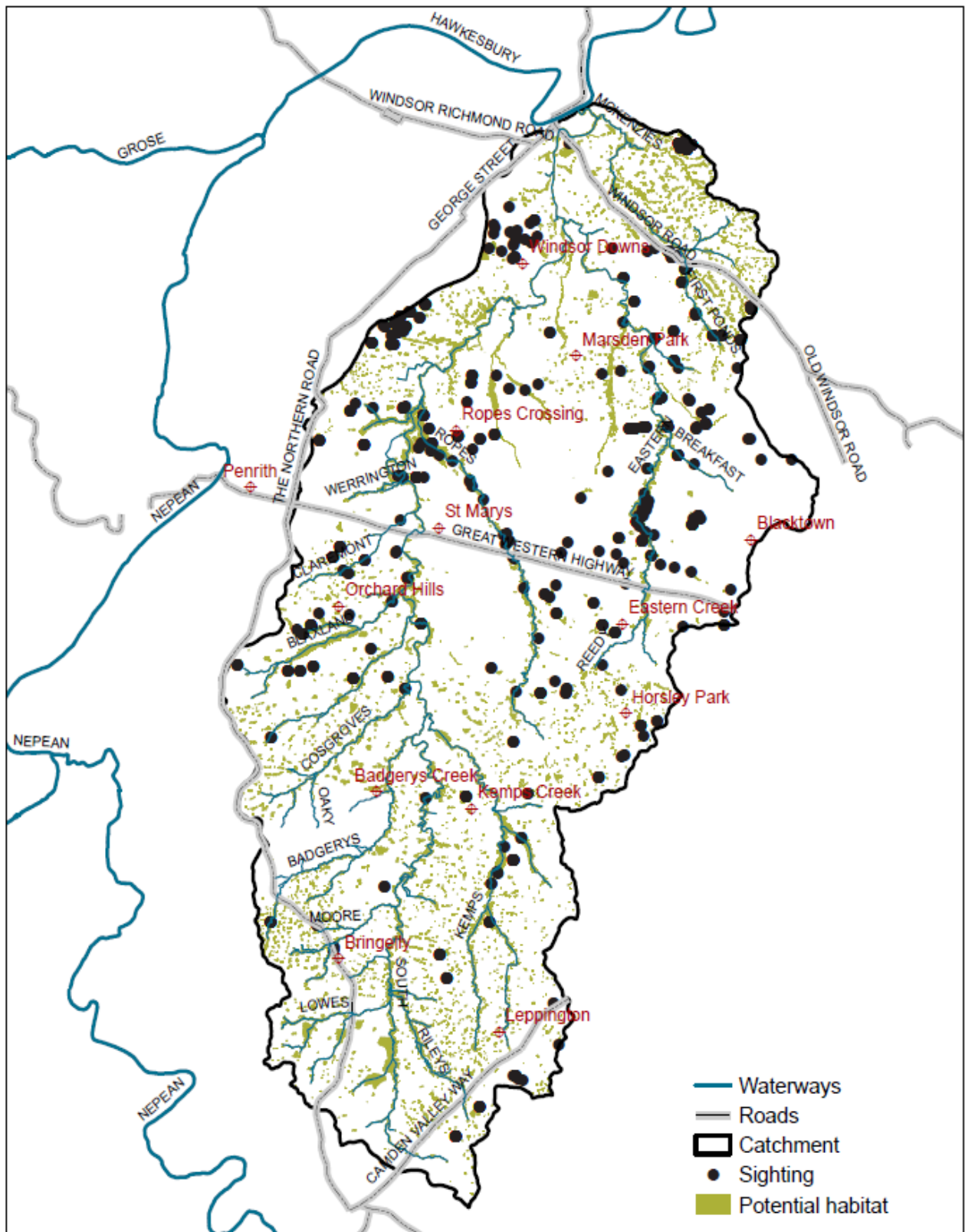


Figure 27 Water dependent Southern Myotis habitat and sightings.

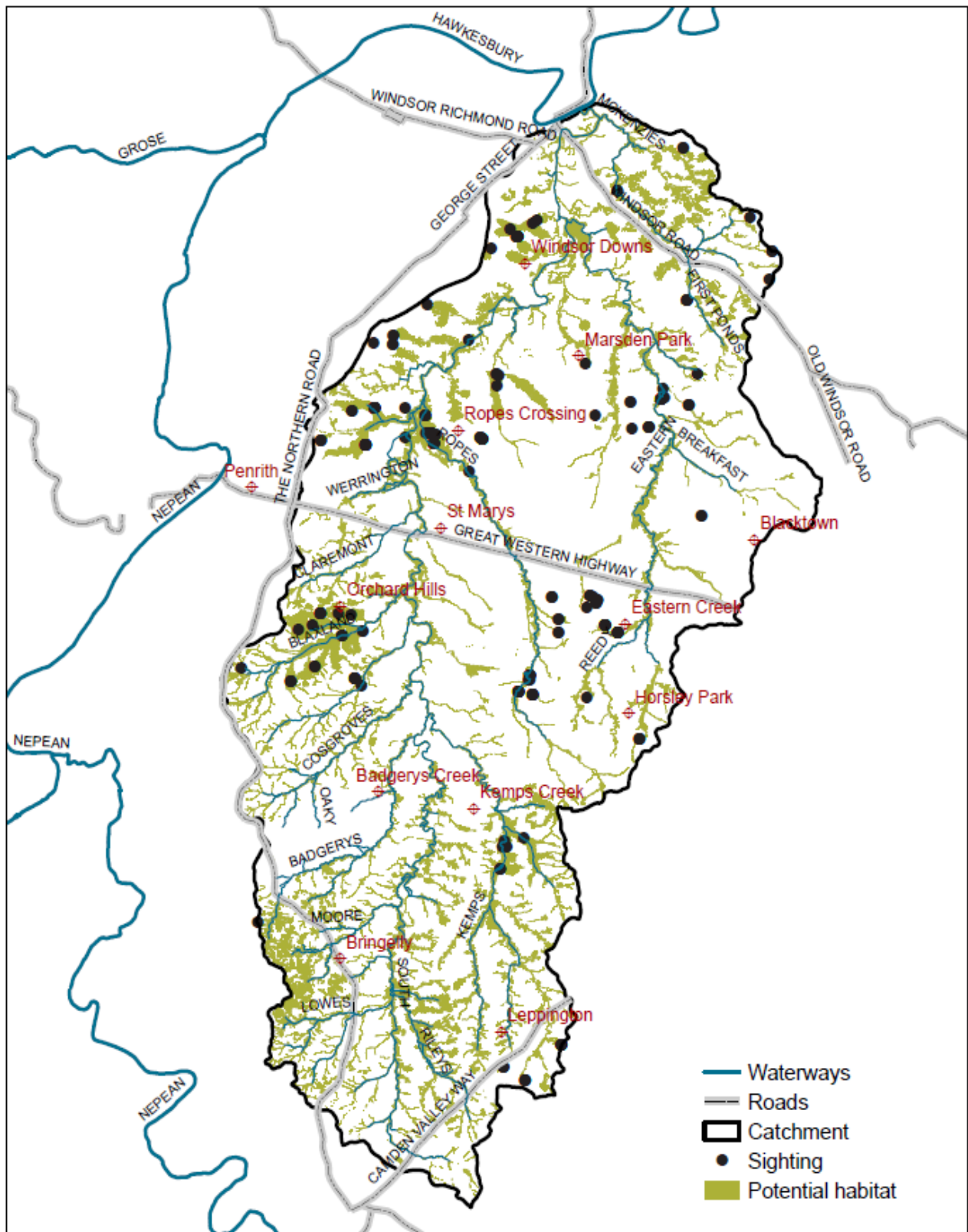


Figure 28 Tree Frog habitat and sightings.

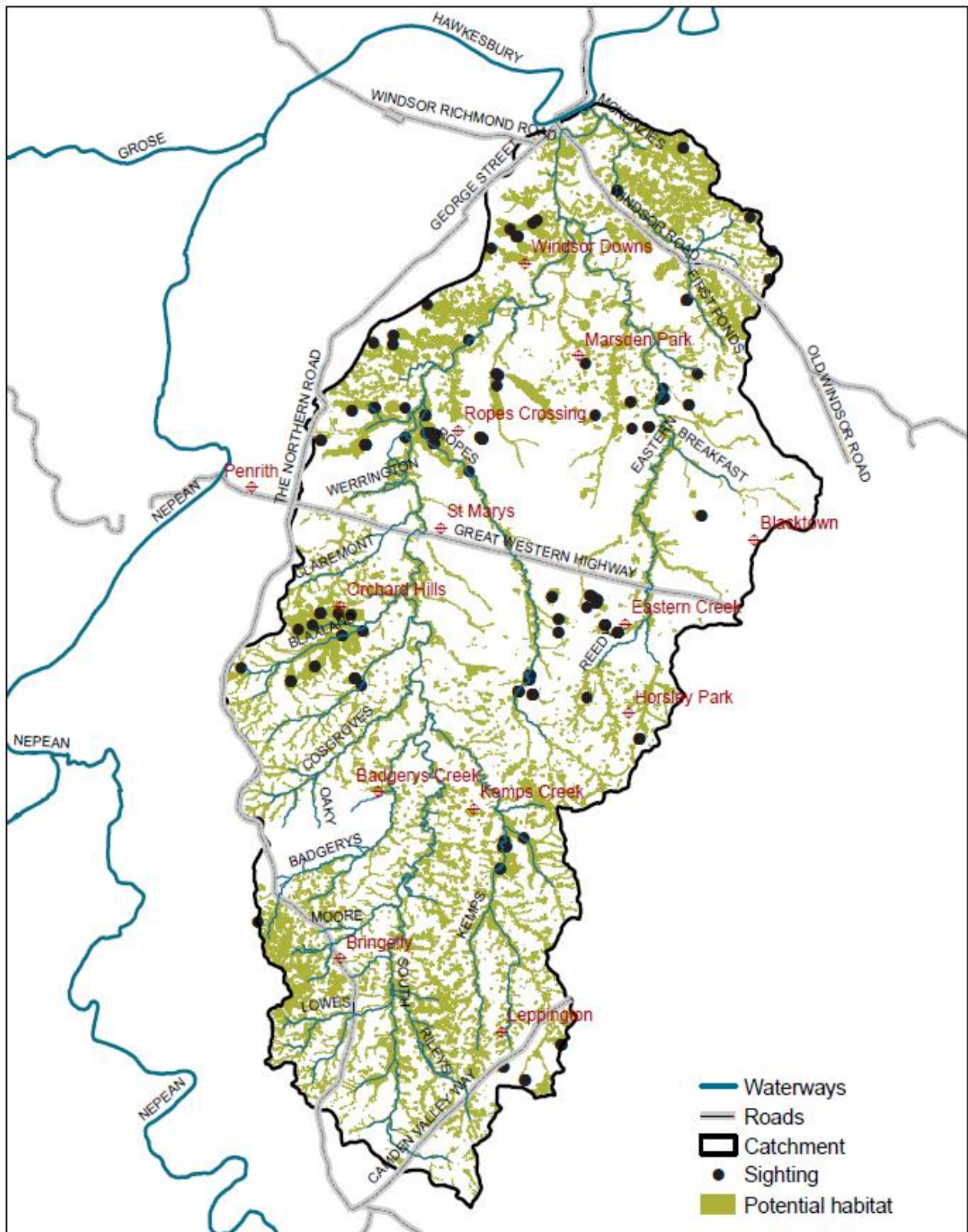


Figure 29 Ground and Burrowing Frog habitat and sightings.

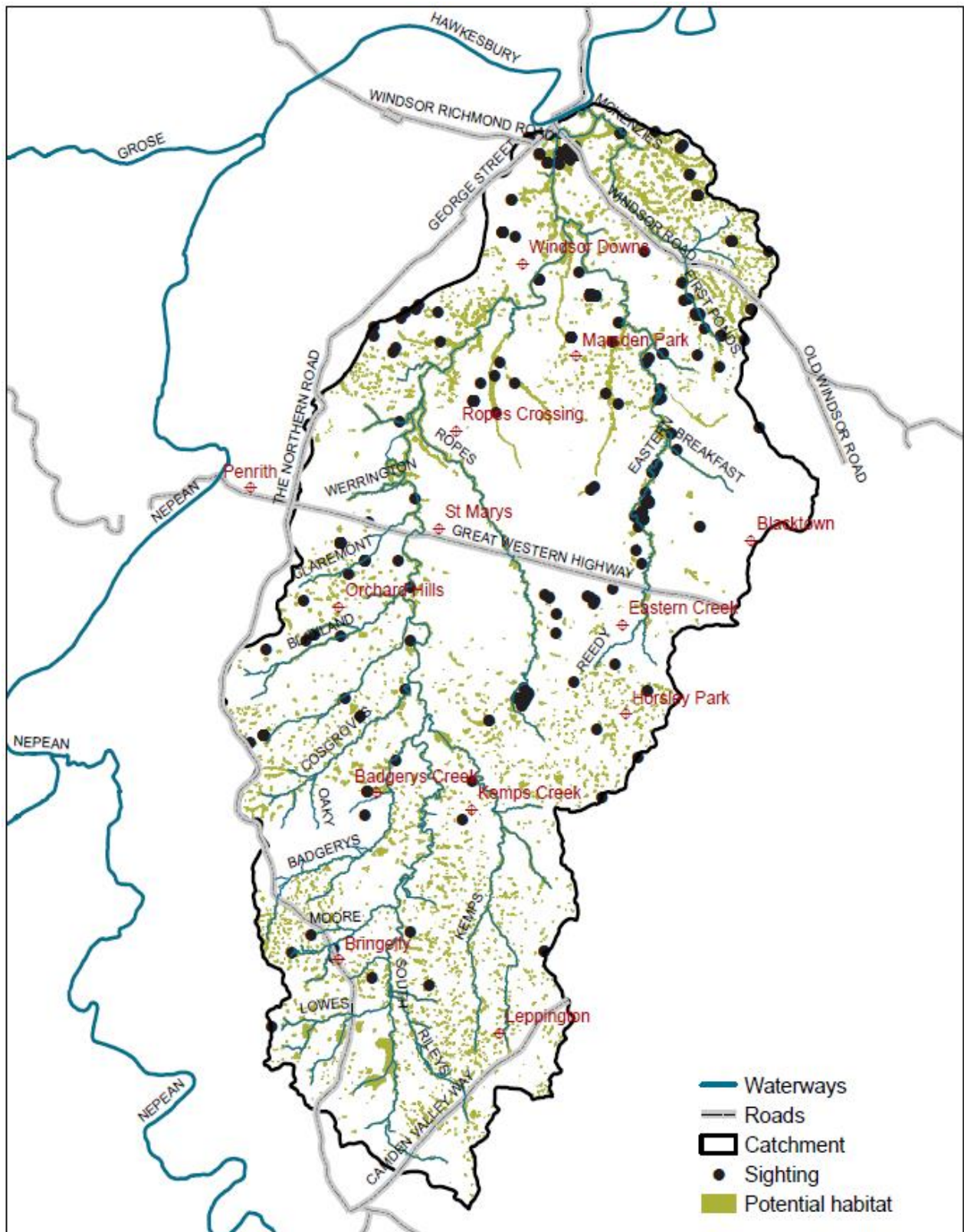


Figure 30 Large Bird Wader habitat and sightings.

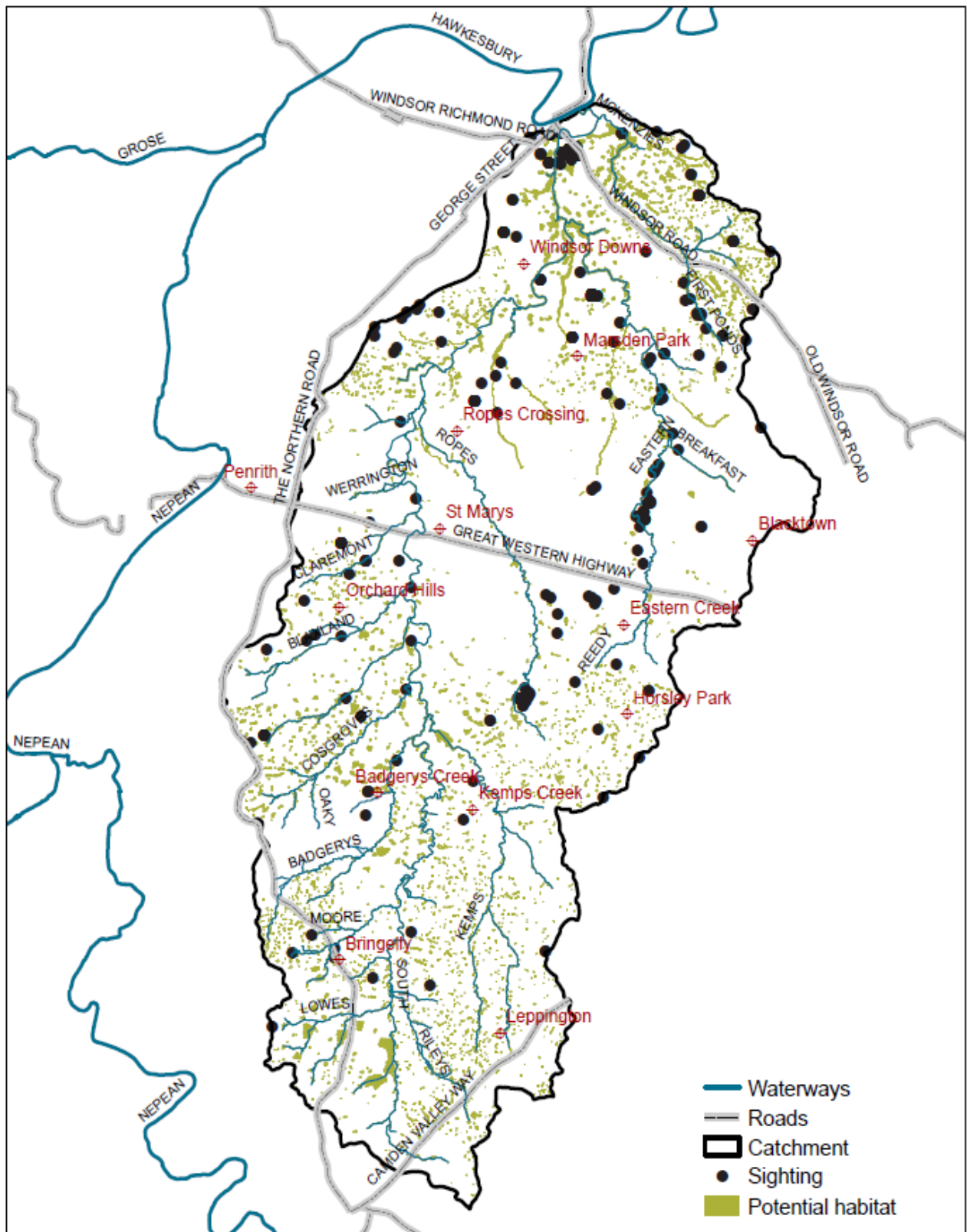


Figure 31 Small Bird Wader habitat and sightings.

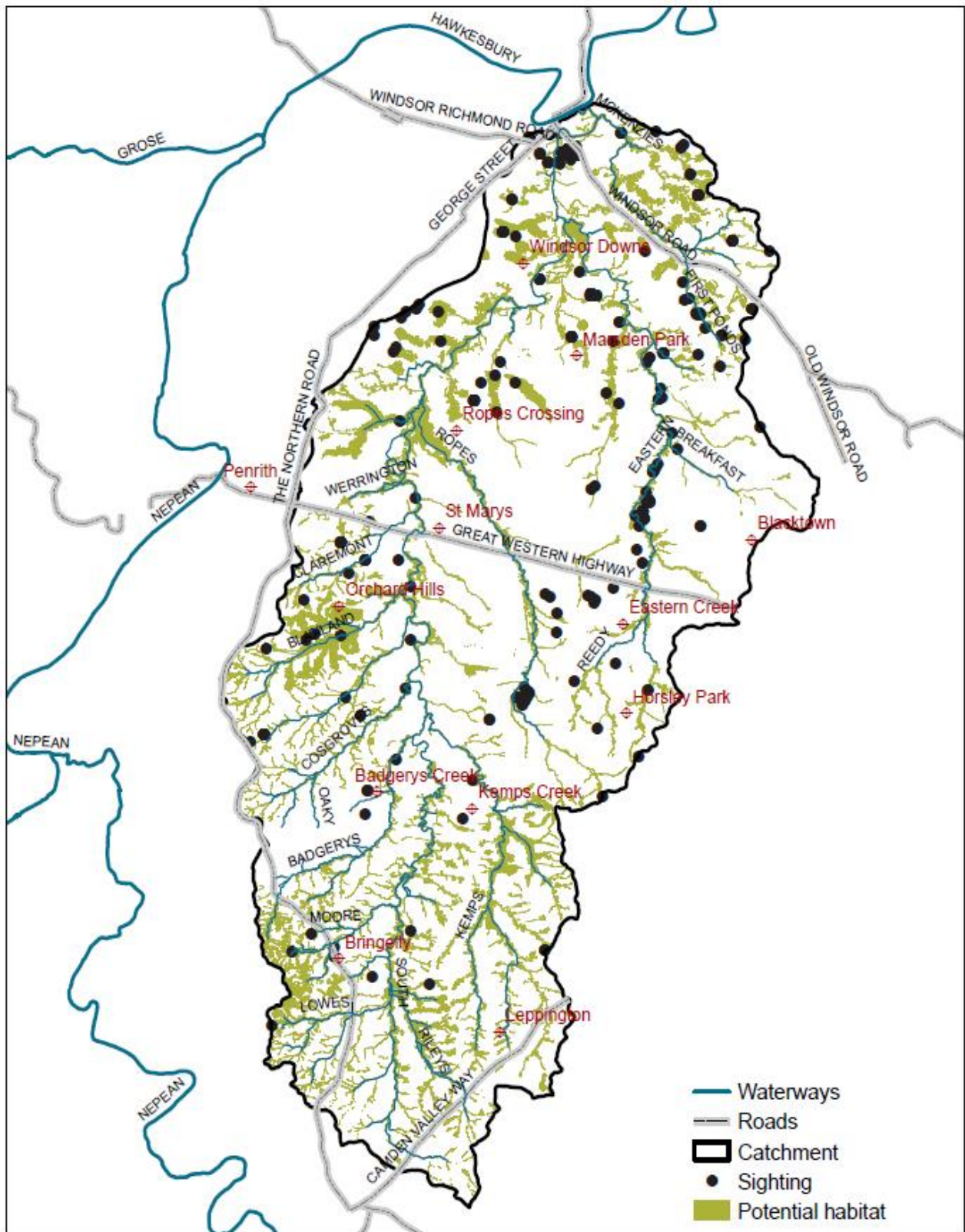


Figure 32 Riparian Vegetation Bird Forager habitat and sightings.

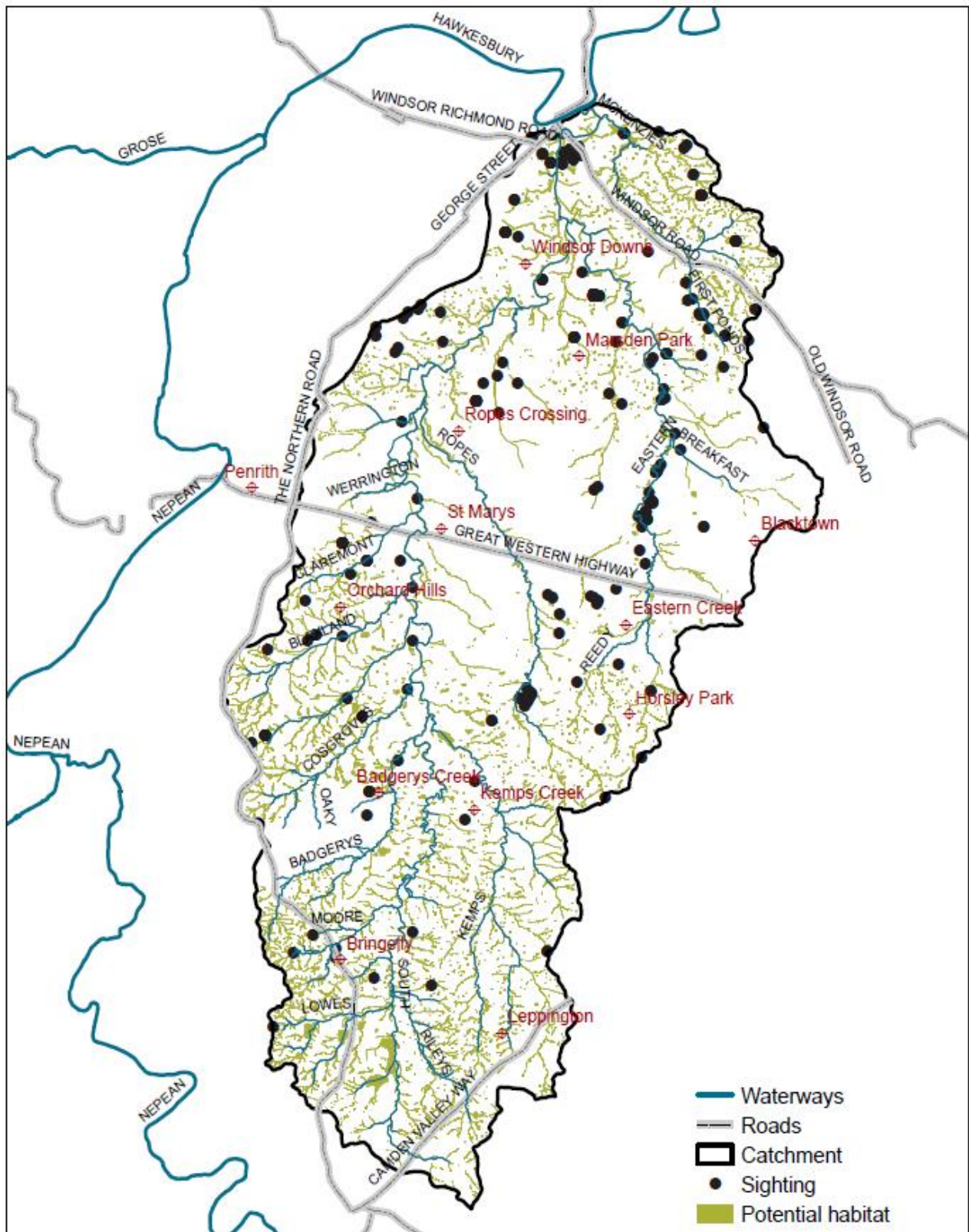


Figure 33 Open Water Bird Foragers habitat and sightings.

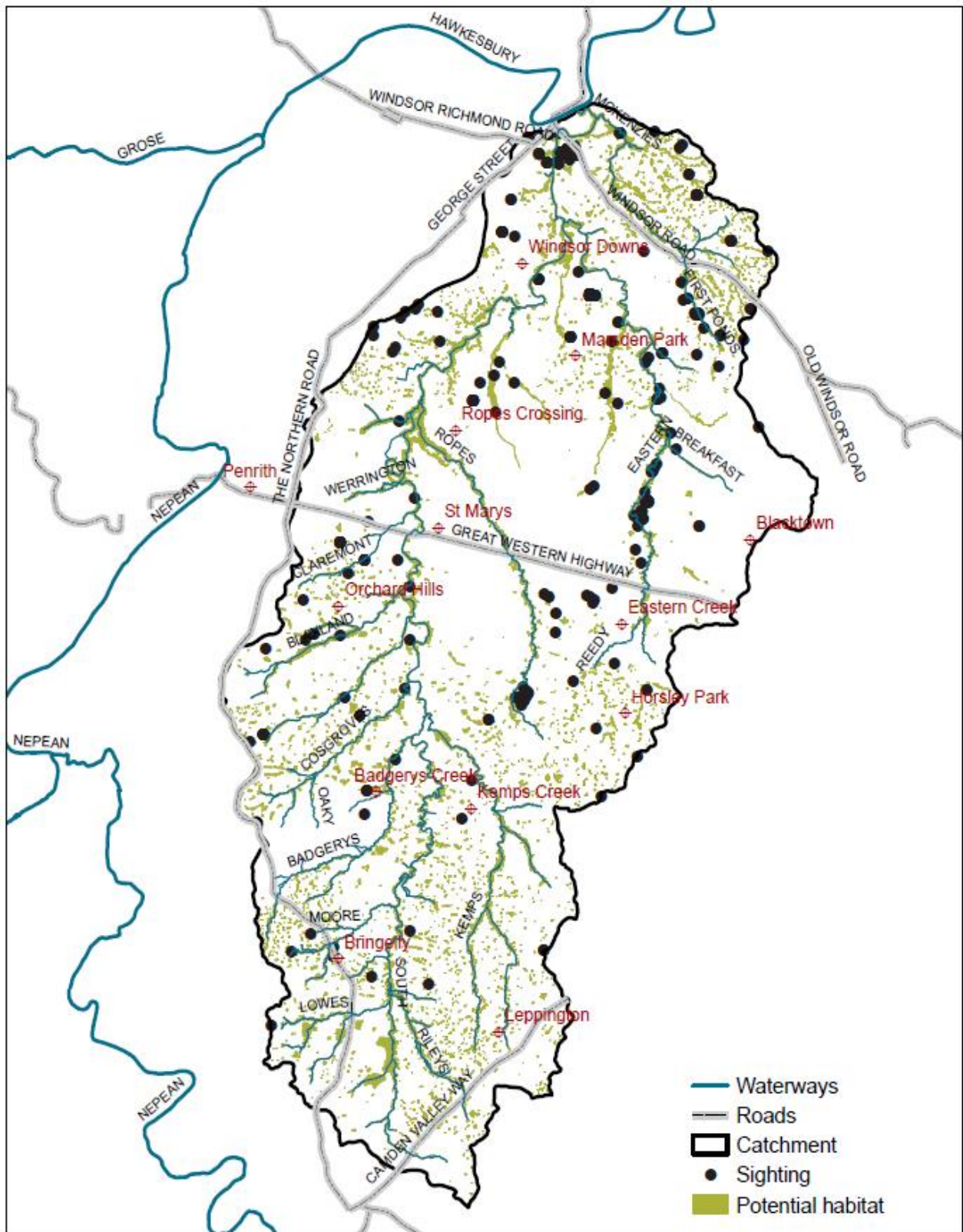


Figure 34 Emergent Vegetation Bird Forager habitat and sightings.

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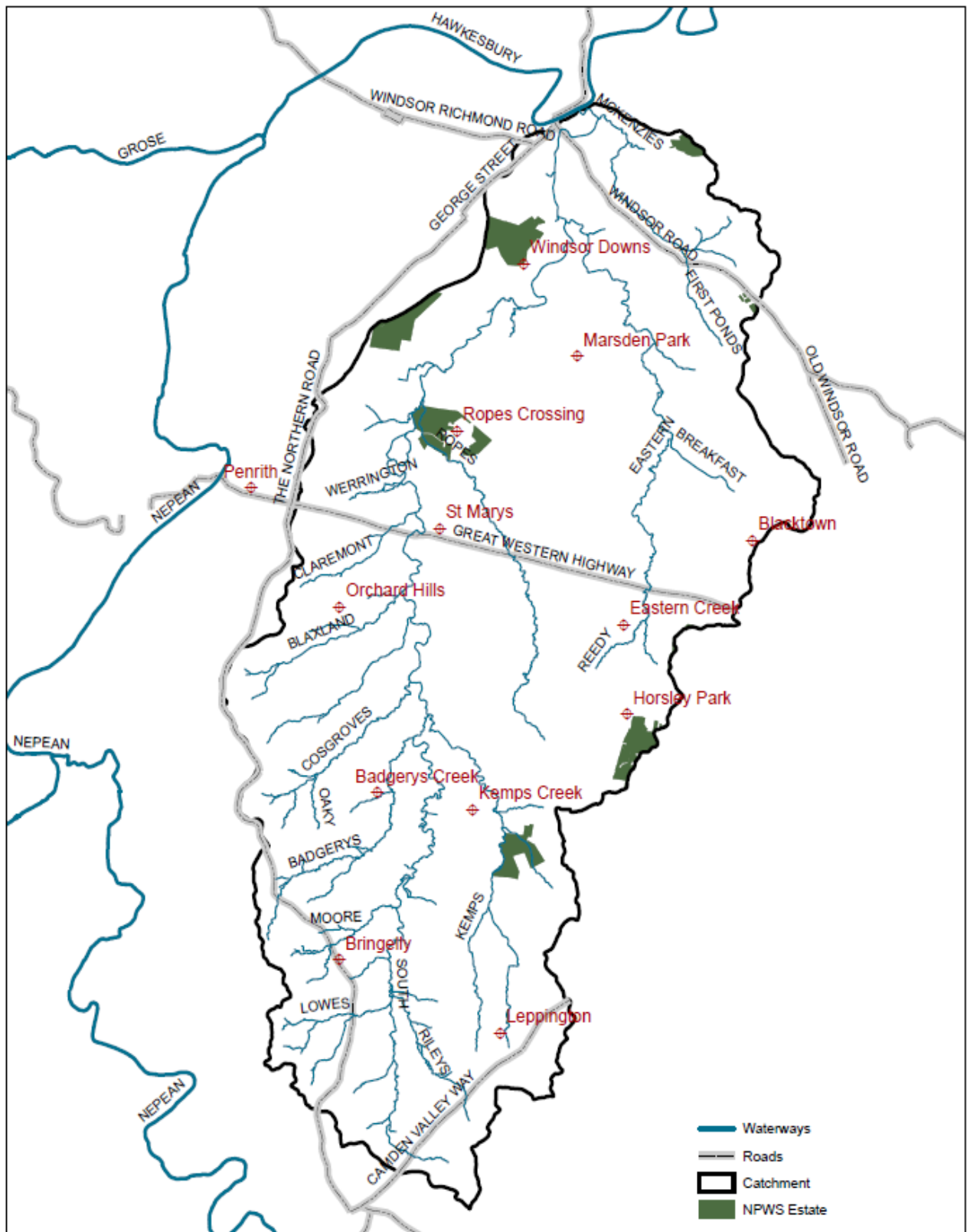


Figure 36 National Parks and Wildlife Service Estate.

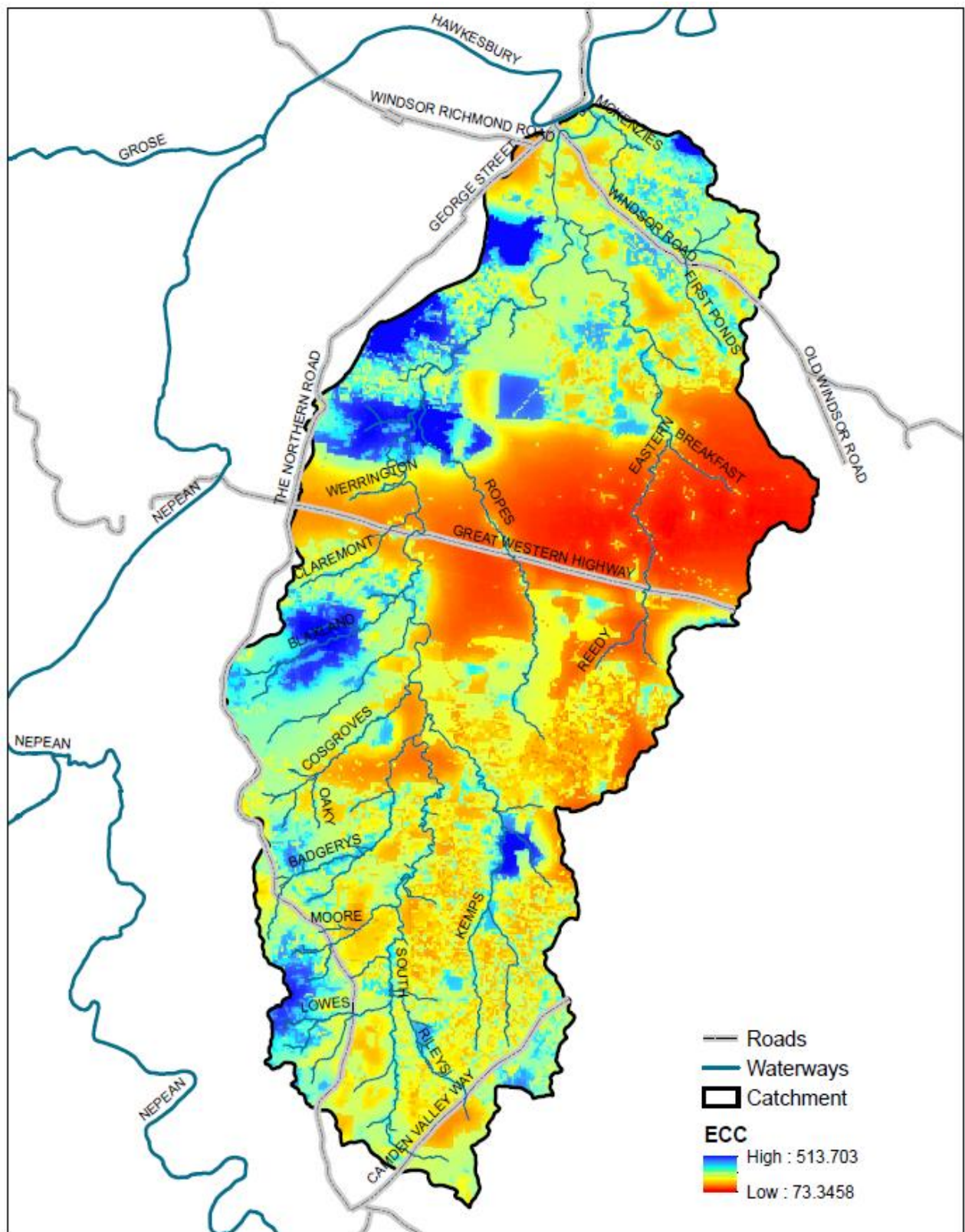


Figure 37 Ecological Carrying Capacity.

15. Appendix 6 – Tables of species lists, datasets and habitat requirements

Table 7 Relationship between the map attributes and units used among the various vegetation datasets available for developing the riparian vegetation (RIP) and wetlands (WET) maps shown in Figure 3. Surface water dependencies (SWD) and the final classification is shown

PCT ¹	REMANT VEGETATION ^{2,3}	NSW EEC ^{1,4,5,6}	EPBC ¹	NATIVE VEGETATION ⁷	RIP	WET	SWD	FINAL CLASS
Broad-leaved Ironbark - Grey Box - Melaleuca decora grassy open forest on clay/gravel soils of the Cumberland Plain, Sydney Basin Bioregion	103 - Shale/Gravel Transition Forest	Shale Gravel Transition Forest in the Sydney Basin Bioregion	Shale Gravel Transition Forest in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Broad-leaved Ironbark - Melaleuca decora shrubby open forest on clay soils of the Cumberland Plain, Sydney Basin Bioregion	3 - Cooks River Castlereagh Ironbark Forest	Cooks River/Castlereagh ironbark forest in the Sydney Basin Bioregion	Cooks River/Castlereagh ironbark forest in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Coastal freshwater lagoons of the Sydney Basin Bioregion and South East Corner Bioregion	36 - Freshwater Wetlands	Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Non-woody wetland			Y	Non-woody wetland
Forest Red Gum - Grey Box shrubby woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion	14 - Moist Shale Woodland	Moist Shale Woodland in the Sydney Basin Bioregion	Western Sydney Dry Rainforest and Moist Woodland on Shale	Dry sclerophyll				Other woody native vegetation

Mapping the natural blue grid elements of Wianamatta-South Creek

PCT ¹	REMNANT VEGETATION ^{2,3}	NSW EEC ^{1,4,5,6}	EPBC ¹	NATIVE VEGETATION ⁷	RIP	WET	SWD	FINAL CLASS
Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	11 - Alluvial Woodland	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Riparian forests (generic)	Y		Y	Riparian woodland
Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	12 - Riparian Forest	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Riparian forests (generic)	Y		Y	Riparian woodland
Grey Box - Forest Red Gum grassy woodland on flats of the Cumberland Plain, Sydney Basin Bioregion	10 - Shale Plains Woodland	Cumberland Plain Woodland in the Sydney Basin Bioregion	Cumberland Plain Woodland in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Grey Box - Forest Red Gum grassy woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion	9 - Shale Hills Woodland	Cumberland Plain Woodland in the Sydney Basin Bioregion	Cumberland Plain Woodland in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Grey Myrtle dry rainforest of the Sydney Basin Bioregion and South East Corner Bioregion	13 - Western Sydney Dry Rainforest	Western Sydney Dry Rainforest in the Sydney Basin Bioregion	Western Sydney Dry Rainforest in the Sydney Basin Bioregion	Dry rainforest				Other woody native vegetation
Hard-leaved Scribbly Gum - Parramatta Red Gum heathy woodland of the Cumberland Plain, Sydney Basin Bioregion	6 - Castlereagh Scribbly Gum Woodland	Castlereagh Scribbly Gum Woodland in the Sydney Basin Bioregion	Castlereagh Scribbly Gum Woodland in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation

Mapping the natural blue grid elements of Wianamatta-South Creek

PCT ¹	REMNANT VEGETATION ^{2,3}	NSW EEC ^{1,4,5,6}	EPBC ¹	NATIVE VEGETATION ⁷	RIP	WET	SWD	FINAL CLASS
Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, Sydney Basin Bioregion	4 - Castlereagh Swamp Woodland	Castlereagh Swamp Woodland	Not listed	Riparian forests (generic)		Y	Y	Woody wetland
Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest of the edges of the Cumberland Plain, Sydney Basin Bioregion	1 - Shale Sandstone Transition Forest (Low Sandstone Influence)	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest of the edges of the Cumberland Plain, Sydney Basin Bioregion	2 - Shale Sandstone Transition Forest (High Sandstone Influence)	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Dry				Other woody native vegetation
Swamp Oak open forest on riverflats of the Cumberland Plain and Hunter Valley	NOT MAPPED	Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions / River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions	Riparian forests (generic)	Y		y	Riparian woodland
Swamp Oak open forest on riverflats of the Cumberland Plain and Hunter Valley	NOT MAPPED	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Riparian forests (generic)	Y		Y	Riparian woodland

(1) NSW BioNet Native Vegetation Classification

(2) Remnant Vegetation of the western Cumberland subregion, 2013 update. VIS ID 4207

- (3) National Parks and Wildlife Service (2002) Interpretation Guidelines for the Native Vegetation Maps of the Cumberland Plain, Western Sydney
- (4) Castlereagh Swamp Woodland community profile
- (5) River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions, community profile
- (6) Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions, community profile
- (7) NSW State vegetation type map, NSW Structure compilation v2p0

Table 8 Water dependent species in the Wianamatta-South Creek catchment

SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	NSW STATUS	COMMONWEALTH STATUS	HABITAT
<i>Botaurus poiciloptilus</i>	Australasian Bittern	Emergent vegetation dependent birds	E2	E1	Freshwater wetlands with tall dense emergent vegetation.
<i>Ardea ibis</i>	Cattle Egret	Large wader birds		CAMBA, JAMBA	Shallow, open and fresh wetlands including grassy meadows and swamps.
<i>Ephippiorhynchus asiaticus</i>	Black-necked Stork	Large wader birds	E2		Swamps, billabongs, watercourses and lagoons on floodplains.
<i>Ixobrychus flavicollis</i>	Black Bittern	Large wader birds	V2		Areas of permanent water and dense vegetation.
<i>Plegadis falcinellus</i>	Glossy Ibis	Large wader birds		CAMBA	Fresh water marshes at the edges of lakes and rivers, lagoons, floodplains, wet meadows, swamps, reservoirs, sewage ponds.
<i>Haliaeetus leucogaster</i>	White-bellied Sea-Eagle	Open water forager birds	V2	CAMBA	Perches and nests in trees, forages over waterways and adjacent land.
<i>Oxyura australis</i>	Blue-billed Duck	Open water forager birds	V2		Deep water in large permanent wetlands and swamps with dense aquatic vegetation.
<i>Calidris acuminata</i>	Sharp-tailed Sandpiper	Small wader birds		CAMBA, JAMBA, ROKAMBA	Prefers muddy edges of shallow fresh or brackish wetlands, with inundated or emergent sedges, grass, saltmarsh or other low vegetation.
<i>Calidris ferruginea</i>	Curlew Sandpiper	Small wader birds	E2	CE1, CAMBA, JAMBA, ROKAMBA	Prefers mudflats, including those around lagoons, lakes, dams, sewage ponds and floodwaters, and inundated shallow and/or vegetated floodplain wetlands including saltmarsh.
<i>Calidris melanotos</i>	Pectoral Sandpiper	Small wader birds		JAMBA, ROKAMBA	Prefers shallow fresh to saline wetlands, including lagoons, swamps, inundated grasslands, river pools, creeks, floodplains and artificial wetlands such as sewage ponds.
<i>Calidris ruficollis</i>	Red-necked Stint	Small wader birds		CAMBA, JAMBA, ROKAMBA	Prefers shallow fresh to saline wetlands, including lagoons, swamps, inundated grasslands, river pools, creeks, floodplains and artificial wetlands such as sewage ponds.

Mapping the natural blue grid elements of Wianamatta-South Creek

SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	NSW STATUS	COMMONWEALTH STATUS	HABITAT
<i>Gallinago hardwickii</i>	Latham's Snipe	Small wader birds		CAMBA, JAMBA, ROKAMBA	Open shallow inundated well vegetated freshwater wetlands, including emergent sedges, grasses and other low vegetation.
<i>Pluvialis fulva</i>	Pacific Golden Plover	Small wader birds		CAMBA, JAMBA, ROKAMBA	Prefers shallow fresh to saline wetlands, including lagoons, swamps, inundated grasslands, river pools, creeks, floodplains and artificial wetlands such as sewage ponds.
<i>Rostratula australis</i>	Australian Painted Snipe	Small wader birds	E2	E1	Open shallow inundated well vegetated freshwater wetlands, including emergent sedges, grasses and other low vegetation.
<i>Tringa glareola</i>	Wood Sandpiper	Small wader birds		CAMBA, JAMBA, ROKAMBA	Well vegetated shallow, freshwater wetlands, and artificial wetlands. Prefers areas with wetland emergent and aquatic plants or grasses, with taller fringing vegetation.
<i>Tringa nebularia</i>	Common Greenshank	Small wader birds		CAMBA, JAMBA ROKAMBA	Prefers muddy edges of shallow fresh or brackish wetlands, with inundated or emergent sedges, grass, saltmarsh or other low vegetation.
<i>Tringa stagnatilis</i>	Marsh Sandpiper	Small wader birds		CAMBA, JAMBA, ROKAMBA	Prefers muddy edges of shallow fresh or brackish wetlands, with inundated or emergent sedges, grass, saltmarsh or other low vegetation.
<i>Stictonetta naevosa</i>	Freckled Duck	Wetland generalist* birds	V2		Freshwater swamps and creeks with dense vegetation over or adjacent to water.
<i>Climacteris picumnus</i>	Brown Treecreeper (eastern subspecies)	Riparian vegetation dependent birds	V2		Eucalypt forest bordering wetlands with an open understorey; fallen timber is for foraging.
<i>Anthochaera phrygia</i>	Regent Honeyeater	Riparian vegetation dependent birds	CE2	CE1	Inhabits, open forests and woodland, including riparian forests of River Sheoak.
<i>Apus pacificus</i>	Fork-tailed Swift	Riparian vegetation dependent birds		CAMBA, JAMBA, ROKAMBA	Inhabit a range of habitats including riparian woodland and tea-tree swamps.
<i>Artamus cyanopterus</i>	Dusky Woodswallow	Riparian vegetation dependent birds	V2		Inhabit a range of habitats including riparian woodland.
<i>Glossopsitta pusilla</i>	Little Lorikeet	Riparian vegetation dependent birds	V2		Forages in open Eucalyptus forest and woodland, particularly riparian forests.

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SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	NSW STATUS	COMMONWEALTH STATUS	HABITAT
<i>Lathamus discolor</i>	Swift Parrot	Riparian vegetation dependent birds	E2	CE1	Forage in Eucalypt woodland and forests. Swamp Mahogany is one of several favoured feeding trees.
<i>Melithreptus gularis</i>	Black-chinned Honeyeater (eastern subspecies)	Riparian vegetation dependent birds	V2		Inhabits open forests and woodlands; river sheoaks are used as nesting habitat.
<i>Merops ornatus</i>	Rainbow Bee-eater	Riparian vegetation dependent birds		JAMBA	Inhabits a range of forest and grassland habitats, including riparian, floodplain and wetland vegetation.
<i>Neophema pulchella</i>	Turquoise Parrot	Riparian vegetation dependent birds	V2		Eucalypt woodland, especially adjoining creeks.
<i>Petroica boodang</i>	Scarlet Robin	Riparian vegetation dependent birds	V2		Inhabits a range of habitats including wet forest, wetlands, and tea-tree swamps.
<i>Stagonopleura guttata</i>	Diamond Firetail	Riparian vegetation dependent birds	V2		Inhabits a range of habitats, often found in riparian areas.
<i>Austronomus australis</i>	White-striped Freetail-bat	Microbats			Forages over woodland and forests. Roosts in tree-hollows, building ceilings.
<i>Chalinolobus dwyeri</i>	Large-eared Pied Bat	Microbats	V2	V1	Forages over woodland and forests containing gullies. Roosts in tree hollows, caves, crevices in cliffs, old mine workings, and in disused bottle-shaped mud nests of the Fairy Martin
<i>Chalinolobus gouldii</i>	Gould's Wattled Bat	Microbats			Forages over forest, open woodland, open areas. Roosts in trees, and built structures (bridges, pipes, culverts, buildings).
<i>Chalinolobus morio</i>	Chocolate Wattled Bat	Microbats			Forages over forest, woodland and open grassland habitats. Forms colonies in tree hollows, caves, buildings.
<i>Falsistrellus tasmaniensis</i>	Eastern False Pipistrelle	Microbats	V2		Prefers moist habitats, with trees taller than 20m. Roosts in Eucalypt hollows, sometimes under loose bark or in buildings.
<i>Miniopterus australis</i>	Little Bentwing-bat	Microbats	V2		Forests and Melaleuca swamps, especially densely vegetated habitats. Roosts in caves, tunnels, tree hollows, abandoned mines, stormwater drains, culverts, bridges, and sometimes buildings

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SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	NSW STATUS	COMMONWEALTH STATUS	HABITAT
<i>Miniopterus schreibersii oceanensis</i>	Eastern Bentwing-bat	Microbats	V2		Forages in forested areas. Caves are the primary roosting habitat; may also use derelict mines, stormwater tunnels, buildings and other man-made structures.
<i>Mormopterus norfolkensis</i>	Eastern Freetail-bat	Microbats	V2		Dry sclerophyll forest, woodland, swamp forests. Mostly roosts in tree hollows, sometimes roosts under bark or in man-made structures.
<i>Mormopterus planiceps</i>	Little Mastiff-bat	Microbats			More common in wet habitats, but recorded from a range of habitats including forests and open woodland. Roosts in tree hollows, roof cavities, waterpipes, other man made structures.
<i>Myotis macropus</i>	Southern Myotis	Microbats	V2		Forages over streams and pools. Roosts close to water in caves, mine shafts, hollow bearing trees, storm water channels, buildings, under bridges, and in dense vegetation.
<i>Nyctophilus geoffroyi</i>	Lesser Long-eared Bat	Microbats			Forages in woodland, wet forest, and some urban areas. Roosts in tree hollows and crevices, under loose bark, in roofs of houses.
<i>Nyctophilus gouldi</i>	Gould's Long-eared Bat	Microbats			Forages in sclerophyll forest and woodland. Roosts in tree hollows, under roofs.
<i>Pteropus alecto</i>	Black Flying-fox	Flying Foxes			Feeds on rainforest fruits, and nectar and pollen from eucalypts, paperbarks, and banksias. Roosts in subtropical rainforest or swamp forest.
<i>Pteropus poliocephalus</i>	Grey-headed Flying-fox	Flying Foxes	V2	V1	Subtropical and temperate rainforests, tall sclerophyll forests, woodlands and swamps, urban gardens and orchards (15). Roosting camps are commonly in gullies, close to water, with a dense vegetation canopy.
<i>Rhinolophus megaphyllus</i>	Eastern Horseshoe-bat	Microbats			Forages in closed forest habitats, and sometimes in drier vegetation types, rural gardens and plantations. Roosts in caves and underground structures.
<i>Saccolaimus flaviventris</i>	Yellow-bellied Sheathtail-bat	Microbats	V2		Forages in forest, woodland, and grassland/pasture. Roosts in tree hollows and buildings, sometimes uses mammal burrows.

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SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	NSW STATUS	COMMONWEALTH STATUS	HABITAT
<i>Scoteanax rueppellii</i>	Greater Broad-nosed Bat	Microbats	V2		Forages along creek and river corridors, in open woodland and forests. Roosting habitat is poorly studied, thought to roost in tree hollows and crevices and under loose bark.
<i>Scotorepens orion</i>	Eastern Broad-nosed Bat	Microbats			Mostly forages in tall, wet forests or rainforest, sometimes in areas of open woodland. Roosts in tree hollows and roofs.
<i>Vespadelus darlingtoni</i>	Large Forest Bat	Microbats			Forages in forests, farmland, and urban areas. Roost in tree hollows and sometimes roost in buildings.
<i>Vespadelus pumilus</i>	Eastern Forest Bat	Microbats			Forages in moist forests. Roosts in tree hollows.
<i>Vespadelus regulus</i>	Southern Forest Bat	Microbats			Forages in woodlands, forests, farmland, and urban areas. Roosts in tree hollows and buildings.
<i>Vespadelus vulturnus</i>	Little Forest Bat	Microbats			Forages in woodlands, dry and wet sclerophyll forest.
<i>Heleioporus australiacus</i>	Giant Burrowing Frog	Burrowing frog	V2	V1	Breeding habitat: pools along first and second order streams, and rain filled depressions. Shelter: sandy and loamy soils with native vegetation cover.
<i>Limnodynastes dumerilii</i>	Eastern Banjo Frog	Burrowing frog			Breeding habitat: stream pools, permanent dams and ponds, rocks and native vegetation adjacent to pools. Shelter: Loamy soils in areas of native vegetation for burrowing.
<i>Platyplectrum ornatum</i>	Ornate Burrowing Frog	Burrowing frog			Breeding habitat: ephemeral pools, puddles, flooded grassland, ditches surrounded by native vegetation. Shelter: burrow during the day and through dry periods along dry sandy watercourses.
<i>Crinia parinsignifera</i>	Eastern Sign-bearing Froglet	Ground frogs			Breeding habitat: ephemeral and permanent pools, grassy vegetation around pools, submerged vegetation. Shelter habitat: logs, plant debris, rocks, in moist depressions.
<i>Crinia signifera</i>	Common Eastern Froglet	Ground frogs			Breeding habitat: ephemeral and permanent pools, surrounded with grassy vegetation. Shelter: logs, plant debris, and rocks, in moist depressions.

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SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	NSW STATUS	COMMONWEALTH STATUS	HABITAT
<i>Limnodynastes peronii</i>	Brown-striped Frog	Ground frogs			Breeding habitat: ephemeral and permanent pools with flooded or emergent vegetation, surrounded by vegetation, plant debris, rock ledges. Shelter: native vegetation, sandy and loamy soils.
<i>Limnodynastes tasmaniensis</i>	Spotted Grass Frog	Ground frogs			Breeding habitat: ephemeral or permanent pools with flooded or emergent vegetation. Shelter: vegetation in and around pools, logs, rocks, plant debris.
<i>Litoria aurea</i>	Green and Golden Bell Frog	Ground frogs	E2	V1	Breeding habitat: shallow ephemeral and permanent pools, with emergent and submerged vegetation, surrounded by tussock grasses or other low dense vegetation. Shelter: piles or rocks, dense tussock vegetation, emergent vegetation, fissures or cracks in ground, logs.
<i>Paracrinia haswelli</i>	Haswell's Froglet	Ground frogs			Breeding habitat: permanent and semi-permanent pools, surrounded by leaf litter, vegetation. Shelter: Vegetation alongside creeks, rocks in creek beds.
<i>Pseudophryne bibronii</i>	Bibron's Toadlet	Ground frogs			Breeding habitat: permanent and semi- permanent pools, flooded vegetation. Breeding occurs at moist sites under rocks, logs, leaf litter, grass clumps, or in a short tunnel in damp soil. Eggs are then washed into pools by rainfall. Shelter: frogs shelter under leaf litter and plant debris in moist soaks and depressions.
<i>Uperoleia fusca</i>	Dusky Toadlet	Ground frogs			Breeding habitat: ephemeral and permanent pools, with submerged plant material, and surrounded by grasses or other vegetation. Shelter: forests with a grassy understorey, sedges and grasses.
<i>Uperoleia laevis</i>	Smooth Toadlet	Ground frogs			Breeding habitat: ephemeral and permanent pools, with submerged plant material, and surrounded with grassy vegetation. Shelter: Grassland and woodland vegetation.
<i>Litoria caerulea</i>	Green Tree Frog	Tree Frogs			Breeding habitat: ephemeral pools. Shelter: trees, hollow tree trunks, crevices in rocks.
<i>Litoria dentata</i>	Bleating Tree Frog	Tree Frogs			Breeding habitat: ephemeral pools surrounded by vegetation. Shelter: rocks and loose bark on trees.

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SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	NSW STATUS	COMMONWEALTH STATUS	HABITAT
<i>Litoria ewingii</i>	Brown Tree Frog	Tree Frogs			Breeding habitat: ephemeral and permanent pools, with submerged plant material or emergent plants, and surrounded by vegetation. Shelter: tree hollows, under bark.
<i>Litoria fallax</i>	Eastern Dwarf Tree Frog	Tree Frogs			Breeding habitat: ephemeral and permanent pools, especially those with emergent reeds. Shelter: leaf axils, emergent vegetation, trees.
<i>Litoria latopalmata</i>	Broad-palmed Frog	Tree Frogs			Breeding habitat: ephemeral and permanent pools, and shallow still water along streams and rivers. Shelter: forests, woodland, grassland, pastures.
<i>Litoria peronii</i>	Peron's Tree Frog	Tree Frogs			Breeding habitat: permanent waterbodies, swamps, pools along creeks, with adjacent or overhanging vegetation, leaf litter. Shelter: trees and shrubs.
<i>Litoria phyllochroa</i>	Leaf-green Tree Frog	Tree Frogs			Breeding habitat: creek pools and ponds, rocky streams, with surrounding or overhanging ferns or leafy vegetation. Shelter: shrubs and low vegetation beside creeks and ponds.
<i>Litoria tyleri</i>	Tyler's Tree Frog	Tree Frogs			Breeding habitat: permanent waterbodies and ponds, with surrounding shrubs or trees. Shelter: trees and other vegetation overhanging ponds.
<i>Litoria verreauxii</i>	Verreaux's Frog	Tree Frogs			Breeding habitat: permanent waterbodies with submerged plant material, and surrounding low or emergent vegetation. Shelter: leaf litter, logs, beneath rocks, trees.

Table 9 Species Sighting Dataset for Water Dependent Threatened and Migratory Birds between January 1995 to December 2017. The valid records were determined by subject matter experts, and the quality checked records reflect the total number of records remaining after accounting for recent urban developments and spatial accuracy within 10 m radius.

SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	VALID RECORDS	QUALITY CHECKED RECORDS	FINAL
<i>Botaurus poiciloptilus</i>	Australasian Bittern	Emergent Vegetation Dependent Large Wader*	3	1	142
<i>Stictonetta naevosa</i>	Freckled Duck	Wetland Generalist*	2	1	
<i>Ardea ibis</i>	Cattle Egret	Large Wader	115	101	
<i>Ephippiorhynchus asiaticus</i>	Black-necked Stork	Large Wader	1	1	
<i>Ixobrychus flavicollis</i>	Black Bittern	Large Wader	21	16	
<i>Plegadis falcinellus</i>	Glossy Ibis	Large Wader	27	23	
<i>Haliaeetus leucogaster</i>	White-bellied Sea-Eagle	Open Water Forager	63	22	23
<i>Oxyura australis</i>	Blue-billed Duck	Open Water Forager	2	1	
<i>Anthochaera phrygia</i>	Regent Honeyeater	Riparian Vegetation Dependent	14	14	171
<i>Apus pacificus</i>	Fork-tailed Swift	Riparian Vegetation Dependent	4	2	
<i>Artamus cyanopterus</i>	Dusky Woodswallow	Riparian Vegetation Dependent	124	98	
<i>Climacteris picumnus vitoriae</i>	Brown Treecreeper (eastern subspecies)	Riparian Vegetation Dependent	4	4	
<i>Glossopsitta pusilla</i>	Little Lorikeet	Riparian Vegetation Dependent	11	10	
<i>Lathamus discolor</i>	Swift Parrot	Riparian Vegetation Dependent	97	8	
<i>Melithreptus gularis</i>	Black-chinned Honeyeater (eastern subspecies)	Riparian Vegetation Dependent	26	12	
<i>Merops ornatus</i>	Rainbow Bee-eater	Riparian Vegetation Dependent	14	5	
<i>Neophema pulchella</i>	Turquoise Parrot	Riparian Vegetation Dependent	5	2	
<i>Petroica boodang</i>	Scarlet Robin	Riparian Vegetation Dependent	16	10	
<i>Stagonopleura guttata</i>	Diamond Firetail	Riparian Vegetation Dependent	8	6	
<i>Calidris acuminata</i>	Sharp-tailed Sandpiper	Small wader	69	59	158
<i>Calidris ferruginea</i>	Curlew Sandpiper	Small wader	4	4	
<i>Calidris melanotos</i>	Pectoral Sandpiper	Small wader	11	11	
<i>Calidris ruficollis</i>	Red-necked Stint	Small wader	15	13	

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SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	VALID RECORDS	QUALITY CHECKED RECORDS	FINAL
<i>Gallinago hardwickii</i>	Latham's Snipe	Small wader	60	30	
<i>Pluvialis fulva</i>	Pacific Golden Plover	Small wader	14	9	
<i>Rostratula australis</i>	Australian Painted Snipe	Small wader	11	6	
<i>Tringa glareola</i>	Wood Sandpiper	Small wader	14	12	
<i>Tringa nebularia</i>	Common Greenshank	Small wader	4	3	
<i>Tringa stagnatilis</i>	Marsh Sandpiper	Small wader	11	11	

*Records for Emergent Vegetation Dependent and Wetland Generalist birds were combined with the Large Wader Birds to produce a single species distribution model.

Table 10 Species Sighting Dataset for frogs between January 1995 to December 2017. The valid records were determined by subject matter experts, and the quality checked records reflect the total number of records remaining after accounting for recent urban developments and spatial accuracy within 10 m radius.

SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	VALID RECORDS	QUALITY CHECKED RECORDS	FINAL
<i>Litoria caerulea</i>	Green Tree Frog	Tree Frog	32	5	117
<i>Litoria dentata</i>	Bleating Tree Frog	Tree Frog	24	6	
<i>Litoria ewingii</i>	Brown Tree Frog	Tree Frog	1	0	
<i>Litoria fallax</i>	Eastern Dwarf Tree Frog	Tree Frog	97	35	
<i>Litoria peronii</i>	Peron's Tree Frog	Tree Frog	88	39	
<i>Litoria phyllochroa</i>	Leaf-green Tree Frog	Tree Frog	3	0	
<i>Litoria tyleri</i>	Tyler's Tree Frog	Tree Frog	7	2	
<i>Litoria verreauxii</i>	Verreaux's Frog	Tree Frog	77	30	
<i>Crinia parinsignifera</i>	Eastern Sign-bearing Froglet	Ground frog	1	0	148
<i>Crinia signifera</i>	Common Eastern Froglet	Ground frog	248	82	
<i>Limnodynastes peronii</i>	Brown-striped Frog	Ground frog	96	26	
<i>Limnodynastes tasmaniensis</i>	Spotted Grass Frog	Ground frog	59	16	
<i>Litoria aurea</i>	Green and Golden Bell Frog	Ground frog	9	1	
<i>Litoria latopalmata</i>	Broad-palmed Frog	Ground frog	14	1	
<i>Paracrinia haswelli</i>	Haswell's Froglet	Ground frog	1	0	
<i>Pseudophryne bibronii</i>	Bibron's Toadlet	Ground frog	9	0	
<i>Uperoleia fusca</i>	Dusky Toadlet	Ground frog	2	0	
<i>Uperoleia laevis</i>	Smooth Toadlet	Ground frog	47	19	
<i>Heleioporus australiacus</i>	Giant Burrowing Frog	Burrowing Frog*	1	0	
<i>Limnodynastes dumerilii</i>	Eastern Banjo Frog	Burrowing Frog*	13	3	
<i>Platypsectrum ornatum</i>	Ornate Burrowing Frog	Burrowing Frog*	3	0	

*Records for Burrowing Frogs were combined with records for Ground Frogs to produce a single species distribution model.

Table 11 Species Sighting Dataset for water dependent bats between January 2000 to April 2018. The valid records were determined by subject matter experts, and the quality checked records reflect the total number of records remaining after accounting for recent urban developments and spatial accuracy within 10 m radius.

SCIENTIFIC NAME	COMMON NAME	HABITAT GROUP	VALID RECORDS	QUALITY CHECKED RECORDS	FINAL
Microbat, species not identified	Microbat, species not identified	Microbat	65	62	938
<i>Austronomus australis</i>	White-striped Freetail-bat	Microbat	67	62	
<i>Chalinolobus dwyeri</i>	Large-eared Pied Bat	Microbat	6	6	
<i>Chalinolobus gouldii</i>	Gould's Wattled Bat	Microbat	212	191	
<i>Chalinolobus morio</i>	Chocolate Wattled Bat	Microbat	78	74	
<i>Falsistrellus tasmaniensis</i>	Eastern False Pipistrelle	Microbat	19	17	
<i>Miniopterus australis</i>	Little Bentwing-bat	Microbat	6	6	
<i>Miniopterus schreibersii oceanensis</i>	Eastern Bentwing-bat	Microbat	67	60	
<i>Mormopterus norfolkensis</i>	Eastern Freetail-bat	Microbat	57	52	
<i>Mormopterus planiceps</i>	Little Mastiff-bat	Microbat	11	11	
<i>Myotis macropus</i>	Southern Myotis	Microbat	48	41	
<i>Nyctophilus geoffroyi</i>	Lesser Long-eared Bat	Microbat	98	98	
<i>Nyctophilus gouldi</i>	Gould's Long-eared Bat	Microbat	8	8	
<i>Rhinolophus megaphyllus</i>	Eastern Horseshoe-bat	Microbat	4	4	
<i>Saccolaimus flaviventris</i>	Yellow-bellied Sheath-tail-bat	Microbat	10	8	
<i>Scoteanax rueppellii</i>	Greater Broad-nosed Bat	Microbat	26	24	
<i>Scotorepens orion</i>	Eastern Broad-nosed Bat	Microbat	74	72	
<i>Vespadelus darlingtoni</i>	Large Forest Bat	Microbat	8	7	
<i>Vespadelus pumilus</i>	Eastern Forest Bat	Microbat	7	6	
<i>Vespadelus regulus</i>	Southern Forest Bat	Microbat	22	22	
<i>Vespadelus vulturnus</i>	Little Forest Bat	Microbat	112	107	
<i>Pteropus alecto</i>	Black Flying-fox	Flying Fox	1	1	47
<i>Pteropus poliocephalus</i>	Grey-headed Flying-fox	Flying Fox	54	46	

Table 12 Datasets to characterise the habitat requirements of iconic species.

DATASET	DATA SOURCE	METHOD OF PREPARATION
1) Sentinel-2 10m image (Blue, Green, Red, Near Infrared bands), with Top of Atmosphere (sun angle) correction.	https://scihub.copernicus.eu/dhus/#/home	A Sentinel 2 multispectral 10m cloud free image collected on 30th January 2018 was sourced and downloaded from the Copernicus Open Access Hub.
2) NDVI Jan 2018	Produced for this project from (1) the Sentinel-2 10m multispectral image	The Normalised Difference Vegetation Index is used to map green (live) vegetation. It is calculated using the formula $(NIR - R)/(NIR + R)$. We calculated NDVI using the 10m Sentinel 2 Jan 2018 image. The NDVI result was then classified into 4 classes using natural breaks. The 4 classes from natural breaks were checked against high resolution digital air photos collected in 2017 by NSW Land and Property Information, and named in order of increasing green-ness: 'Very Green', 'Moderately Green', 'Sparse green', and 'bare and urban surfaces'. The resulting vegetation green-ness classes were used as inputs to generate cost surfaces for cost distance calculations.
3) NSW Imagery	https://data.nsw.gov.au/data/dataset/lpi-web-services-spatial-data	High resolution (10cm) imagery provided by the NSW imagery web service. The most recent imagery available for the Wianamatta-South Creek catchment at the time of study was collected from 24/2/2016 to 03/05/2016.
4) NSW Landuse 2013	https://datasets.seed.nsw.gov.au/dataset/nsw-landuse-2013	The is dataset show how the landscape of NSW was used for food production, forestry, nature conservation, infrastructure, and urban development, as of 2013.
5) NSW Roads	P:\Corporate\Themes\Infrastructure\Transport\Transport.qdb	The Environment, Energy and Science Group of DPIE maintains a compilation of road mapping. The most recent updates (at the time of this study) within the Wianamatta-South Creek Catchment were completed in 2015.
6) Urban surfaces January 2018	Produced for this project. Combines information from datasets (1), (3), (4) and (5).	The dataset was produced from (4) the NSW Landuse 2013 data, (3) NSW imagery (2016), (1) the Sentinel image (January 2018) and (5) the NSW Roads dataset. Appendix 1, Section 10.3 provides details on the sequence of steps for developing the dataset
7) Woody Extent and Foliage Projective Cover - SPOT, OEH algorithm, NSW coverage 2011 (Fisher et al 2016).	http://data.auscover.org.au/xwiki/bin/view/Product+pages/nsw+5m+woody+extent+and+fpc	A map of woody vegetation extent for NSW for 2011, with 5m pixels. A full description of the methods can be found in Fisher et al/2016 .
8) Woody vegetation 2018	Produced for this project. Combines information from datasets (7), (3) and (4).	The available woody vegetation dataset (7) for 2011 was overlayed on (3) the NSW imagery and (1) the Sentinel image January 2018. Areas that had been recently cleared for urban development were manually removed.

Mapping the natural blue grid elements of Wianamatta-South Creek

DATASET	DATA SOURCE	METHOD OF PREPARATION
9) Strahler stream order.	Environment, Energy and Science Group of DPIE	This dataset adopts the linework from the NSW Hydro Line Dataset (https://sdi.nsw.gov.au/nswsdi/catalog/search/resource/details.page?uuid=%7B4C00C37F-8424-45DD-BB96-1ABEAEDDB39C%7D), but with stream order subsequently added to produce the Stream Order Strahler dataset.
10) NSW Hydro Area	https://datasets.seed.nsw.gov.au/dataset/nsw-hydrography	The NSW Hydro Area Dataset1 is produced by NSW Land and Property Information, and identifies waterbodies across all of New South Wales. The dataset is produced at fine scale and identifies waterbodies using air photo interpretation of water and landform features.
11) Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207.	https://datasets.seed.nsw.gov.au/dataset/remnant-vegetation-of-the-western-cumberland-subregion-2013-update-vis_id-4207fd1f4	Maps Plant Community Types and Endangered Ecological Communities. Community extent data is updated to 2013, condition data was collected pre 1999 and has not been updated. Further detail on map methods and vegetation communities are available from (NPWS 2002, http://www.environment.nsw.gov.au/resources/nature/cumbPlainMappingInterpguidelines.pdf).
12) Perennial streams, 3rd order and higher streams, and waterbodies	Produced for this project from datasets (9), (10) and (3).	Identifies waterbodies and streams likely contain water most of the time. Formed by first combining (10) Hydro area and (9) Strahler stream order datasets. Streams were included if they were mapped as perennial or were of Strahler stream order 3 or greater. The dataset was then manually updated to 2016 using (3) the NSW high resolution imagery to add and remove farm dams.
13) All streams and waterbodies	Produced for this project from datasets (9), (10) and (3).	Identifies all intermittent streams waterbodies and dams. Formed by first combining (10) Hydro area and (9) Strahler stream order datasets. The dataset was then manually updated to 2016 using (3) the NSW high resolution imagery to add and remove farm dams.
14) Digital Elevation Model (DEM) 5 Metre Grid of Australia	https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search?node=srv#/metadata/22be4b55-2465-4320-e053-10a3070a5236	The Digital Elevation Model (DEM) 5 Metre Grid of Australia derived from LiDAR model represents a National 5 metre (bare earth) DEM which has been derived from some 236 individual LiDAR surveys between 2001 and 2015.

Table 13 Water source and cost datasets developed for fauna habitat use groups.

HABITAT GROUP	WATER SOURCE DATASET	COST DATASET	DATA SOURCE (CROSS REFERENCE TABLE 12)
Ground Frogs	All streams and waterbodies	1 Native vegetation (all PCTs)	NSW Structure Compilation V2p0, Vegetation community map 2018
		2 Other very green vegetation	NDVI Jan 2018
		4 Other green vegetation	NDVI Jan 2018
		16 Other sparse green vegetation	NDVI Jan 2018
		1000 Bare ground and urban surfaces	NDVI Jan 2018 Urban surfaces January 2018
Tree Frogs and Riparian Vegetation Dependent Birds	All streams and waterbodies	1 Native woodlands and forests (all woody PCTs)	NSW Structure Compilation V2p0, Vegetation community map 2018
		4 Other woody vegetation	Woody Vegetation 2018
		16 Other very green non woody vegetation	NDVI Jan 2018, Woody vegetation 2018.
		32 Other green non woody vegetation	NDVI Jan 2018, Woody vegetation 2018
		64 Other sparse green non woody vegetation	NDVI Jan 2018, Woody vegetation 2018
Small Wader Birds	3rd order and greater streams, perennial streams, and waterbodies.	1000 Bare ground and urban surfaces	NDVI Jan 2018, Urban surfaces January 2018
		1 Non woody wetland PCT	NSW Structure Compilation V2p0, Vegetation community map 2018
		2 Bare Ground (not surfaced)	NDVI Jan 2018, Urban surfaces January 2018
		4 Other green non woody vegetation	NDVI Jan 2018, Woody vegetation 2018
Large Wader Birds	3rd order and greater streams, perennial streams, and waterbodies.	1000 woody vegetation and urban surfaces	Woody Vegetation 2018, Urban surfaces 2018
		1 Non woody wetland PCT	NSW Structure Compilation V2p0, Vegetation community map 2018
		2 Other very green vegetation	NDVI Jan 2018
		4 Other green Vegetation	NDVI Jan 2018
		16 Other sparse green vegetation	NDVI Jan 2018
		1000 Bare ground and urban surfaces	NDVI Jan 2018,

Mapping the natural blue grid elements of Wianamatta-South Creek

HABITAT GROUP	WATER SOURCE DATASET	COST DATASET	DATA SOURCE (CROSS REFERENCE TABLE 12)
			Urban surfaces January 2018
Emergent Vegetation Dependent and Wetland Generalist Birds.	3rd order and greater streams, perennial streams, and waterbodies.	1 Emergent Vegetation PCTs*	NSW Structure Compilation V2p0, Vegetation community map 2018
		2 Very green vegetation	NDVI Jan 2018
		16 Green vegetation	NDVI Jan 2018
		32 Sparse green vegetation	NDVI Jan 2018
		64 Bare ground (not surfaced)	NDVI Jan 2018, Urban surfaces January 2018
		1000 Urban surfaces	Urban surfaces January 2018
Open Water Forager Birds.	3rd order and greater streams, perennial streams, and waterbodies.	1 Native vegetation (all PCTs)	NSW Structure Compilation V2p0, Vegetation community map 2018
		2 Other very green vegetation	NDVI Jan 2018
		4 Other green vegetation	NDVI Jan 2018
		16 Sparse green vegetation	NDVI Jan 2018
		1000 Bare ground and urban surfaces	NDVI Jan 2018, Urban surfaces January 2018
Microbats (except Southern Myotis)	All streams and waterbodies	1 Microbat PCTs*** (excluding Southern Myotis PCTs)	NSW Structure Compilation V2p0, Vegetation community map 2018
		16 Other native vegetation (all other PCTs)	NSW Structure Compilation V2p0, Vegetation community map 2018
		64 Woody non-native vegetation	NSW Structure Compilation V2p0, Vegetation community map 2018, Woody vegetation 2018.

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HABITAT GROUP	WATER SOURCE DATASET	COST DATASET	DATA SOURCE (CROSS REFERENCE TABLE 12)
		1000 Bare ground, urban surfaces, and non-native non woody vegetation.	NDVI Jan 2018, Urban surfaces January 2018, NSW Structure Compilation V2p0, Vegetation community map 2018, Woody Vegetation 2018
Southern Myotis	3rd order and greater streams, perennial streams, and waterbodies.	1 Southern Myotis PCTs*** with water dependencies**.	NSW Structure Compilation V2p0, Vegetation community map 2018
		4 Other Southern Myotis PCTs***	NSW Structure Compilation V2p0, Vegetation community map 2018
		16 Other native vegetation (all other PCTs)	NSW Structure Compilation V2p0, Vegetation community map 2018
		64 Woody non-native vegetation	NSW Structure Compilation V2p0, Vegetation community map 2018, Woody vegetation 2018.
		1000 Bare ground, urban surfaces, and non-native non woody vegetation.	NDVI Jan 2018, Urban surfaces January 2018, Woody vegetation 2018, NSW Structure Compilation V2p0, Vegetation community map 2018
Flying Foxes	3rd order and greater streams, perennial streams, and waterbodies.	1 Flying Fox PCTs***	NSW Structure Compilation V2p0, Vegetation community map 2018
		16 Other native vegetation (all other PCTs)	NSW Structure Compilation V2p0, Vegetation community map 2018
		64 Woody non-native vegetation	NSW Structure Compilation V2p0, Vegetation community map 2018, NDVI Jan 2018
		1000 Bare ground, urban surfaces, and non-native non woody vegetation.	NDVI Jan 2018, Urban surfaces January 2018, Woody vegetation 2018, NSW Structure Compilation V2p0, Vegetation community map 2018.

* PCTs with emergent vegetation included: PCT 781 Coastal freshwater lagoons of the Sydney Basin Bioregion, PCT 1067 Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, and PCT 837 Forest Red Gum Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain. **PCTs with surface water dependencies and associated with Southern Myotis habitat included PCT 1067 Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, and PCT 837 Forest Red Gum Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain. *** Further details of the PCTs selected as suitable bat habitat are provided in Table A2-77.

Table 14 NSW Plant Community Type (PCT) association with bat habitat.

*PCT NUMBER	LARGE EARED PIED BAT	EASTERN FALSE PIPISTRELLE	LITTLE RENTWING-BAT	EASTERN RENTWING-BAT	EASTERN FREETAIL BAT	SOUTHERN MYOTIS	GREY HEADED FLYING FOX	YELLOW-BELLIED SHEATHTAIL-BAT	GREATER BROAD-NOSED BAT
	<i>Chalinolobus dwyeri</i>	<i>Falsistrellus tasmaniensis</i>	<i>Miniopterus australis</i>	<i>Miniopterus schreibersii oceanensis</i>	<i>Mormopterus norfolkensis</i>	<i>Myotis macropus</i>	<i>Pteropus poliocephalus</i>	<i>Saccolaimus flaviventris</i>	<i>Scoteanax rueppellii</i>
	V1, V2	V2	V2	V2	V2	V2	V1, V2	V2	V2
724	✓	✓	✓	✓	✓	✓	✓	✓	✓
725	✓	✓	✓	✓	✓	✓	✓	✓	✓
830	✓	✓	✓	✓	✓	✓	✓	✓	✓
835	✓	✓	✓	✓	✓	✓	✓	✓	✓
849	✓	✓	✓	✓	✓	✓	✓	✓	✓
850	✓	✓	✓	✓	✓	✓	✓	✓	✓
883	✓	✓	✓	✓	✓	✓	✓	✓	✓
1067	✓	✓	✓	✓	✓	✓	✓	✓	✓
1395	✓	✓	✓	✓	✓	✓	✓	✓	✓

* Data Source: NSW Threatened Species Profile database. V1 = listed as Vulnerable on the *NSW Biodiversity Conservation Act 2016*. V2 = listed as Vulnerable on the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

PCT 724: Broad-leaved Ironbark - Grey Box - Melaleuca decora grassy open forest on clay/gravel soils of the Cumberland Plain, Sydney Basin Bioregion

PCT 725: Broad-leaved Ironbark - Melaleuca decora shrubby open forest on clay soils of the Cumberland Plain, Sydney Basin Bioregion

PCT 830: Forest Red Gum - Grey Box shrubby woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion

PCT 835: Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion

PCT 849: Grey Box - Forest Red Gum grassy woodland on flats of the Cumberland Plain, Sydney Basin Bioregion

PCT 850: Grey Box - Forest Red Gum grassy woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion

PCT 883: Hard-leaved Scribbly Gum - Parramatta Red Gum heathy woodland of the Cumberland Plain, Sydney Basin Bioregion

PCT 1067: Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, Sydney Basin Bioregion

PCT 1395: Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest of the edges of the Cumberland Plain, Sydney Basin Bioregion

Table 15 NSW Plant Community Types (PCT), status, dependency on surface water stores (SWT) association with bat habitat.

PCT	COMMUNITY DESCRIPTION	NSW ENDANGERED ECOLOGICAL COMMUNITY	EPBC NAME	SWT
724: Broad-leaved Ironbark - Grey Box - Melaleuca decora grassy open forest on clay/gravel soils of the Cumberland Plain, Sydney Basin Bioregion	103 - Shale/Gravel Transition Forest	Shale Gravel Transition Forest in the Sydney Basin Bioregion	Shale Gravel Transition Forest in the Sydney Basin Bioregion	N
725: Broad-leaved Ironbark - Melaleuca decora shrubby open forest on clay soils of the Cumberland Plain, Sydney Basin Bioregion	3 - Cooks River Castlereagh Ironbark Forest	Cooks River/Castlereagh ironbark forest in the Sydney Basin Bioregion	Cooks River/Castlereagh ironbark forest in the Sydney Basin Bioregion	N
781: Coastal freshwater lagoons of the Sydney Basin Bioregion and South East Corner Bioregion	36 - Freshwater Wetlands	Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Y
830: Forest Red Gum - Grey Box shrubby woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion	14 - Moist Shale Woodland	Moist Shale Woodland in the Sydney Basin Bioregion	Western Sydney Dry Rainforest and Moist Woodland on Shale	N
835: Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	11 - Alluvial Woodland	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Y
835: Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	12 - Riparian Forest	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Y
849: Grey Box - Forest Red Gum grassy woodland on flats of the Cumberland Plain, Sydney Basin Bioregion	10 - Shale Plains Woodland	Cumberland Plain Woodland in the Sydney Basin Bioregion	Cumberland Plain Woodland in the Sydney Basin Bioregion	N
850: Grey Box - Forest Red Gum grassy woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion	9 - Shale Hills Woodland	Cumberland Plain Woodland in the Sydney Basin Bioregion	Cumberland Plain Woodland in the Sydney Basin Bioregion	N
877: Grey Myrtle dry rainforest of the Sydney Basin Bioregion and South East Corner Bioregion	13 - Western Sydney Dry Rainforest	Western Sydney Dry Rainforest in the Sydney Basin Bioregion	Western Sydney Dry Rainforest in the Sydney Basin Bioregion	Y
883: Hard-leaved Scribbly Gum - Parramatta Red Gum heathy woodland of the Cumberland Plain, Sydney Basin Bioregion	6 - Castlereagh Scribbly Gum Woodland	Castlereagh Scribbly Gum Woodland in the Sydney Basin Bioregion	Castlereagh Scribbly Gum Woodland in the Sydney Basin Bioregion	N
1067: Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, Sydney Basin Bioregion	4 - Castlereagh Swamp Woodland	Castlereagh Swamp Woodland	Not listed	Y
1395: Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest of the edges of the Cumberland Plain, Sydney Basin Bioregion	1 - Shale Sandstone Transition Forest (Low Sandstone Influence)	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	N
1395: Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest of the edges of the Cumberland Plain, Sydney Basin Bioregion	2 - Shale Sandstone Transition Forest (High Sandstone Influence)	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	N

16. Appendix 7 – Literature Review

This Appendix contains two main sections of literature reviewed. The first section lists literature that informed the methods for modelling of habitats of functions groups of iconic species of waterbirds, water dependent bats and frogs. The second section lists the literature that informed the habitat requirements of specific species.

16.1 Methods for developing datasets of habitats for functional groups of water dependent iconic species

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16.2 Habitat requirements of waterbirds, water dependent bats and frogs

16.2.1 Threatened and migratory birds

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