Government of **Western Australia**
Department of **Water and Environmental Regulation**

Groundwater-dependent environmental values of the

Dinner Hill and Irwin focus areas

Water for Food: Midlands groundwater and land assessment

Environmental water report series
Report no. 30
June 2018

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Summary

The Midlands groundwater and land assessment project (the Midlands project) is a State government project that is investigating groundwater availability, land capability and crop suitability in the Midlands area, between Gingin and Dongara. This region is one of the most economically promising irrigation zones in Western Australia. The Midlands project has two focus areas:

- Dinner Hill: the south-western corner of the Dinner Hill groundwater subarea near Dandaragan
- Irwin: an area south of the Irwin River near Dongara (Figure 1).

Abstracting groundwater for irrigation can affect groundwater levels at sensitive features in the landscape. Groundwater declines can affect the amount of water available:

- in farm water sources such as soaks and shallow bores
- in ecological features such as wetlands and watercourses
- to the roots of groundwater-dependent vegetation.

This report summarises the results of a literature review, database searches and limited field surveys. It describes features susceptible to groundwater decline in the Dinner Hill and Irwin focus areas and their social, economic, cultural and ecological values, such as:

- stock water
- stock shelter trees and food from riverine plants and pasture
- irrigation water from river baseflow
- indigenous cultural values
- heritage values
- recreational or tourism uses
- ecological and biodiversity values.

The report and mapping will be used to inform an allocation limit review relevant to the Dinner Hill focus area. It may also be used by proponents, in proposals to take groundwater, through identifying and avoiding drawdown at high value groundwater-dependent sites.

This report is structured as follows:

- Section 1 provides a project introduction, including the setting in the State government funded programs and a brief background on the study areas.
- Section 2 covers the biophysical setting, including climate, water resources and vegetation.
- Section 3 describes the methods used in this study.
- Sections 4 and 5 present the results for the Dinner Hill and Irwin study areas, respectively.
- Section 6 provides guidance for applying the information in this report to an allocation limit review.

The Appendices contain background information, including how the information in this report applies to water licence assessments, as well as the results of database searches used to identify the high value sites, species and communities.

1 Introduction

There are currently eleven State government supported projects focused on significantly increasing irrigated agriculture across Western Australia. The primary objective of these projects is to identify water and land resources, as well as irrigation technologies, that can enable Western Australia's fresh food and animal protein production to increase its contribution to regional economies by at least 50 per cent by 2025 and 100 per cent by 2050.

The Midlands groundwater and land assessment project is investigating groundwater availability, land capability and crop suitability in the Midlands area, between Gingin and Dongara. The two focus areas chosen for the Midlands project are:

- Dinner Hill: the south-western corner of the Dinner Hill groundwater subarea near Dandaragan
- Irwin: an area south of the Irwin River near Dongara (Figure 1).

The Midlands project requires information on opportunities and constraints for groundwater abstraction, as groundwater is the main prospective source of water considered for irrigation in these areas.

This report describes sites where groundwater discharge, or connectivity to groundwater, supports social, cultural and economic values and benefits such as:

- stock water supply
- shelter and food
- irrigation water from river baseflow
- indigenous cultural values
- heritage values
- recreational or tourism use as well as ecological and biodiversity values.

Consumptive use of groundwater-derived surface water is captured along with non-consumptive values as both may be affected by groundwater abstraction.

The report and mapping will be used to inform an allocation limit review relevant to the Dinner Hill focus area. It may also be used by proponents in proposals to take groundwater through identifying and avoiding drawdown at high value groundwater-dependent sites.

1.1 Study areas

The Midlands groundwater and land assessment area is in the northern Perth Basin. The Dinner Hill and Irwin focus areas are subsets of the broader Midlands assessment area, and are shown in Figure 1.

Taking groundwater for irrigated agriculture in these focus areas may impact surrounding areas through direct drawdown or changes in the water balance. Because of this, our study areas are spatially broader than the Dinner Hill and Irwin focus areas. Their spatial extent is informed by our current understanding of the hydrogeology with regards to potential extent of drawdown and direction of groundwater flow.

Dinner Hill study area

The Dinner Hill study area comprises the focus area, buffered by 10 km on the western, north-eastern and eastern boundaries, and by 30 km on the southern boundary. This accounts for southwards and westwards groundwater flow past the southern boundary of the Dinner Hill groundwater subarea. The area encompasses watercourses which are may receive baseflow from the Leederville-Parmelia aquifer, however the aquifer(s) supporting baseflow are not yet confirmed.

Irwin study area

The Irwin study area comprises the focus area plus a 10 km buffer. This covers the known spatial extent of baseflow in the Irwin River.

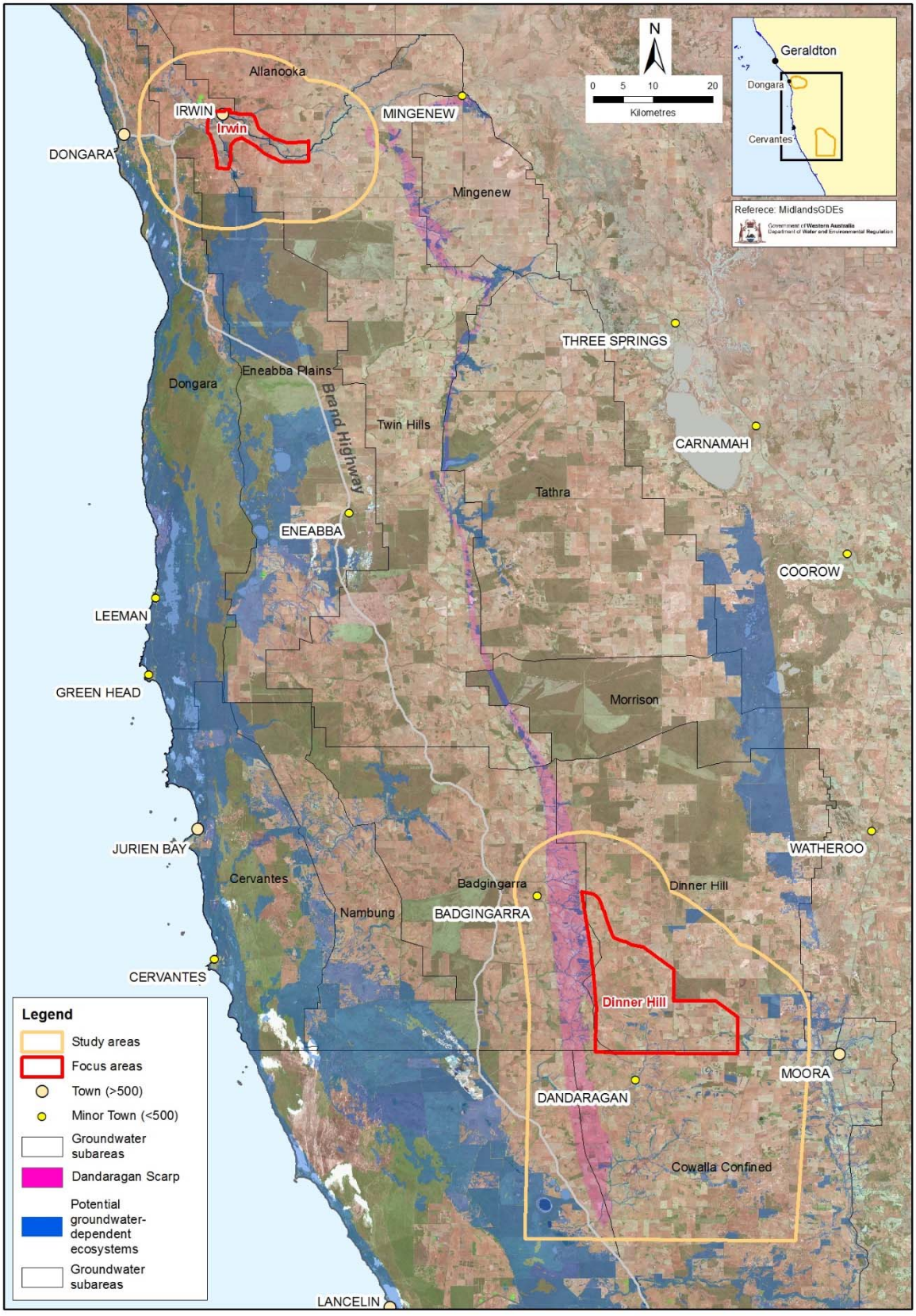

Figure 1 Location of the Irwin and Dinner Hill focus areas and study areas

2 Understanding the biophysical setting

2.1 Climate

The study areas are located in a region in Western Australia with a warm temperate Mediterranean climate characterised by low temperatures and high rainfall in winter and high temperatures and low rainfall throughout summer (Figure 2). These conditions promote summer groundwater dependency in ecosystems where groundwater is accessible.

The region's rainfall occurs across a gradient with lower rainfall in the north, increasing southward, a difference which is observed between the two study areas. The average annual rainfall near the Irwin study area at Dongara is 402.6 mm (Bureau of Meteorology station no. 008044 between 1965–2015). The average annual rainfall near the Dinner Hill study area at Badgingarra is higher, at 523.5 mm (Bureau of Meteorology station no. 009037 between 1965–2015).

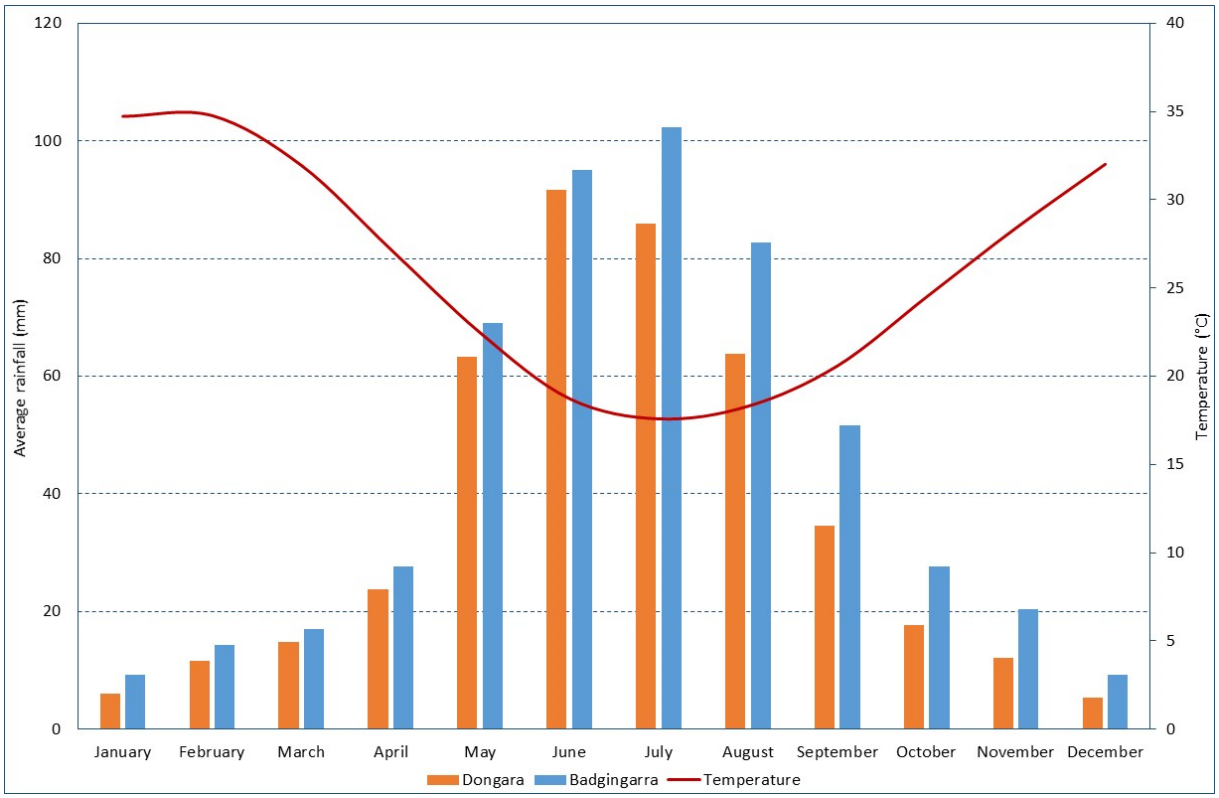

Figure 2 Average monthly rainfall and maximum temperatures at Badgingarra, and average monthly rainfall at Dongara

2.2 Water resources

Dinner Hill study area

In the Dinner Hill study area, shallow groundwater is found primarily along valleys through which watercourses flow. In some watercourses, surface water derived from shallow groundwater discharge (baseflow) is taken for commercial purposes, notably for stock water and to supplement commercial irrigation.

Anecdotal reports from landholders suggest that baseflow peaked five to ten years ago, and is now in decline, particularly in the Minyulo Brook and its tributaries. Groundwater trends are relatively complex and will be analysed through hydrogeological investigations for the Midlands project, and through the East Midlands component of the State Groundwater Investigation Program.

Broadly, groundwater levels rose over several decades with waterlogging becoming a problem, particularly in the West Koojan – Gillingarra area (Kay 2001). More recently however, the rate of rise has slowed and in some areas groundwater levels are declining. In some areas this is attributable to groundwater abstraction, while in others declining rainfall recharge may play a role.

The *Jurien groundwater allocation plan* (DoW 2010a) recognises three groundwater resources in the study area: the Mirrabooka aquifer, the Surficial aquifer and the Leederville-Parmelia aquifer.

All three aquifers are known to sustain groundwater-dependent ecosystems. Ecosystems may also be sustained by perched groundwater on subsurface laterite (prevalent although patchy in the study area: Kay 2001) or laterally continuous clay layers (see Figure 15 of DoW 2017). This can make it difficult to identify which aquifer supports any given groundwater-dependent ecosystem. In addition current aquifer mapping is reliable at regional, but not local, scale so to identify which aquifer supports which groundwater-dependent ecosystem will typically require local investigations.

The Leederville-Parmelia aquifer is the most prospective for the take of larger volumes of groundwater. Hydrogeological investigations for the Midlands project have produced an updated conceptualisation of this aquifer for the Dinner Hill area (Schafer and Hoare 2018). Outputs from this work may assist in determining which groundwater-dependent ecosystems are supported by the Leederville-Parmelia aquifer in the study area.

The Dinner Hill focus area is contained entirely in the Dinner Hill groundwater subarea which Department of Water and Environmental Regulation manages under the *Jurien groundwater allocation plan* (DoW 2010a). It is immediately north of, and hydraulically connected to, the Cowalla Confined groundwater subarea, managed under the *Gingin groundwater allocation plan* (DoW 2015). Commercial use of surface water in the study area remains unlicensed, because there are no proclaimed surface water areas under the *Rights in Water and Irrigation Act 1914.*

Irwin study area

In the Irwin study area, shallow groundwater occurs primarily near the Irwin River and its tributaries. It was developed for stock water through construction of shallow bores and soaks. Permanent surface water features on the Irwin River were reported as early as 1910 (Campbell 1910). However, deposition of sediment into the channel has filled some pools (Warman 2008), so that permanent surface water features may be less prevalent today, despite rising groundwater levels in response to land clearing in recent decades (Schafer 2015). Anecdotal reports from landholders in the area of Mendara Spring suggest that groundwater quality at the water table is marginal, with fresher water found a little deeper in the aquifer.

The *Arrowsmith groundwater allocation plan* (DoW 2010b) recognises two groundwater resources in the study area: the Yarragadee aquifer and its overlying and hydraulically connected Surficial aquifer. Both aquifers are known to sustain groundwater-dependent ecosystems associated with the Irwin River and its tributaries, and wetlands and vegetation further west in a north-south landscape depression at the base of the Gingin Scarp. The Yarragadee aquifer is the most prospective resource for larger volume groundwater licences, and supports the study area's groundwater-dependent ecosystems.

The Irwin focus area spans three groundwater subareas:

- Allanooka subarea north of the Irwin River
- Twin Hills subarea south of the Irwin River
- Eneabba Plains subarea which lies west of both the Allanooka and Twin Hills subareas.

These are managed by the department under the *Arrowsmith groundwater allocation plan* (DoW 2010b). Any commercial use of surface water in the study area remains unlicensed, because there are no proclaimed surface water areas under the *Rights in Water and Irrigation Act 1914*.

2.3 Vegetation

Due to agricultural clearing only a small portion of the original vegetation remains in the Dinner Hill and Irwin study areas. This vegetation is largely along watercourses (riparian), associated with springs or found in reserves. Because of the extensive clearing the remaining vegetation forms important habitat corridors.

Dinner Hill study area

Prior to European settlement, native vegetation in the Dinner Hill study area was dominated by three vegetation complexes recognised by Beard (1979):

- Marri (*Corymbia calophylla*) woodland – including a riverine sub-component with river gums dominant (*Eucalyptus camaldulensis*) (e3Mi – see Appendix E for vegetation codes)
- low woodland of *Banksia attenuata* & *B. menziesii* (b1,2Li)
- low woodland of *Banksia prionotes* (b3Li) as per Beard (1979) (Figure 3).

Casuarina ?obesa is also found on some upper tributaries which join Minyulo Brook from the east. Banksia communities in the study area (b1, 2Li and b3Li) may satisfy the community description for the new endangered ecological community listing of Banksia Woodlands of the Swan Coastal Plain under the *Environment Protection and Biodiversity Conservation Act 1999* (DoE 2016a).

Irwin study area

Prior to European settlement, native vegetation in the Irwin study area was dominated by two vegetation complexes recognised by Beard (1979). They are the York Gum woodlands (e6Mi – see Appendix E for vegetation codes), and shrub-lands where scrub-heath is present on lateritic sandplain in the central Geraldton Sandplain Region (x4SZc) (Figure 4). The watercourses are lined with River Gums, *Eucalyptus camaldulensis* (Stuart-Street 2005).

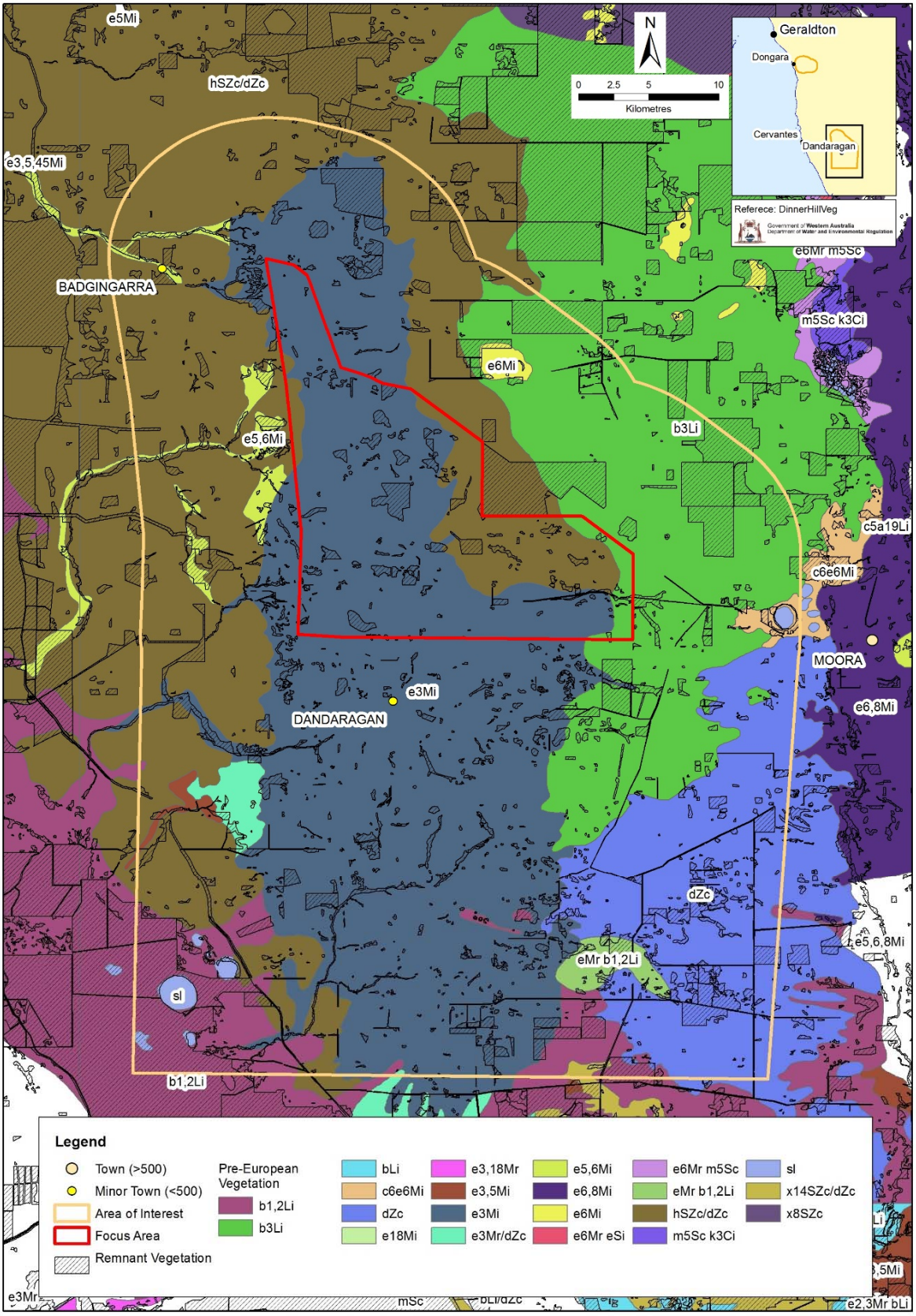

Figure 3 Remnant vegetation (hatched) overlain on pre-European vegetation complexes (see Appendix E for codes)

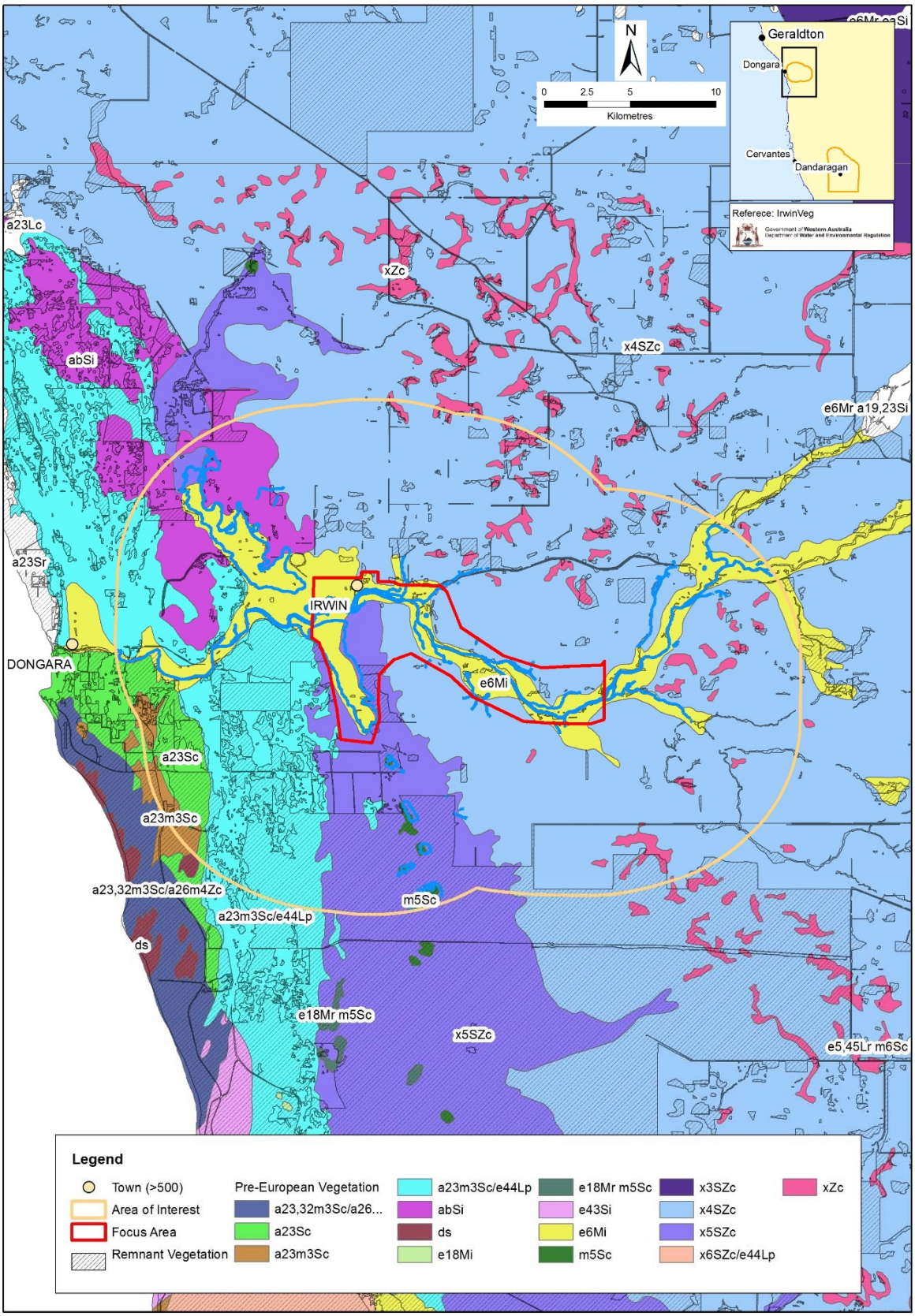

Figure 4 Remnant vegetation (hatched) overlain on pre-European vegetation complexes (see Appendix E for codes)

3 Methods

3.1 Identifying and mapping potential groundwater-dependent ecosystems and their values

Mapping potential groundwater-dependent ecosystems

Groundwater-dependent ecosystems in the northern Perth Basin are typically found where groundwater is shallow (DoW 2009). To identify and map ecosystems over shallow groundwater, we used spatial datasets which identify ecosystem extent, and clipped or intersected these layers to show only those features in locations where depth to groundwater is less than 20 m.

The datasets we used are listed in Table 1. The depth-to-groundwater layer was generated by Rutherford et al. 2005, and mapped features are assigned to one of three depth-to-groundwater categories; 0-5 m, 5-10 m or 10-20 m. While groundwater-dependent vegetation is typically found at depths less than 10 m to groundwater (DoW 2009), we used 20 m depth-to-groundwater threshold because tree roots can access groundwater at 15 m at some sites on the northern Perth Basin (DoW 2017). This also accounts for the possibility of error caused by extrapolation between points of measured groundwater depth, in creating the depth-to-groundwater map.

The result is a set of spatial datasets which show the distribution of potential groundwater-dependent ecosystems in the study areas (Figure 5 and Figure 10). Each polygon representing a potential groundwater-dependent ecosystem has a depth-to-groundwater class (0-5 m, 5-10 m or 10-20 m) as well as an ecosystem type class (wetland, watercourse or vegetation). These are relevant attributes in assessing groundwater drawdown risk.

Table 1 Mapping datasets used to identify potential groundwater-dependent ecosystems

Ecosystem type		Mapping dataset (custodian)	
		Dinner Hill	**Irwin**
Wetlands	Features over less than 20 m depth to groundwater, in the study areas	Geomorphic Wetlands, Swan Coastal Plain dataset [Department of Biodiversity, Conservation and Attractions, Western Australia]	No wetland mapping available
Watercourses & some wetlands		Hydrography, Linear (Hierarchy) [Department of Water and Environmental Regulation, Western Australia]	
Native vegetation		Native vegetation current extent – Western Australia [Department of Primary Industries and Regional Development, Western Australia]	

Mapping environmental (in-situ) values of groundwater

Note that only the values layers derived from publicly available data are available for release.

In-situ environmental values of groundwater play a role in determining what level of drawdown impact is environmentally acceptable, when the department sets allocation limits and assesses applications to take water. The level of impact considered acceptable is lower for sites that the community values highly for their economic, social, cultural or ecological benefits. The department is guided in identifying high value sites through relevant policy (Table 2 and Appendix F).

Table 2 Mapping layers depicting environmental values relevant to water allocation

Custodian and mapping layer	Relevance of the layer to impact assessment
Department of Biodiversity, Conservation and Attractions: Managed Lands and Waters	Spatial datasets which identify environmentally significant water-dependent ecosystems (see also Appendix F).
Department of Biodiversity, Conservation and Attractions: Threatened & Priority Flora	
Department of Biodiversity, Conservation and Attractions: Threatened Fauna	
Department of Biodiversity, Conservation and Attractions: Threatened and Priority Ecological Community Buffers in WA	
Department of the Environment, Water, Heritage and the Arts (Federal): Directory of Important Wetlands in Australia Wetlands	
Department of Water and Environmental Regulation: Environmentally Sensitive Areas	
Department of Planning, Lands and Heritage: Aboriginal Sites Register	
Department of Water and Environmental Regulation: Mid-West potential groundwater-dependent ecosystems and associated values points, polygons and lines	Collates information from tourism brochures, websites and interviews with local stakeholders (e.g. local and state government employees), on social, cultural and ecological values of potential groundwater-dependent ecosystem sites in the northern Perth Basin.

Limitations of the spatial datasets

The spatial datasets can be used to indicate the distribution, depth to groundwater, ecosystem type and high environmental value sites in an area of interest.

In regards to distribution, the spatial datasets represent regional-scale distribution and do not comprehensively capture each groundwater-dependent ecosystem relevant to a licence assessment. The layer helps to identify the landscape areas to focus on for a zoomed-in visual assessment using aerial photography, seeking

features such as dense vegetation, wetlands and watercourses. Field assessment may also be required.

In regards to environmental value, the available spatial datasets do not provide a comprehensive inventory of all high value sites. This is because survey, mapping and values assessment is not complete in the northern Perth Basin area.

None of the mapping included stygofauna records, because there was little survey for stygofauna in the study areas. However, neither study area contains likely stygofauna habitat because the geology is primarily deep sands and clays. Stygofauna are most likely to be found where geological formations contain significant saturated pores and voids (EPA 2013).

3.2 Database searches

A search of the Protected Matters Search Tool administered by the Commonwealth Department of Environment and Energy (DoE 2016b) was undertaken to identify any Matters of National Environmental Significance which would be protected under the *Environmental Protection and Biodiversity Conservation Act 1999*. This tool reports on the presence of sites, species and communities.

Searches of the Department of Biodiversity, Conservation and Attractions' threatened species (flora and fauna) and ecological communities were undertaken to provide further detail on the mapping (section 3.1). This was required because the spatial datasets do not detail species or community type. Knowing the species or community helps determine the potential for groundwater dependency. Threatened species and communities are protected through the *Environmental Protection Act 1986* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

We searched the Atlas of Living Australia (2016) for protected fauna records from in the study areas. This tool compiles datasets from a range of sources including the Western Australian Museum (2014) and Birdlife Australia (2016) documenting all species recorded including those which are not protected under any legislation. For the purposes of this study, we filtered the output to include only those species that were protected and not identified through previous searches. As our previous database searches identified a range of fauna protected under state and federal legislation, the only new species found were listed marine species[1] – including many migratory birds which utilise wetlands.

[1] Listed marine species as per the Declaration under section 248 of the *Environment Protection and Biodiversity Conservation Act 1999* - List of Marine Species

Social and cultural values were predominantly identified through the use of spatial layers (Table 2), however, two additional searches were conducted through:

- Shire of Dandaragan Municipal Inventory of Heritage Places (Shire of Dandaragan 2004)
- Shire of Irwin Municipal Inventory of Heritage Places (Shire of Irwin 2005).

The results of database searches are presented in Appendices A, B and C.

3.3 Literature review

A literature review captured information from government agency websites and reports, Natural Resource Management group reports - such as Northern Agricultural Catchment Council and West Midlands Group, published research (journal articles and student theses) and news articles.

3.4 Irwin River site visit

On 21 and 22 of June 2016, the department's project ecologist, accompanied by the project hydrogeologist, conducted a fauna and vegetation assessment of selected groundwater discharge sites. Sites visited included Irwin Spring, Mendara Spring and nearby reaches of the Irwin River. Field notes from these site assessments are in Appendix D.

3.5 Summaries of site characteristics, values and management objectives

The database searches (Section 3.2), literature review (Section 3.3) and field visit to the Irwin River (Section 3.4) provided a range of sources to identify the values of potential groundwater-dependent ecosystems, supplementing the mapped information in the spatial datasets (Section 3.1). Summaries are presented in Section 4 (Dinner Hill study area) and Section 5 (Irwin study area). Based on the values found, information relevant to managing drawdown, informed by legislation and policy, is in Section 6.

4 Dinner Hill: in-situ values of groundwater

4.1 Overview

In-situ groundwater in the Dinner Hill study area supports a range of values including:

- habitat for Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*)
- threatened flora species such as Foote's Grevillea (*Grevillea calliantha),* which was translocated to Minyulo Nature Reserve
- various areas of migratory bird habitat
- an Aboriginal Heritage site along the Minyulo Brook
- conservation reserves
- irrigation water for growing potatoes and resources for stock including water, food and shelter.

Potential groundwater-dependent ecosystems in the Dinner Hill study area are associated with the following five main areas (Figure 5):

- the Minyulo, Yatheroo and Caren-Caren Brooks and their tributaries
- watercourses, where they cross the Dandaragan Scarp at the western extent of the Dandaragan Plateau, including the headwaters of the Hill River
- the Yallalie Basin (a suspected meteorite impact structure at the head of the Minyulo Brook)
- wetlands at the base of Gingin Scarp, at the eastern extent of the Swan Coastal Plain
- Lake Dallaroo and nearby wetlands west of Moora town site.

Comparison of mapped potential groundwater-dependent ecosystems (Figure 5) with patterns of lush vegetation on aerial photography indicates that the mapping may omit some groundwater-dependent ecosystems, primarily along minor tributaries.

Detail on the groundwater-dependent environmental values for individual sites is presented in Table 3. Table 3 may be used to identify sites relevant to local-scale drawdown impact assessment (such as for a water licence application) and their values.

Figure 8 summarises the groundwater-dependent values found across all sites in the Dinner Hill study area (Table 3), in relation to three ecosystem components that support them – surface water, wetland vegetation and groundwater-dependent trees.

Groundwater-dependent ecosystems can be found alone or in various combinations. For example, one site might support only groundwater-dependent trees, while another supports groundwater-dependent trees, wetland vegetation, and surface

water derived from groundwater. The former site would tolerate greater drawdown without losing its groundwater-dependent values than the latter.

Knowing which ecosystem components are present at a given site assists in choosing a groundwater level objective that will maintain the site's values. This report provides a management framework that can be used to propose groundwater management objectives. The framework integrates the information from Table 3 and Figure 8. Setting objectives is an important step for setting allocation limits and assessing water licences.

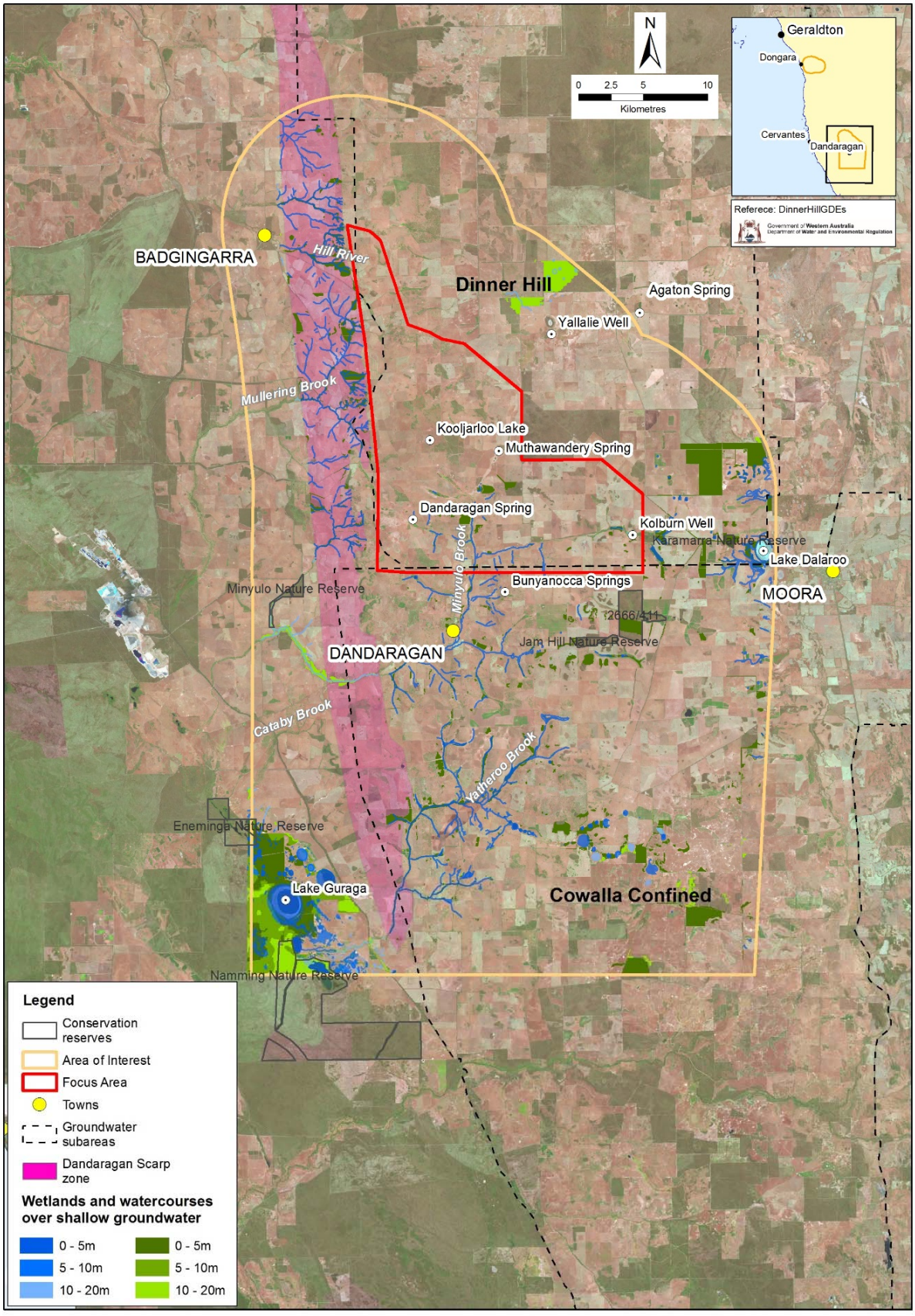

Figure 5 Potential groundwater-dependent ecosystems of the Dinner Hill study area

Minyulo, Yatheroo and Caren-Caren brooks and their tributaries

In the Dinner Hill study area, shallow groundwater is found along the incised valleys of the Minyulo, Caren-Caren and Yatheroo brooks and their tributaries. Here:

- Shallow and discharging groundwater supports reliable surface water, riparian trees and wetland vegetation.
- Reliable surface water provides water for farm use (irrigation water for potatoes and presumably farm water sources including stock water), a water source for terrestrial fauna, reliable aquatic habitat for protected fauna species including wetland birds, and presumably contributes to the indigenous cultural value of the Minyulo Brook.
- Riparian trees probably provide shelter for stock, erosion control, a habitat corridor for terrestrial fauna, and habitat for protected species.
- Wetland vegetation provides habitat for wetland birds and may be important for stock feed (including introduced pasture growing in wetlands).

Along the Minyulo Brook there are several springs, including the Muthawandery Spring, which Rutherford et al. (2005) suggested is supported by discharge from the Leederville aquifer. At Muthawandery Spring and perhaps elsewhere on the Minyulo and Caren Caren brooks, lateritic horizons of low hydraulic permeability are found in shallow subsurface horizons (DoW 2017). These layers may delay infiltration of rain and surface flows, and further analysis is required to clarify the relationship between groundwater in the Leederville or Parmelia aquifers and overlying ecosystems.

Across the east of the Dandaragan Plateau (particularly, east of Dandaragan town site), chains of wetlands form indistinct drainage lines which lead westwards into tributaries of the Minyulo Brook. Some of these contain permanent water, such as areas of discharge near Kolburn Road (Figure 6; taken near Kolburn Well – see Figure 5).

An interesting feature approximately two kilometres north of the western tributaries of Minyulo Brook is Kooljarloo Lake. It is located high in the landscape with a minimal surface water catchment and elevated rims, however it appears to have near-permanent surface water (Geoscience Australia 2016), which may indicate groundwater contributions. The great depth to the potentiometric surface in the Leederville-Parmelia aquifer (greater than 20 m according to Schafer and Hoare 2018), suggests it may be sustained by a perched aquifer.

Figure 6 Wetland in western tributary of Minyulo Brook, near Kolburn Road

Watercourses crossing the Dandaragan Scarp

Shallow groundwater is mapped extensively along, and just east of, the Dandaragan Scarp. Groundwater is particularly shallow and discharges along the incised watercourses which cross the Scarp, including the Windjardie Creek, Hill River, Mullering Brook and other unnamed watercourses. Along these watercourses, shallow and discharging groundwater supports:

- Riparian trees, which provide shelter for stock, erosion control, habitat corridors for terrestrial fauna and habitat for protected birds.
- Reliable farm water sources including excavated soaks or dams along or in watercourses.

The role of groundwater in sustaining these water sources would require in-field or landholder surveys. The source of groundwater may also need to be resolved to determine whether the source is the regional Leederville-Parmelia aquifer, or a shallower aquifer.

The presence and significance of wetland vegetation habitats of the shallow groundwater zone of the Dandaragan Scarp are not readily discernible from aerial photography and field surveys would be required to assess them. During a brief field visit to a dam in this zone in July 2017, department staff surmised the dam appeared to collect surface water runoff as well as receiving groundwater discharge.

Carnaby's Black-Cockatoos (*Calyptorhynchus latirostris*) (Figure 7) were observed in the nearby riparian trees, frog calls were heard and wetland birds seen in the dam.

*Figure 7 Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) observed in a riparian tree of a watercourse crossing the Dandaragan Scarp*

The Yallalie Basin and vicinity

The Yallalie Basin is a depression of approximately 12 km in diameter, thought to have been formed by a meteorite strike (Dentith 1999). Land in the depression is mostly cleared, however there are three environmental features of note:

- a lake at the head of the Minyulo Brook
- remnant vegetation, some of which may meet the criteria for the Threatened Ecological Community listing Banksia Woodlands of the Swan Coastal Plain (DoE 2016a)
- Agaton Spring, which appears to support native vegetation in a reserve.

Establishing whether these features are groundwater-dependent and, if so, which aquifers may be involved, may require site investigations because the local hydrogeology in the basin is anomalous in the region.

The Yallalie Basin contains groundwater in a shallow surficial aquifer, with lower permeability sediments causing southwards flows in the Leederville-Parmelia aquifer to be diverted around the basin (DoW 2017). There may be some hydraulic

connection between the upper sands of the basin and the underlying Leederville-Parmelia aquifer, allowing the aquifer to be recharged from the basin (DoW 2017).

In the Basin, groundwater near the lake feature is reported to be over 20 m below ground level and brackish to saline, while the lake is underlain by low permeability silts and clays (DoW 2017). This suggests that the lake itself may not be groundwater-dependent. However, remnant vegetation in the north-north-west of the basin is mapped as occurring over shallow groundwater and is potentially groundwater-dependent.

Agaton Spring, located approximately five kilometres east of the Yallalie Basin on the Coomberdale West Road, warrants further consideration. It did not appear on shallow groundwater mapping (Figure 5), however the Agaton Project (Balleau 1972) identifies it as an area of shallow groundwater, and aerial photography suggests that it supports wetland vegetation.

Similarly, there are several watercourses which arise approximately six kilometres west of the western rim of the basin which drain eastwards into the basin. They are not captured in Figure 5 because groundwater in the regional aquifer is more than 20 m below ground in their location. However, the vegetation along these watercourses including River Gums (*Eucalyptus camaldulensis*) suggests that they may receive baseflow.

Swan Coastal Plain, base of Gingin Scarp

Lake Guraga, Namming Lake and wetlands in the Namming Nature Reserve such as Crackers Swamp (Figure 8) lie at the base of the Gingin Scarp. These wetlands receive surface flows from Caren-Caren Brook (Halse 1993), which is thought to receive baseflow from the aquifers of the Dandaragan Plateau. Lake Guraga is a nationally important wetland listed in the Directory of Important Wetlands of Australia (Environment Australia 2001) for its waterbird habitat values and as an example of a large brackish/saline lake (DEC 2009). The lake is also listed as an Environmentally Sensitive Area under the Environmental Protection *Clearing of Native Vegetation Regulations 2004*.

Figure 8 Crackers Swamp in the Namming Nature Reserve

Since about the 1940s, local people have affected water levels in these lakes by controlling flows through the north and south branches of Caren Caren Brook. Initially, surface flows were diverted into the south branch and into the reserve's wetlands, to prevent land near Namming Lake from flooding. In 1972, the Shire of Dandaragan restored flows to the northern branch, via Namming Lake and into Lake Guraga. Restoring this original pattern was intended to supplement the falling water levels in Lake Guraga, to support recreation and wildlife habitat (Crook 1984).

In 1993 further alteration to surface flows in the system e.g. flood control works and diversion for irrigation have led to the hydrology of Lake Guraga being changed, with it now receiving a greater contribution from groundwater (DoE 2009). North of these wetlands, groundwater levels were rising in response to land clearing since the 1990s (DoW 2017). These changes to water regime will be relevant considerations in setting groundwater management objectives for the area.

Current conceptual modelling suggests that groundwater resources of this part of the Swan Coastal Plain may be hydraulically connected to those of the Dandaragan Plateau (De Silva 2015). This, combined with the potential for baseflow in the Caren Caren Brook to be supported by groundwater of the Dandaragan Plateau, suggests that increased allocation from Dandaragan Plateau resources may influence the hydrology of these coastal plain wetlands.

In this part of the Swan Coastal Plain, groundwater sustains:

- Aquatic habitat and wetland vegetation associated with Lake Guraga (a nationally important wetland), Namming Lake and wetlands in Namming Nature Reserve, supporting protected wetland birds.
- Groundwater-dependent vegetation, including protected Banksia woodland (DoE 2016a) and vegetation protected in Namming Nature Reserve.

Lake Dalaroo and nearby wetlands

A cluster of saline wetlands associated with Lake Dalaroo is found west of Moora town site. The surface water component provides habitat for waterbirds. These lakes are located in shallow surficial sediments overlying the Kardinya Shale, and shallow depth to groundwater suggests the water table is relevant to their water regimes (Figure 5).

A 1931 museum record of a Rakali (native water rat) near Lake Dalaroo (Atlas of Living Australia 2016) suggests that this species was once more widespread in the northern Perth Basin than it is today.

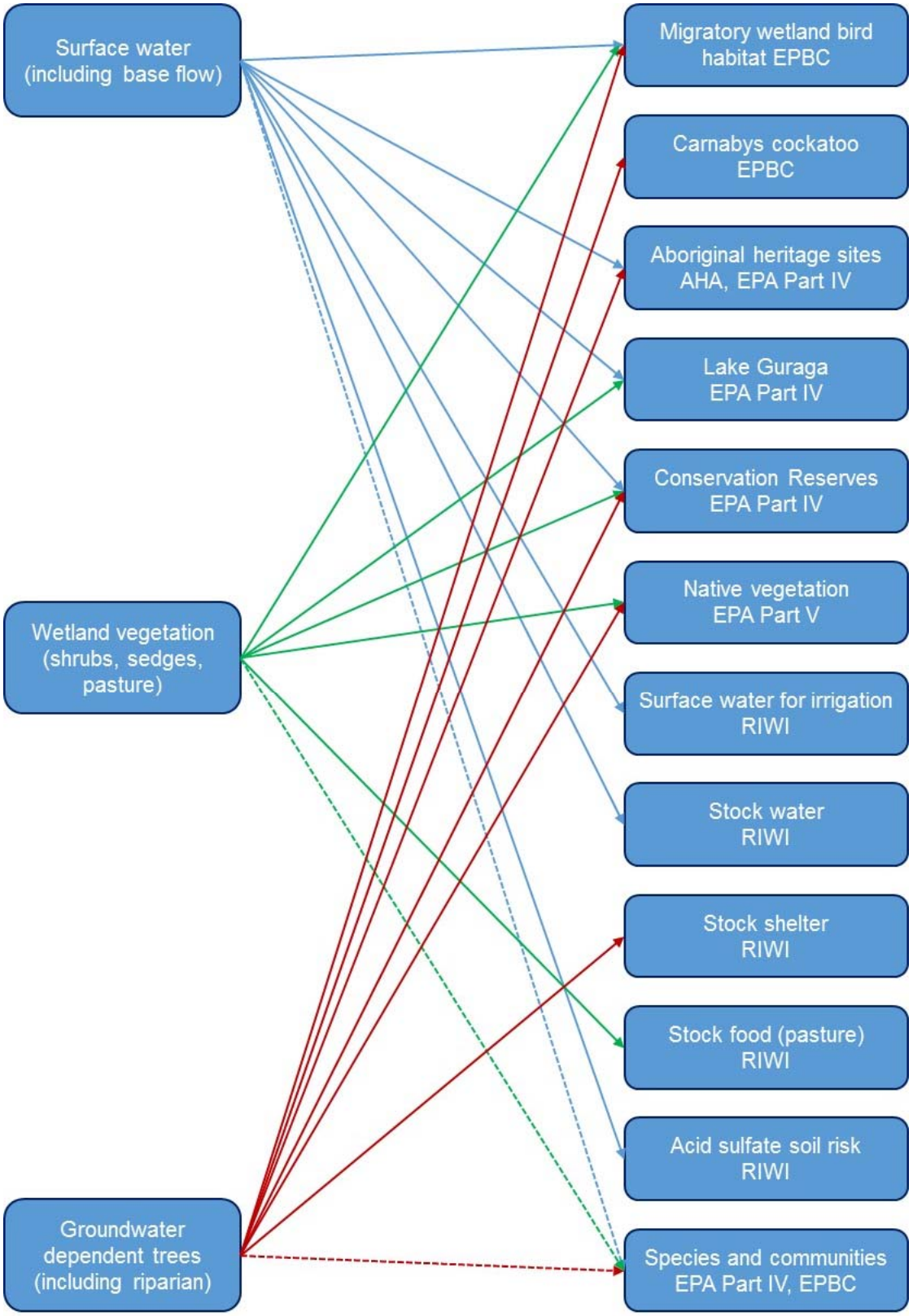

Figure 9 Groundwater-dependent environmental values in the Dinner Hill study area

4.2 Values of groundwater-dependent sites

Table 3 provides a summary of named sites in the Dinner Hill study area and their groundwater-dependent values identified through values mapping, database searches (see Appendices), literature review and a site visit. The values in Table 3 refer to mapped landscape features and should be read with consideration of the protected flora and fauna identified through database searches (see Appendix A).

The preferred habitat of flora and fauna is important when referring to the groundwater-dependent component and values. An example of this is the presence of the Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) which has a preference for Eucalyptus woodlands and shrub-lands dominated by *Hakea spp*. and *Banksia* spp. An example of protected flora identified in the study area is the Slender Andersonia (*Andersonia gracilis*) which has a preference for swamps and is identified as being threatened by destruction of wetlands and rising water tables (DEC 2006).

Table 3 Environmental, social and cultural values of potential groundwater-dependent ecosystems in the Dinner Hill study area

Landscape feature/ area	Specific site	Groundwater-dependent component			Value	Dataset/reference(s)
		Surface water	Wetland vegetation	Groundwater-dependent trees		
Caren Caren Brook	Whole brook	x	-	-	Social/economic: water diverted from the brook for irrigation Environment: flows to Namming Lake, Crackers Swamp and Lake Guraga (see below).	Department of Environmental Conservation (now Department of Biodiversity, Conservation and Attractions) (2009) Hydrography, linear spatial layer
		-	-	x	Social/economic: shelter for stock, erosion control Environment: habitat corridor, habitat for protected fauna	Aerial Photography spatial layer Atlas of Living Australia (2016) Native Vegetation Current Extent – Department of Primary Industries and Regional Development spatial layer (Agriculture)
Minyulo Brook	Whole brook	x	x	-	Social/economic: Stock watering, irrigation Cultural: Named after the coloured snake known as Minyaal and the lizard known as Youlaart, the brook was utilised for water, food, plants for traditional medicines, and as a meeting place	Department of Parks and Wildlife (now Department of Biodiversity, Conservation and Attractions) (2016a) database search Hydrography, Linear spatial layer Mid-West potential groundwater-dependent ecosystems spatial layer Observations Rutherford et al. (2005) South West Aboriginal Land and Sea Council (2012)
		-	-	x	Social/economic: shelter for stock, erosion control Environment: habitat corridor, habitat for protected birds, e.g. Carnaby's Black-Cockatoo sightings recorded in close proximity to the brook	Aerial Photography spatial layer Atlas of Living Australia (2016) Native Vegetation Current Extent – Department of Primary Industries and Regional Development spatial layer (Agriculture)
Minyulo Brook	Walyering Pool[2]	x	-	x	Environment: pool located on the brook - supported by discharge from Yarragadee formation; vegetation intact despite large scale clearing in surrounding landscape; supports threatened and priority flora	DPaW (2016a) database search Mid-West potential groundwater-dependent ecosystems spatial layer Rutherford et al. (2005)
	Minyulo Nature Reserve	-	-	x	Environment: translocation site for the threatened flora species *Grevillea calliantha*; supports several priority/threatened flora and fauna	Department of Environmental Conservation (now Department of Biodiversity, Conservation and Attractions) (2010) Department of Parks and Wildlife (now Department of Biodiversity, Conservation and Attractions) Managed Lands and Waters spatial layer Department of Parks and Wildlife (now Department of Biodiversity, Conservation and Attractions) (2016a) database search

[2] Walyering Pool was mapped as a potential groundwater-dependent ecosystem with value, however, it is worth noting it is supported by the Yarragadee formation and is unclear whether drawdown in the Leederville-Parmelia aquifer will have any effect on the pool

Landscape feature/ area	Specific site	Groundwater-dependent component			Value	Dataset/reference(s)
		Surface water	Wetland vegetation	Groundwater-dependent trees		
	Muthawandery Spring	-	-	x	Environment: vegetation intact at spring site despite large scale clearing on the surrounding landscape	Aerial photography spatial layer Native Vegetation Current Extent – Department of Primary Industries and Regional Development spatial layer (Agriculture) Rutherford et al. (2005)
	Dandaragan Spring	x	x	-	Cultural: Aboriginal name for the spring "Dandaraga" meaning good kangaroo country Social: historically used for droving Environment: habitat for waterbirds	Hydrography, Linear spatial layer Mid-West potential groundwater-dependent ecosystems spatial layer Rutherford et al. (2005) Shire of Dandaragan (2016)
Dandaragan Scarp	Dams and soaks	x	-	-	Social/Economic: stock/farm water supply (dams and soaks)	Aerial photography3 spatial layer
	Winjardie Creek, Hill River, Mullering Brook etc.	x	-	x	Social/Economic: stock shelter Environment: Carnaby's Black-Cockatoo habitat (species recorded in close proximity to the brooks); habitat for freshwater fish (e.g. Hill River supports Nightfish, *Bostockia porosa*)	Aerial photography spatial layer Atlas of Living Australia (2016) Morgan et al. (2011)
Dandaragan Scarp	Mullering Brook	x	?	x	Cultural: Aboriginal Registered Site - mythological, camp, artefacts/scatter, water source Environment: supports several threatened and priority flora	Aboriginal Sites Register System spatial layer DPaW (2016a) database search
Yallalie Crater	Whole area	x	-	x	Environment: vegetation communities with Banksia dominant. Potentially protected under the *Environmental Protection, Biodiversity and Conservation Act* 1999 (Commonwealth) as Threatened ecological community "Banksia woodlands of the Swan Coastal Plain"	Atlas of Living Australia (2016); Beard (1979) DEC (2016a) Hydrography, Linear spatial layer
Swan Coastal Plain	Lake Guraga	x	x	x	Environment: Directory of Important Wetlands in Australia, 49 waterbird species recorded (3 species breeding); internationally important stop-over for 15 species of migratory waterbirds4; Environmentally Sensitive Area – Clearing Regulations; receives inflow from the Caren Caren Brook system	DEC (2009) Environmentally Sensitive Areas spatial layer
	Namming Lake	x	x	x	Social: recreation – used by the locals as a swimming hole over summer Environment: receives inflow from Caren Caren Brook and connects to Lake Guraga (DIWA); habitat for waterbirds (including several protected)	Atlas of Living Australia (2016) DEC (2009) Hydrography, Linear spatial layer Mid-West potential groundwater-dependent ecosystems spatial layer

[3] Groundwater discharge vs. runoff requires field truthing at the dams and soaks

[4] Protected under various international agreements – CAMBA, JAMBA, and/or ROKAMBA

Landscape feature/ area	Specific site	Groundwater-dependent component			Value	Dataset/reference(s)
		Surface water	Wetland vegetation	Groundwater-dependent trees		
	Namming Nature Reserve, (incl. Crackers Swamp, depth-gauged lake)	x	x	x	Environment: Western Shield Program; Vegetation communities with Banksia dominant. Potentially protected under the *Environmental Protection, Biodiversity and Conservation Act* 1999 (Commonwealth) as Threatened ecological community “Banksia woodlands of the Swan Coastal Plain”	Atlas of Living Australia (2016) Beard (1979) Department of the Environment (2016a) DPaW Managed Lands and Waters spatial layer Mid-West potential groundwater-dependent ecosystems spatial layer
Swan Coastal Plain	Eneminga Nature Reserve	x	x	x	Social: recreation – previously duck shooting site (now prohibited) Environment: Western Shield Program; Vegetation communities with Banksia dominant. Potentially protected under the *Environmental Protection, Biodiversity and Conservation Act* 1999 (Commonwealth) as Threatened ecological community “Banksia woodlands of the Swan Coastal Plain”	Aerial Photography spatial layer Atlas of Living Australia (2016) Beard (1979) DoE (2016b) Mid-West potential groundwater-dependent ecosystems spatial layer
Lake Dalaroo		x	?	x	Environment: Lake (non-perennial) that supports various bird fauna (including several protected)	Aerial Photography spatial layer Atlas of Living Australia (2016) Hydrography, Linear spatial layer

5 Irwin: in-situ values of groundwater

5.1 Overview

In-situ groundwater in the Irwin study area supports a range of values including:

- habitat for Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*)
- migratory bird habitat
- the Slender Tree Frog (*Litoria adelaidensis*)
- Rakali (native water rat) at the northern limits of their ranges
- an Aboriginal Heritage site along the Irwin River
- resources for stock including water, food and shelter
- nature reserve.

Potential groundwater-dependent ecosystems in the Irwin study area (Figure 10) are largely associated with:

- the Irwin River and its associated creeks/channels and springs (Mendara and Irwin Spring were the focus of the field trip in Appendix D)
- a landscape depression at the base of the Gingin Scarp, where wetlands and groundwater-dependent vegetation are found.

Comparison of mapped potential groundwater-dependent ecosystems (Figure 10) with aerial photography indicates that the mapping is a reliable depiction of the extent of potential groundwater-dependent ecosystems in the Irwin study area.

Detail on the groundwater-dependent environmental values for individual sites is presented in Table 4. Table 4 may be used to identify sites relevant to local-scale drawdown impact assessments (e.g. water licence application) and their values.

Figure 14 summarises the groundwater-dependent values found across all sites in the Irwin study area (Table 4), in relation to three ecosystem components that support them – surface water, wetland vegetation and groundwater-dependent trees.

Groundwater-dependent values can be found alone or in various combinations. For example, one site might support only groundwater-dependent trees, while another supports groundwater-dependent trees, wetland vegetation, and surface water derived from groundwater. The former site would tolerate greater drawdown without losing its groundwater-dependent values than the latter.

Knowing which ecosystem components are present at a given site assists in choosing a groundwater level objective that will maintain the site's values. Section 6 of this report provides a management framework that can be used to propose groundwater management objectives. The framework integrates the information from Table 4 and Figure 14. Setting objectives is an important step for setting allocation limits and assessing applications for water licences.

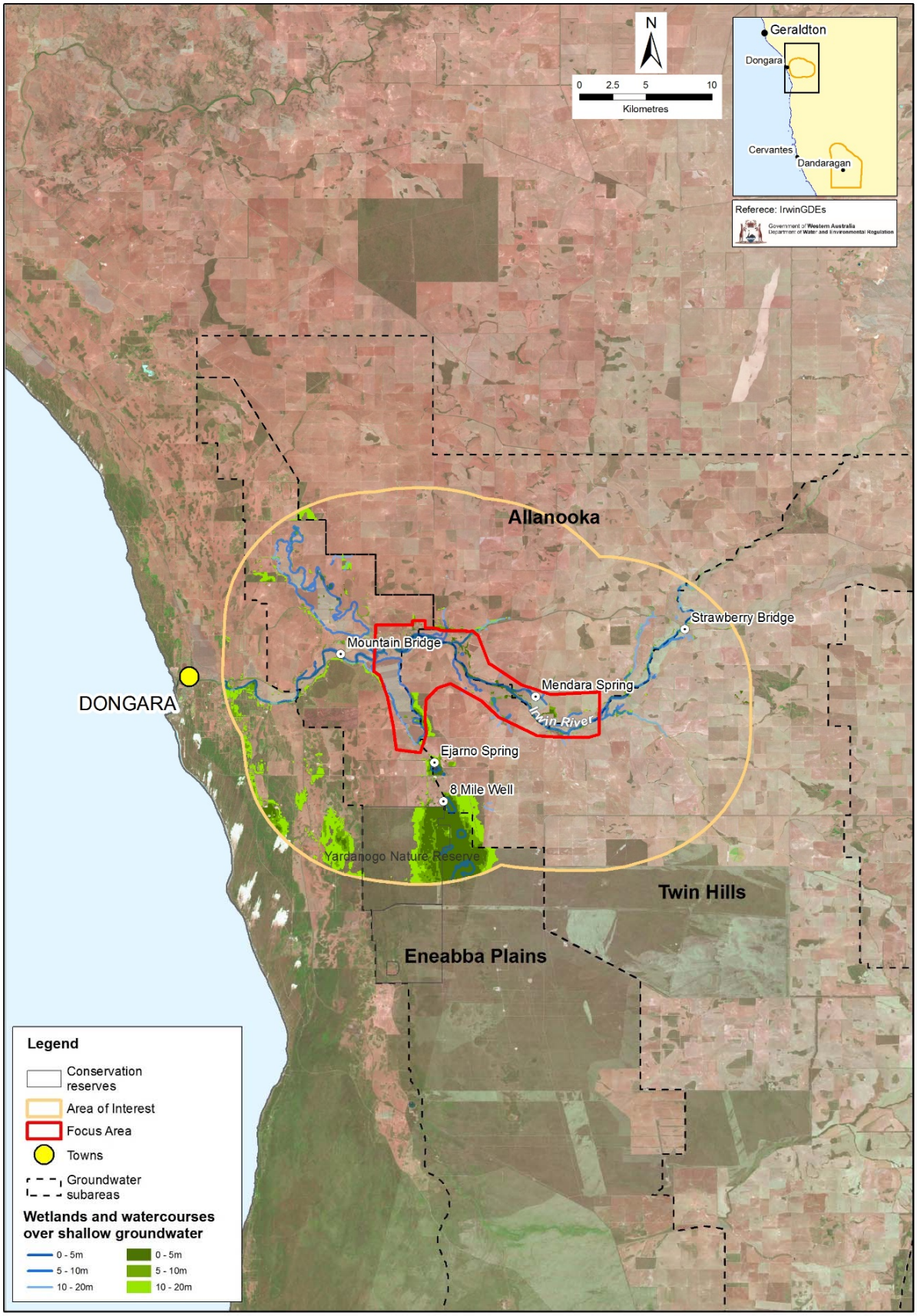

Figure 10 Potential groundwater-dependent ecosystems of the Irwin study area

Irwin River and tributaries

The Irwin River, in the Shire of Irwin, is approximately 158 km long (Shire of Irwin 2016), extending both upstream and downstream of the study area. The river is ephemeral in its upper reaches, but flows perennially in its mid to lower reaches (between Strawberry Bridge and Mountain Bridge) due to groundwater discharge from the Yarragadee formation (HydroConcept Pty Ltd 2015; Schafer 2015; Shire of Irwin 2016).

The Yarragadee formation is largely concealed by alluvium and colluvium along the river (DoW 2007), but outcrops as well-cemented sandstone in some areas as seen in Figure 11. Groundwater also discharges from the Yarragadee Aquifer at Mendara Spring situated in the Irwin River valley (Rutherford 2006), and at Irwin Spring on Springy Creek (DoW 2017).

Figure 11 Sandstone outcrop, surface water and riparian trees along the Irwin River

Warman (2008) refers to anecdotal reports that an unnamed spring in the Irwin study area began to flow permanently in 1965, coinciding with a period of above-average rainfall and increased local groundwater levels. In contrast, earlier reports show that Mendara Spring and Irwin Spring were permanent water sources since 1910 (Figure 12 – photographic excerpt from (Campbell 1910)). Despite today's permanent flow at springs and increasing groundwater levels, this same permanence of water was not observed in the Irwin River itself. Consulting with landholders is recommended to help describe changes to water regimes, and the value of discharge for farm water.

Mondara Spring, Irwin River.

Fig. 40.

Image courtesy of the Geoscience and Resource Strategy Division, Department of Mines, Industry Regulation and Safety. © State of Western Australia 2018

Figure 12 Photograph of Mendara Spring showing permanent surface water prior to 1910: excerpt from Campbell (1910)

Since European settlement, the Irwin River valley has undergone significant modification. Land clearing in particular has led to increased erosion in the upper sections of the river, causing channel widening. This widening has led to the formation of an aggrading river[5] downstream due to the deposition of the bedload material. Historically the river channel in this section was much deeper with reports of people being able to ride a horse underneath the Irwin Bridge. However, in recent years the same bridge has a clearance of less than one metre. While annual base flow does exist in this section of the river, there are no longer any deep pools due to the aggradation (Warman 2008).

The loss of large, deep pools may have impacted the species present in the river, as pools provide refuge for many aquatic species including native freshwater fish. The clearing of vegetation and aggrading river have likely caused a change in the species able to persist in the river and on its fringes.

Today the Irwin River still supports native fish in the lower reaches near the estuary e.g. Black Bream, Swan River Goby however, upstream in the study area it only

[5] Aggradation is the term used in geology for the increase in land elevation. In a river system this is largely due to the deposition of sediment (hence an aggrading river)

supports the introduced freshwater fish species, the Green Swordtail,(*Xiphophorus helleri)*, which can outcompete native species in modified and highly variable systems (Morgan & Gill 2004).

The shallow and discharging groundwater along the Irwin River and its tributaries supports:

- Reliable surface water, which provides stock water, a water source for terrestrial fauna, and probably contributes to the indigenous cultural value of the Irwin River.
- Riparian trees, which probably provide shelter for stock, erosion control, a habitat corridor for terrestrial fauna, and habitat for protected species.
- Wetland vegetation, which probably provides stock feed (pasture).

Base of Gingin Scarp wetlands and vegetation

Alluvial soils are found over shallow groundwater in the landscape depression at the base of the Gingin Scarp. A chain of wetlands occupies this depression, extending some 30 km south from the Irwin River. Nearest the river the depression is cleared, and the alluvial soils in it are under investigation by the Department of Agriculture and Food for their potential for irrigated agriculture as part of the Midlands project.

Ejarno Spring occurs in remnant vegetation in these wetlands and just south of the cleared area. It feeds a large, reliably permanent surface water feature surrounded by River Gums (*E. camaldulensis*) and wetland vegetation (Figure 13). A small clearing west of Ejarno Spring, visible on aerial photography, suggests it may were used as a farm water source. However, despite any historical modification the site has high environmental value and may have significance for the local Aboriginal people (AWE 2016).

The site supports wetland birds and fauna which require aquatic habitat. The northern-most Western Australian sighting of the Rakali (native water rat) is from this location (Trocini 2015). Ejarno Spring may be of high ecological significance to the species, given that its range in the northern Perth Basin was probably much broader prior to European settlement see Section 4.1.

Figure 13 Permanent surface water feature at Ejarno spring

Further south, this chain of wetlands crosses into a large tract of uncleared crown land. These wetlands are of high conservation value (Endemic 2012) and support surface water and wetland vegetation habitats, bordered by groundwater-dependent terrestrial vegetation (Casson 2012). Yardanogo Nature Reserve lies at the south-western extent of this feature, and contains vegetation over shallow groundwater. The Slender Tree Frog was found at the northern limit of its range in this nature reserve.

The shallow and discharging groundwater in wetlands at the base of the Gingin Scarp supports:

- Reliable surface water, which provides farm water supply (Ejarno Spring), habitat for wetland birds and aquatic species including the Rakali (native water rat), and a water source for terrestrial fauna.
- Wetland vegetation which provides habitat for significant species such as the Slender Tree Frog and the Rakali, and may support pasture for stock feed.

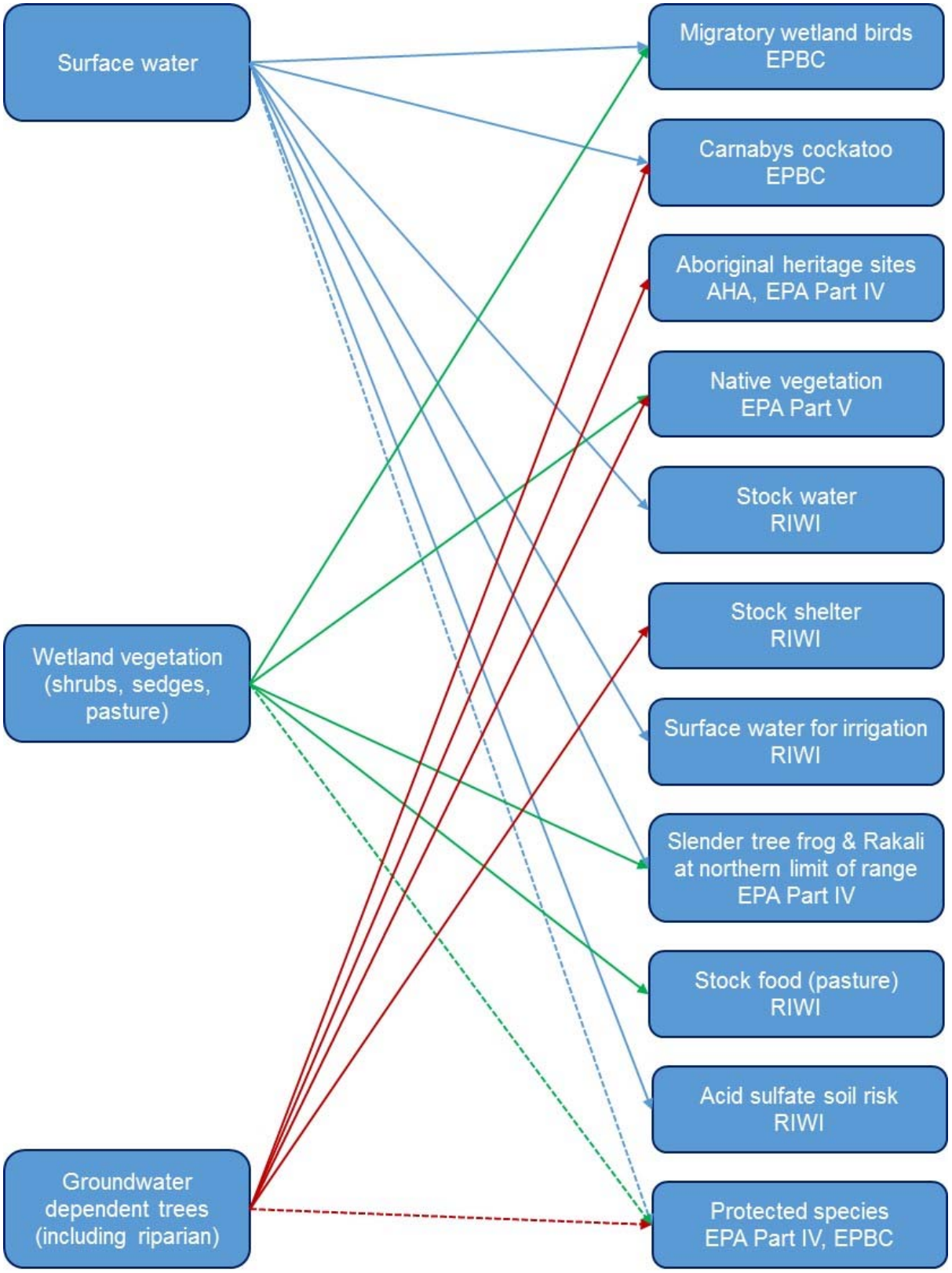

Figure 14 Groundwater-dependent environmental values in the Irwin study area

5.2 Values of groundwater-dependent sites

Table 4 provides a summary of named sites in the Irwin study area and their groundwater-dependent values as identified through:

- values mapping
- database searches (see Appendices)
- literature review
- a site visit.

The values in Table 4 refer to mapped landscape features and should be read with consideration of the protected flora and fauna identified through database searches (Appendix B).

The preferred habitat e.g. waterways, riverbanks, woodlands of flora and fauna is important when referring to the groundwater-dependent component and values. An example of this is the presence of the Endangered Carnaby's Black-Cockatoo (*Calyptorhynchus latirostris*) which has a preference for Eucalyptus woodlands and shrublands dominated by *Hakea spp*. and *Banksia* spp.

Table 4 Environmental, social and cultural values of the Irwin study area

Landscape feature	Specific site	Groundwater-dependent component			Value	Dataset/reference(s)
		Surface water	Wetland vegetation	Groundwater-dependent trees		
Irwin River and tributaries	Irwin River	x	-	-	Environment: contributes to the water balance at Irwin River estuary which supports several threatened fauna species; lower reaches and the estuary support several native freshwater species (e.g. Swan River Goby) Cultural: Irwin River Estuary named Thungarra (a place of seals), Aboriginal Registered Site – Irwin River (mythological), Aboriginal Heritage Site in the Irwin River valley – Stoney Hill (yam/food resource[6]) Social: Irwin River mouth is a site for recreation with various trails and lookouts	Aboriginal Sites Register System spatial layer DEC (2016b) DPaW (2016a) database search Gerritsen (no date) Land Insights (2014) Mid-West potential groundwater-dependent ecosystems spatial layer Morgan & Gill (2004) Schafer (2015) Shire of Irwin (2015) Warman (2008)
		-	x	x	Environment: bank stabilisation, supports priority/threatened flora, provides habitat for fauna (including threatened fauna)	
	Mendara Spring	x	-	-	Environment: Habitat for aquatic fauna Social/Economic: Stock watering	Hydrography, Linear Personal observations (field trips) Rutherford et al. (2005)
		-	x	x	Environment: Habitat for amphibians and avian fauna (including several Listed Marine species[7]), Groundwater-dependent (supported by the Yarragadee aquifer)	
Irwin River and Tributaries	Irwin Spring	x	-	-	Environment: habitat for aquatic fauna; groundwater-dependent (supported by the Yarragadee aquifer) Social/Economic: stock watering	Personal observations (field trips) Atlas of Living Australia (2016)
					Environment: Habitat for amphibians and avian fauna	
	Springy Creek	x	-	-	Environment: several springs located along the creek supported by the Yarragadee formation	Personal observations (field trips) Rutherford et al. (2005)
		-	x	-	Environment: vegetation in-tact along the creek in an otherwise largely cleared region	
	Walcott Soak	x	-	-	Environment: groundwater-dependent (supported by the Yarragadee aquifer)	Rutherford et al.(2005)
Base of scarp wetlands	Six Mile Swamp	x	x	x	Social: area of interest for the public	Mid-West potential groundwater-dependent ecosystems spatial layer
	Ejarno Spring	x	x	x	Social: area of interest for the public Cultural: May have significance for the local Aboriginal people (O'Connor, cited in AWE 2016) Environment: Northern-most Western Australian sighting of the Rakali (native water rat) is from this location, record of Frog species, Litoria adelaidensis, near its northern extent	AWE (2016) Mid-West potential groundwater-dependent ecosystems spatial layer Trocini et al. (2015)
	Eight Mile Well & wetland	x	x	x	Social: historical droving occurred at this site; recreational public walking trails with interpretive signage	Mid-West potential groundwater-dependent ecosystems spatial layer
	Yardanogo Nature Reserve	-	-	x	Social: recreation – site used as a point of interest for Geocaching in the mid-west district Environment: frog species, *Litoria adelaidensis*, near its northern extent Environment: habitat for Priority Flora	Atlas of Living Australia (2016) DPaW (2016a) database search Mid-West potential groundwater-dependent ecosystems spatial layer

6 The Yam (*Dioscorea hastifolia*) is not a groundwater-dependent species; however, in the region, there is evidence that wells (accessing groundwater) were used to water the Yams on a scale large enough for the widespread cultivation noted in the area (Gerritsen, no date)

7 "Listed marine" species as per the Declaration under section 248 of the *Environment Protection and Biodiversity Conservation Act 1999* – List of Marine Species

6 Applying the information

Water allocation planning in Western Australia: A guide to our process (DoW 2011) describes our approach to water planning. Water allocation plans outline how much water can be sustainably taken from a surface or groundwater resource and the rules that apply to accessing and taking water. Allocation plans allow individual use while protecting the resource as a whole for social, environmental and economic benefits.

An important part of the allocation planning process is understanding the relationship between ecosystems and the water resources that support them. These relationships are known as ecological water requirements and we aim to maintain them at a low level of risk (WRC 2000).

Currently, decisions about the allocation and licensing of groundwater take in the Dinner Hill and Irwin study areas are made in line with the *Jurien groundwater allocation plan* (DoW 2010a) and the *Arrowsmith groundwater allocation plan* (DoW, 2010b) respectively.

This report provides new and more detailed information about groundwater-dependent ecosystems in the Dinner Hill and Irwin study areas. This information will be considered in any new or updated water allocation planning work. Importantly it will also be used when assessing new licence applications and the impacts of groundwater abstraction.

There are two important considerations in planning for future groundwater use in both the Dinner Hill and Irwin study areas that were highlighted by the Midlands groundwater and land assessment project. Firstly, recognising that shallow or discharging groundwater supports both farm values and ecological values. For example, farm water sources like soaks, shallow bores and river baseflow support wetland plants, riparian trees and aquatic habitat.

These provide benefits for farming such as fodder, shelter and water for stock. Secondly, there was substantial historic groundwater level rises since land clearing commenced in the Dinner Hill and Irwin study areas. It may be appropriate to draw down on a portion of this groundwater ‘capital’, however it might present a regionally-rare opportunity to maintain wet ecological refuges and farm water sources as rainfall declines with climate change (DoW 2017).

It is also important that proponents applying for a licence to take groundwater in the study areas use the information in this report to understand possible impacts from their proposed abstraction, and prepare their application for assessment DWER. Guidance on how to do this is provided in Appendix F.

Appendices

Appendix A — Environmental value search results for Dinner Hill

Threatened and priority flora (DPaW 2016a) – this search identified priority and threatened flora listed under:

1 the Department's Threatened (Declared Rare) and Priority Flora database

2 the Western Australian Herbarium Specimen

3 the Department's Threatened and Priority Flora List[8].

Table A1 Protected flora species historically recorded in the Dinner Hill study area.

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)^
Species in bold are potentially groundwater-dependent			
Acacia cochlocarpa subsp. cochlocarpa	Spiral-fruited Wattle	CR (WA), EN (Commonwealth)	Sandy clay or laterite
Acacia cummingiana	N/A	P3 (WA)	Sandplains, lateritic breakaways
Acacia epacantha	N/A	P3 (WA)	Lateritic gravelly loam, clay
Acacia flabellifolia	N/A	P3 (WA)	Low hills & ridges
Acacia forrestiana	Forest's Wattle	VU (WA and Commonwealth)	Gullies, hills, breakaways
Acacia isoneura subsp. nimia	N/A	P3 (WA)	Sandplains & ridges
Acacia lirellata subsp. lirellata	N/A	P3 (WA)	Sandy & loamy soils
Acacia plicata	**N/A**	**P3 (WA)**	**Along drainage lines**
Acacia splendens	Splendid Wattle	CR (WA), EN (Commonwealth)	White sand over clay, slopes of breakaways
Acacia vassalii	Vassal's Wattle	CR (WA), EN (Commonwealth)	Sandy loam
Acacia wilsonii	N/A	EN (WA)	Sandy clay over laterite
Allocasuarina ramosissima	N/A	P3 (WA)	Lateritic soils, gravel

[8] This list contains species that are declared rare (Conservation Code R or X for those presumed to be extinct), poorly known (Conservation Codes P1, 2 or 3), or require monitoring (Conservation Code P4). VU=Vulnerable, EN=Endangered, CR=Critically Endangered

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)^
Andersonia gracilis	**Slender Andersonia**	**VU (WA), EN (Commonwealth)**	**Winter wet areas, near swamps**
Anigozanthos humilis subsp. Badgingarra (S.D. Hopper 7114)	**N/A**	**P2 (WA)**	**River-banks, winter-wet swamps**
Anigozanthos viridis subsp. terraspectans	**Dwarf Green Kangaroo Paw**	**VU (WA, Commonwealth)**	**Winter-wet depressions**
Arnocrinum drummondii	N/A	P3 (WA)	White or yellow sand
Arnocrinum gracillimum	N/A	P2 (WA)	White, grey, yellow or lateritic sand
Asterolasia drummondii	Gairdner Range Starbush	P4 (WA)	Lateritic hills & sandplains
Babingtonia cherticola	N/A	P3 (WA)	Chert hills, sandplains over laterite
Babingtonia delicata	**N/A**	**P1 (WA)**	**Sandy soils close to wetlands, seasonally wet low-lying areas**
Baeckea sp. Dandaragan (G. Paczkowska s.n. PERTH 08245606)	-	P1 (WA)	-
Banksia catoglypta	N/A	VU (WA)	Lateritic breakaways
Banksia dallanneyi subsp. pollosta	N/A	P3 (WA)	Flats, lateritic rises
Banksia fraseri var. crebra	N/A	P3 (WA)	-
Banksia nobilis subsp. fragrans	N/A	P3 (WA)	Lateritic rises
Banksia prionophylla	N/A	P1 (WA)	Dry grey sand, surface boulders
Banksia pteridifolia subsp. vernalis	N/A	P3 (WA)	White/grey sand over laterite
Banksia serratuloides subsp. perissa	Northern Serrate Dryandra	EN (WA), CR (Commonwealth)	Gravelly lateritic soils
Banksia splendida subsp. macrocarpa	N/A	P3 (WA)	Lateritic gravel
Banksia subulata	Awled Honeypot	P3 (WA)	White/grey or yellow sand over laterite

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)^
Beaufortia eriocephala	Woolly Bottlebrush	P3 (WA)	Lateritic sandy soils, slopes
Beyeria gardneri	N/A	P3 (WA)	Yellow sand
Beyeria similis	N/A	P2 (WA)	Sandplains
Boronia scabra subsp. condensata	N/A	P2 (WA)	Upper slopes, edge of lateritic breakaways
Caladenia dundasiae	Patricia's Spider Orchid	P1 (WA)	Well-drained soils under wandoo
Calandrinia dielsii	N/A	P2 (WA)	-
Calectasia palustris	**Swamp Tinsel Lily**	**P2 (WA)**	**Seasonally inundated swamplands**
Calytrix platycheiridia	N/A	P2 (WA)	Yellow/brown sand, low ridges
Catacolea enodis	N/A	P2 (WA)	Deep white sand over laterite
Chamelaucium sp. Cataby (G.J. Keighery 11009)	Griffin's Waxflower	VU (WA, Commonwealth)	Brown loam, sandy clay, lateritic gravel & slopes
Chamelaucium sp. Wongan Hills (B.H. Smith 1140)	N/A	P3 (WA)	-
Chordifex chaunocoleus	**Heath Rush**	**P4 (WA)**	**Drainage lines, depressions**
Chordifex reseminans	N/A	P2 (WA)	Dry sand, heath
Comesperma rhadinocarpum	Slender-fruited Comesperma	P2 (WA)	Sandy soils
Conospermum eatoniae	N/A	P3 (WA)	Deep white sand, sandy clay loam
Conospermum scaposum	**N/A**	**P3 (WA)**	**Low swampy areas**
Conostephium magnum	**N/A**	**P4 (WA)**	**Sand dunes, swamplands, drainage channels**
Conostylis micrantha	Small-flowered Conostylis	VU (WA), EN (Commonwealth)	White or grey sand, sandplains
Cristonia biloba subsp. pubescens	N/A	P2 (WA)	-
Cryptandra sp. Cowcowing (Wittwer W 1210)	N/A	P3 (WA)	-

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)^
Dampiera tephrea	N/A	P2 (WA)	Sand, gravelly loam
Daviesia dielsii	Diel's Daviesia	EN (WA, Commonwealth)	Sandy, often gravelly soils
Desmocladus biformis	N/A	P3 (WA)	Sandy clay, lateritic soils, dry sites
Desmocladus elongatus	N/A	P4 (WA)	White or grey sand, dry kwongan
Desmocladus microcarpus	N/A	P2 (WA)	-
Desmocladus nodatus	N/A	P3 (WA)	-
Dicrastylis velutina	N/A	P3 (WA)	Sandy soils, gravelly loam
Drosera marchantii subsp. prophylla	N/A	P3 (WA)	Laterite-silica sand soils, hilltops
Eleocharis keigheryi	**Keighery's Eleocharis**	**VU (WA, Commonwealth)**	**Freshwater, creeks, clay pans**
Eucalyptus absita	Badgingarra Box	CR (WA), EN (Commonwealth)	White lateritic sand, paddocks
Eucalyptus absita x loxophleba	N/A	P1 (WA)	Lateritic sand
Eucalyptus dolorosa	Dandaragan Mallee	CR (WA), EN (Commonwealth)	Laterite, hillsides
Eucalyptus macrocarpa subsp. elachantha	Small-leaved Mottlecah	P4 (WA)	Hillslopes, ridges, sandplains
Eucalyptus macrocarpa x pyriformis	N/A	P3 (WA)	Hills, rocky ironstone ridges, sandplains
Eucalyptus pendens	Badgingarra Mallee	P4 (WA)	Hillsides, breakaways, sandplains
Eucalyptus rhodantha var. rhodantha	Rose Mallee	VU (WA, Commonwealth)	Sand over laterite, hillslopes
Eucalyptus rhodantha var. x petiolaris	Stalked Rose Mallee	P4 (WA)	Sandy loam, hillslopes
Eucalyptus subangusta subsp. virescens	N/A	P3 (WA)	Yellow sand, white clay
Eucalyptus x balanites	Cadda Road Mallee	CR (WA), EN (Commonwealth)	Sandy soils with lateritic gravel

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)^
Eucalyptus x carnabyi	N/A	P4 (WA)	Grey sand, sandy loam, lateritic ridges
Gastrolobium appressum	Scale-leaf Poison	EN (WA), VU (Commonwealth)	Sand with quartz gravel, sandplains, low-rises
Gastrolobium nudum	N/A	P2 (WA)	Brown loam, gravel, granite, flats, slopes
Gastrolobium rotundifolium	Gilbernine Poison	P3 (WA)	Heavy clay, loam, granite, low rises
Gompholobium gairdnerianum	N/A	P3 (WA)	Sandy clay, sandstone, hill summits, slopes
Gompholobium roseum	N/A	P2 (WA)	-
Grevillea amplexans subsp. adpressa	N/A	P1 (WA)	Yellow sand, loam, dunes
Grevillea amplexans subsp. semivestita	N/A	P2 (WA)	Yellow clayey sand, laterite
Grevillea calliantha	Foote's Grevillea	CR (WA), EN (Commonwealth)	Sand over laterite, gravel
Grevillea christineae	Christine's Grevillea	EN (WA, Commonwealth)	Sandy clay, often moist
Grevillea florida	N/A	P3 (WA)	Sandplain, slopes, road verges
Grevillea saccata	Pouched Grevillea	P4 (WA)	Yellow/brown sand, lateritic gravel
Grevillea synapheae subsp. minyulo	N/A	P1 (WA)	Gravel, laterite
Grevillea tenuiloba	N/A	P3 (WA)	Sand, clay loam, granite outcrops
Grevillea thelemanniana subsp. Cooljarloo (B.J. Keighery 28 B)	N/A	P1 (WA)	-
Grevillea thyrsoides subsp. pustulata	N/A	P3 (WA)	Sand, sandy gravel
Grevillea thyrsoides subsp. thyrsoides	N/A	P3 (WA)	Sand, sandy lateritic gravel
Guichenotia alba	N/A	P3 (WA)	Low-lying flats, depressions
Hakea longiflora	N/A	P3 (WA)	White sand, loam, gravel, breakaways

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)^
Hakea megalosperma	Lesueur Hakea	VU (WA, Commonwealth)	Grey sand, loam, lateritic hills
Hemigenia curvifolia	N/A	P2 (WA)	Sandy soils
Hensmania stoniella	**N/A**	**P3 (WA)**	**Lateritic sand, often winter-wet**
Hibbertia propinqua	N/A	P4 (WA)	Open mallee woodland over heath
Hibbertia spicata subsp. leptotheca	Glossy-leaved Coastal Guinea flower	P3 (WA)	Near-coastal limestone ridges, outcrops, cliffs
Hydrocotyle sp. Coorowensis (P.G. Wilson 12580)	N/A	P2 (WA)	-
Hypocalymma linifolium	N/A	P1 (WA)	Sand
Hypocalymma serrulatum	N/A	P3 (WA)	Grey/white sand, along drainage lines
Hypocalymma sp. Cataby (G.J. Keighery 5151)	N/A	P2 (WA)	Grey sand
Hypocalymma sp. Dandaragan (C.A. Gardner 9014)	N/A	P1 (WA)	-
Hypocalymma tetrapterum	**N/A**	**P3 (WA)**	**Riverbanks, breakaways**
Hypolaena robusta	N/A	P4 (WA)	White sand, sandplains
Isopogon panduratus subsp. palustris	N/A	P3 (WA)	-
Jacksonia carduacea	N/A	P3 (WA)	Grey sand, sandy clay
Jacksonia rubra	N/A	P2 (WA)	Clayey sand
Jacksonia velutina	N/A	P4 (WA)	Sandplains & sandhills
Lechenaultia galactites	N/A	P3 (WA)	Yellow sand, laterite, clay, gravel, sandplains
Lechenaultia juncea	Reed-like Leschenaultia	P3 (WA)	White, grey or yellow sand, sandy gravel
Lepidobolus quadratus	N/A	P3 (WA)	Lateritic gravel, dry kwongan

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)^
Leucopogon sp. Badgingarra (R. Davis 421)	N/A	P2 (WA)	Grey sand, dry white sand, hills, plains
Lyginia excelsa	N/A	P1 (WA)	Dry heath & Banksia woodland
Macarthuria keigheryi	Keighery's Macarthuria	EN (WA, Commonwealth)	White or grey sand
Meionectes tenuifolia	N/A	P3 (WA)	-
Menkea draboides	N/A	P3 (WA)	Red sand or clay, granite
Papistylus grandiflorus	N/A	P2 (WA)	Granite, hillslopes, plains
Patersonia spirifolia	Spiral-leaved Patersonia	EN (WA, Commonwealth)	Sand over laterite, low hills
Petrophile septemfida	N/A	P3 (WA)	Dry white sand over laterite
Phlebocarya pilosissima subsp. pilosissima	N/A	P3 (WA)	White or grey sand, lateritic gravel
Podotheca uniseta	N/A	P3 (WA)	Sandy loam, Samphire flats
Ptychosema pusillum	Dwarf Pea	VU (WA, Commonwealth)	Sand, rises
Regelia megacephala	N/A	P4 (WA)	Quartzite hills
Rhetinocarpha suffruticosa	Shrubby Myriocephalus	P1 (WA)	Gravelly loam, slopes, small ridges
Scaevola globosa	N/A	P3 (WA)	Sandy soils
Scholtzia sp. Gunyidi (J.D. Briggs 1721)	N/A	P2 (WA)	Sandy loam, gentle slopes
Spirogardnera rubescens	Spiral Bush	VU (WA), EN (Commonwealth)	Laterite, sand over laterite, loam
Stawellia dimorphantha	Arrowsmith Stilt-lily	P4 (WA)	White, grey, yellow sand
Stylidium aeonioides	N/A	P4 (WA)	Sandy clay loam over laterite, hillsides
Stylidium hymenocraspedum	N/A	P3 (WA)	Sand over laterite, heath, hillslopes, open woodland
Stylidium inversiflorum	N/A	P4 (WA)	Sand over laterite, sandplains, hillslopes

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)^
Stylidium periscelianthum	**Pantaloon Triggerplant**	**P3 (WA)**	**Loamy clay, moist soils pockets, wet flats**
Stylidium sacculatum	N/A	P3 (WA)	Clayey sand, lower slopes and flats
Synaphea endothrix	N/A	P3 (WA)	Gravelly loam, sand, lateritic rises
Tetratheca angulata	N/A	P3 (WA)	Sandy to gravelly laterite soils, low hill crests
Thelymitra apiculata	Cleopatra's Needles	P4 (WA)	Grey sand, laterite gravel
Thelymitra pulcherrima	Northern Queen of Sheba	P2 (WA)	Gravel
Thryptomene nitida	N/A	P3 (WA)	-
Thysanotus sp. Badgingarra (E.A. Griffin 2511)	N/A	P2 (WA)	Grey sand with lateritic gravel
Thysanotus vernalis	N/A	P3 (WA)	Sandy loam
Urodon capitatus	N/A	P3 (WA)	Sandy gravelly soils, plains
Verticordia insignis subsp. eomagis	N/A	P3 (WA)	Sandy soils over laterite, sandplains, rocky rises
Wurmbea tubulosa	**Long-flowered Nancy**	**EN (Commonwealth), VU (WA)**	**River banks, seasonally-wet places**

Commonwealth is where the species is protected under the Environmental Protection, Biodiversity and Conservation Act 1999 (Commonwealth)

The table below presents the results of a Protected Matters search (DoE 2016b).

Table A2 Protected flora species likely to occur in the Dinner Hill study area

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)
Species in bold are potentially groundwater-dependent			
Acacia cochlocarpa subsp. cochlocarpa	Spiral-fruited Wattle	CR (WA), EN (Commonwealth)	Clayey sand, gravelly soils
Acacia forrestiana	Forest's Wattle	VU (WA, Commonwealth)	Lateritic gravelly soils
Acacia splendens	Splendid Wattle	CR (WA), EN (Commonwealth)	White sand over clay

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)
Andersonia gracilis	**Slender Andersonia**	**VU (WA), EN (Commonwealth)**	**Winter wet areas, near swamps**
Banksia fuscobractea	Dark-bract Banksia	CR (WA, Commonwealth)	Lateritic gravel, grey sand
Banksia serratuloides subsp. perissa	Northern Serrate Dryandra	EN (WA), CR (Commonwealth)	Gravelly lateritic soils
Banksia serratuloides subsp. serratuloides	Southern Serrate Dryandra	VU (WA, Commonwealth)	Loam or clay loam over laterite, sandy gravel
Caladenia huegelii	King Spider-orchid	CR (WA), EN (Commonwealth)	Grey or brown sand
Chamelaucium sp. Cataby	Griffin's Wax Flower	VU (WA, Commonwealth)	-
Chamelaucium sp. Gingin	Gingin Wax	VU (WA), EN (Commonwealth)	White/yellow sand in open woodland
Conospermum densiflorum subsp. unicephalatum	One-headed Smokebush	EN (WA, Commonwealth)	Clay soils, low-lying areas
Daviesia dielsii	Diels' Daviesia	EN (WA, Commonwealth)	Sandy, gravelly soils
Drakaea elastica	**Glossy-leafed Hammer Orchid**	**CR (WA), EN (Commonwealth)**	**Winter-wet swamps**
Eleocharis keigheryi	**Keighery's Eleocharis**	**VU (WA, Commonwealth)**	**Freshwater, creeks, clay pans**
Eremophila scaberula	**Rough Emu Bush**	**CR (WA), EN (Commonwealth)**	**Winter-wet plains**
Eucalyptus absita	Badgingarra Box	CR (WA), EN (Commonwealth)	White lateritic sand
Eucalyptus balanites	Cadda Mallee	CR (WA), EN (Commonwealth)	Sandy soils with lateritic gravel
Eucalyptus crispata	Yandanooka Mallee	EN (WA), VU (Commonwealth)	Sand, loam with lateritic gravel
Eucalyptus dolorosa	Dandaragan Mallee	CR (WA), EN (Commonwealth)	Laterite, hillsides
Eucalyptus impensa	Eneabba Mallee	CR (WA), EN (Commonwealth)	Yellow sand, lateritic hills
Eucalyptus leprophloia	Scaly Butt Mallee	EN (WA, Commonwealth)	White or grey sand over laterite, valley slopes
Eucalyptus recta	Silver Mallet	VU (WA), EN (Commonwealth)	Sandy laterite
Grevillea calliantha	Foote's Grevillea	CR (WA), EN (Commonwealth)	Sand over laterite, gravel

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)
Grevillea christineae	Christine's Grevillea	EN (WA, Commonwealth)	Sandy clay, often moist
Grevillea curviloba subsp. incurve	Narrow curved-leaf Grevilla	EN (WA, Commonwealth)	Winter-wet heath
Hakea megalosperma	Lesueur Hakea	VU (WA, Commonwealth)	Lateritic hills & rocks
Hemiandra gardneri	Red Snakebush	CR (WA), EN (Commonwealth)	Clayey sand, sandplains
Leucopogon obtectus	Hidden Beard-heath	EN (WA, Commonwealth)	Grey sand
Paracaleana dixonii	Sandplain Duck Orchid	VU (WA), EN (Commonwealth)	Grey sand over granite
Ptychosema pusillum	Dwarf pea	VU (WA, Commonwealth)	Sand, rises
Spirogardnera rubescens	Spiral Bush	VU (WA), EN (Commonwealth)	Sand over laterite, loam
Thelymitra dedmaniarum	Cinnamon Sun Orchid	CR (WA), EN (Commonwealth)	Open woodland, Granite outcrops
Thelymitra stellata	Star Sun-orchid	EN (WA, Commonwealth)	Sand, gravel, lateritic loam

Threatened and priority fauna (DPaW 2016a). This search utilised the department's threatened fauna databases, which include species that are declared as:

- rare or likely to become extinct (Schedule 1)
- birds protected under an international agreement (Schedule 3)
- other specially protected fauna (Schedule 4).

Note – all species may have potential-groundwater dependence based on habitat preference.

Table A3 Priority and threatened fauna historically recorded in the Dinner Hill Study Area.

Species name	Common name	Conservation status	Preferred habitat (DoE 2016c and IUCN 2016)
Calyptorhynchus baudinii	Baudin's Cockatoo	EN (WA), VU (Commonwealth)	*Eucalyptus* forests with understoreys of proteaceous trees including *Banksia spp*.
Calyptorhynchus latirostris	Carnaby's Black-Cockatoo	EN (WA, Commonwealth)	*Eucalyptus* woodlands and shrublands dominated by *Hakea spp*. and *Banksia spp*.

Species name	Common name	Conservation status	Preferred habitat (DoE 2016c and IUCN 2016)
Merops ornatus	Rainbow bee-eater	Marine (Commonwealth), Migratory (Commonwealth, JAMBA)	Open woodlands, shrublands and cleared areas in close proximity to permanent water
Ardea modesta (alba)	Eastern great egret	Marine (Commonwealth), Migratory (Commonwealth, JAMBA)	Wide range of wetlands (inland and coastal, freshwater and saline, natural and artificial)
Oxyura australis	Blue billed duck	P4 (WA)	Permanent deep water-bodies, freshwater to saline, rushes and sedges for nesting

Protected fauna and/or their habitat likely to occur in the Dinner Hill study area is shown in Table A4, derived from DoE (2016b).

Table A4 Protected fauna and/or their habitat likely to occur in the Dinner Hill study area

Species name	Common name	Conservation status	Preferred habitat (DoE 2016c and IUCN 2016)
Species in bold are potentially groundwater-dependent			
Dasyurus geoffroii	Chuditch/ Western quoll	VU (WA, Commonwealth)	Eucalyptus forest, dry woodlands and mallee shrublands
Egernia stokesii	Western Spiny-tailed Skink	VU (WA), EN (Commonwealth)	Eucalyptus woodlands and Acacia-dominated shrubland
Idiosoma nigrum	Shield-backed trapdoor spider	VU (WA, Commonwealth)	Clay soils, Acacia shrubland, gullies and southern facing slopes
Leipoa ocellata	Malleefowl	VU (WA, Commonwealth)	Semi-arid and arid zones, shrublands and low woodlands dominated by mallee vegetation
Apus pacificus	Fork-tailed swift	Migratory Marine (Commonwealth), International agreement (CAMBA, JAMBA, ROKAMBA)	Aerial, coastal dunes, nesting on mountain cliffs and rock caves
Ardea ibis	**Cattle egret**	**Migratory Wetland (Commonwealth), International agreement (JAMBA)**	**Tropical and temperate grasslands, agricultural pasture, terrestrial wetlands**

Species name	Common name	Conservation status	Preferred habitat (DoE 2016c and IUCN 2016)
Calidris ferruginea	**Curlew Sandpiper**	**CR (Commonwealth), VU (WA) Migratory Wetland (International agreement)**	**Intertidal mudflats, mangroves, estuaries, lakes and dams**
Haliaeetus leucogaster	**White-bellied sea-eagle**	**Marine (Commonwealth)**	**Coastal habitat, terrestrial wetlands**
Motacilla cinerea	**Grey wagtail**	**Migratory Terrestrial (Commonwealth), International agreement (CAMBA, ROKAMBA)**	**Forested areas, farmlands, streams and lowland watercourses**
Numenius madagascariensis	**Eastern Curlew**	**CR (Commonwealth), VU (WA) Migratory Wetland (International agreement)**	**Intertidal mudlfats, mangrove swamps, estuaries and lagoons**
Pandion haliaetus	**Osprey**	**Migratory Wetland (Commonwealth), International agreement (Bonn)**	**Coastal habitat, terrestrial wetlands, offshore islands**
Rostratula australis	**Australian painted snipe**	**EN (WA, Commonwealth), Marine (Commonwealth)**	**Shallow terrestrial freshwater wetlands and waterlogged grasslands**
Thinornis rubricollis	**Hooded plover**	**Marine (Commonwealth)**	**Sandy ocean beaches, open dunes, coastal salt lakes**
Tringa nebularia	**Common Greenshank**	**Migratory Marine (Commonwealth), International agreement (CAMBA, JAMBA, ROKAMBA)**	**Estuaries, mudflats, swamps, billabongs, flooded crops**

Commonwealth is where the species is protected under the Environmental Protection, Biodiversity and Conservation Act 1999 (Commonwealth)

Listed marine species with potential groundwater dependence recorded in the Dinner Hill Study Area are shown in Table A, derived from the Atlas of Living Australia (2016).

Table A5 Listed marine species with potential groundwater dependence recorded in the Dinner Hill study area

Species name	Common name	Preferred habitat (DoE 2016c and IUCN 2016)	Source(s)
Accipiter fasciatus	Brown goshawk	Timbered areas, with water sources including artificial important in inland areas	Birdlife Australia (2016)
Actitis hypoleucos	Common sandpiper	Coastal and inland wetlands (saline and fresh)	Birdlife Australia (2012a)
Anthus novaeseelandiae	Australasian pipit	Wet heaths, open woodland	Birdlife Australia (2016)
Biziura lobata	Musk duck/diver	Deep freshwater lagoons, dense reed beds	Birdlife Australia (2016)
Chrysococcyx lucidus	Shining bronze cuckoo	Woodlands, paperbark thickets, lays eggs in nests of other species which inhabit watercourses e.g. Gerygone's, thornbills	Birdlife Australia (2012a; 2016)
Hirundo neoxena	Welcome swallow	Urban/farmland, forests, wetlands	Birdlife Australia (2012a; 2016)
Pelecanus conspicillatus	Australian pelican	Freshwater (lakes, swamps, rivers), estuarine & marine wetlands	Birdlife Australia (2012b; 2016)
Petrochelidon nigricans	Tree martin	Open woodland habitats, urban areas, often near waterways	Birdlife Australia (2016)
Threskiornis Molucca	Australian white ibis	Swamps, lagoons, floodplains, urban parks and gardens	Birdlife Australia (2012c)
Threskiornis spinicollis	Straw-necked ibis	Wet and dry grasslands, swamps and lagoon margins	Birdlife Australia (2012b; 2016)
Todiramphus sanctus	Sacred kingfisher	Woodlands, mangroves and river valleys	Birdlife Australia (2012c; 2016)

Table A6 Potential groundwater-dependent ecosystem values of the Dinner Hill study area identified through the Mid-west values spatial layers

Site	Features	Value
Hill River	Watercourse (River)	Recreation – heritage trails and wildflowers
	Twyata Nature Reserve	Recreation – wildflower walk trail to Twyata Pool
Mahomet Spring	Spring	Indigenous - Afghan camel wagons used to pull up to big waterhole load and unload. Afghans used to come in freshwater for camels. Unload wheat at wharf. Big camel camp
Dandaragan Spring	Spring	Indigenous – Aboriginal name for the spring "Dandaraga", Historically used for droving
Lake Dalaroo	Lake	Ecosystem services – Western Swamp tortoise
Namming Lake	Lake	Recreation – used by the locals as a swimming hole, congregate over summer
Eneminga Nature Reserve	Vegetation	Recreation – previously duck shooting site (now prohibited)
Namming Nature Reserve	Vegetation	Environment – part of Western Shield Program

Appendix B — Environmental value search results for Irwin

Threatened and priority flora (DPaW 2016a) – this search identified threatened and priority flora listed under:

1 Threatened (Declared Rare) and Priority Flora database

2 the Western Australian Herbarium Specimens

3 Threatened and Priority Flora List[9].

Table B1 Protected flora in the Irwin study area (inclusive of WA herbarium records)

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)
Species in bold are potentially groundwater-dependent			
Acacia isoneura subsp. isoneura	-	P3	Yellow/brown sand, flats and low rises
Acacia telmica	**-**	**P3**	**Low-lying seasonally moist areas**
Baeckea sp. Walkaway (A.S. George 11249)	-	P3	Yellow/brown sand, undulating plains, hillslopes
Banksia fraseri var. crebra	-	P3	-
Calytrix eneabbensis	-	P4	Sandplains
Conostylis dielsii subsp. teres	Irwin's Conostylis	EN (Commonwealth), VU (WA)	Low open woodland
Conostylis micrantha	Small-flowered Conostylis	EN (Commonwealth), VU (WA)	Sandplains
Eremaea acutifolia	Rusty Eremaea	P3	Grey or yellow sand, sandplains
Eucalyptus zopherophloia	Blackbutt Mallee	P4	Grey/white sand, coastal areas
Grevillea hirtella	-	P3	Sand, often with gravel
Stawellia dimorphantha	Arrowsmith stilt-lily	P4	White, grey, yellow sand
Thryptomene nitida	-	P3	-

[9] This list contains species that are declared rare (Conservation Code R or X for those presumed to be extinct), poorly known (Conservation Codes P1, 2 or 3), or require monitoring (Conservation Code P4). VU=Vulnerable, EN=Endangered, CR=Critically Endangered

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)
Verticordia densiflora var. roseostella	-	P3	Sandy gravelly soils
Wurmbea tubulosa	**Long-flowered Nancy**		

Commonwealth is where the species is protected under the Environmental Protection, Biodiversity and Conservation Act 1999 (Commonwealth)

Table B2 Protected flora species (or their associated habitat) likely to occur in the Irwin study area as per the Protected Matters search (DoE 2016b)

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)
Species in bold are potentially groundwater-dependent			
Caladenia hoffmanii	**Hoffman's Spider-orchid**	**EN (Commonwealth, WA)**	**Rocky outcrops and hillsides, ridges, swamps and gullies**
Chorizema humile	Prostrate Flame Pea	EN (Commonwealth), CR (WA)	Sandy clay or loam
Conostylis dielsii subsp. teres	Irwin's Conostylis	EN (Commonwealth), VU (WA)	Low open woodland
Conostylis micrantha	Small-flowered Conostylis	EN (Commonwealth), VU (WA)	White or grey sand. Sandplains
Daviesia speciosa	Beautiful Daviesia	EN (Commonwealth, VU)	Undulating plains, rises
Eucalyptus balanites	Cadda Mallee	EN (Commonwealth), CR (WA)	Sandy soils with lateritic gravel
Eucalyptus crispata	Yandanooka Mallee	VU (Commonwealth), EN (WA)	Sand, loam with lateritic gravel
Eucalyptus impensa	Eneabba Mallee	EN (Commonwealth), CR (WA)	Yellow sand, lateritic hills
Eucalyptus leprophloia	Scaly Butt Mallee	EN (Commonwealth, WA)	White or grey sand over laterite, valley slopes
Hemiandra gardneri	Red Snakebush	EN (Commonwealth), CR (WA)	Clayey sand, sandplains
Hypocalymma longifolium	**Long-leaved Myrtle**	**VU (Commonwealth, WA)**	**Rocky breakaways, swampland**
Leucopogon marginatus	Thick-margined Leucopogon	EN (Commonwealth, WA)	Yellow & gravelly lateritic sand. Undulating plains
Paracaleana dixonii	Sandplain Duck Orchid	EN (Commonwealth), VU (WA)	Grey sand over granite
Schoenia filifolia subsp. subulifolia	**Mingenew Everlasting**	**EN (Commonwealth, WA)**	**Swampy flats, tops of breakaways, crabholes**

Species name	Common name	Conservation status	Preferred habitat (DPaW 2016b)
Tetratheca nephelioides	N/A	CR (Commonwealth), EN (WA)	Outcrops, undulating hills, ridges
Thelymitra stellata	Star Sun-orchid	EN (Commonwealth, WA)	Sand, gravel, lateritic loam
Wurmbea tubulosa	**Long-flowered Nancy**	**EN (Commonwealth), VU (WA)**	**River banks, seasonally-wet places**

Commonwealth is where the species is protected under the Environmental Protection, Biodiversity and Conservation Act 1999 (Commonwealth)

Threatened and priority fauna (DPaW 2016a) – this search utilised the department's threatened fauna databases, which include species that are declared as:

- rare or likely to become extinct (Schedule 1)
- birds protected under an international agreement (Schedule 3)
- other specially protected fauna (Schedule 4).

Table B3 Protected fauna species recorded in the Irwin study area

Species name	Common name	Conservation status	Preferred habitat (DoE 2016c, IUCN 2016)
Species in bold are potentially groundwater-dependent			
Calyptorhynchus latirostris	**Carnaby's Black-Cockatoo**	**EN (WA, Commonwealth)**	**Eucalyptus woodlands and shrublands dominated by *Hakea spp*. and *Banksia spp*.**
Neelaps calonotos	**Western black-striped snake**	**P3**	**Banksia woodlands and sandy areas**
Phasmodes jeeba	-	P2 (WA), VU (IUCN)	Terrestrial

Commonwealth is where the species is protected under the Environmental Protection, Biodiversity and Conservation Act 1999 (Commonwealth)

Table B4 Listed marine species with potential groundwater dependence recorded in the Irwin study area; identified through the Atlas of Living Australia (2016)

Species name	Common name	Preferred habitat (DoE 2016c, IUCN 2016)	Sources
Anthus novaeseelandiae	Australasian pipit	Wet heaths, open woodland	Birdlife Australia (2016)
Hirundo neoxena	Welcome swallow	Wide variety of habitats, often associated with watercourses	Birdlife Australia (2012c) Birdlife Australia (2016)

Table B5 Protected fauna species (or their associated habitat) likely to occur in the Irwin study area as per the Protected Matters search (DoE 2016b)

Species name	Common name	Conservation status	Preferred habitat (DoE 2016c and IUCN 2016)
Species in bold are potentially groundwater-dependent			
Dasyurus geoffroii	Chuditch/Western Quoll	VU (WA, Commonwealth)	Eucalyptus forest, dry woodlands and mallee shrublands.
Egernia stokesii badia	Western Spiny-tailed Skink	VU (WA) EN (Commonwealth)	Eucalyptus woodland (primarily *Eucalyptus loxophleba*), with numerous fallen logs.
Idiosoma nigrum	Shield-backed trapdoor spider	VU (WA, Commonwealth)	Clay soils, Acacia shrubland, gullies and southern facing slopes.
Apus pacificus	Fork-tailed Swift	Migratory Marine (Commonwealth), International agreement (CAMBA, JAMBA, ROKAMBA)	Aerial, coastal dunes, nesting on mountain cliffs and rock caves.
Ardea ibis	**Cattle Egret**	**Migratory Wetland (Commonwealth), International agreement (JAMBA)**	**Tropical and temperate grasslands, agricultural pasture, terrestrial wetlands.**
Ardea modesta (alba)	**Eastern Great Egret**	**Migratory Wetland (Commonwealth), International agreement (JAMBA)**	**Wide range of wetlands (inland and coastal, freshwater and saline, natural and artificial).**
Calidris ferruginea	**Curlew Sandpiper**	**CR (Commonwealth), VU (WA) Migratory Wetland (International agreement)**	**Intertidal mudlfats, mangroves, estuaries, lakes and dams.**
Calyptorhynchus latirostris	**Carnaby's Black-Cockatoo**	**EN (WA, Commonwealth)**	**Eucalyptus woodlands and shrublands dominated by *Hakea spp*. and *Banksia spp*.**
Leipoa ocellata	Malleefowl	VU (WA, Commonwealth)	Semi-arid and arid zones, shrublands and low woodlands dominated by mallee vegetation.
Merops ornatus	**Rainbow Bee-eater**	**Migratory Terrestrial (Commonwealth), International agreement (JAMBA)**	**Open woodlands, shrublands and cleared areas in close proximity to permanent water.**
Motacilla cinerea	**Grey Wagtail**	**Migratory Terrestrial (Commonwealth), International agreement (CAMBA, ROKAMBA)**	**Forested areas, farmlands, streams and lowland watercourses.**

Species name	Common name	Conservation status	Preferred habitat (DoE 2016c and IUCN 2016)
Numenius madagascariensis	**Eastern Curlew**	**CR (Commonwealth), VU (WA) Migratory Wetland (International agreement)**	**Intertidal mudlfats, mangrove swamps, estuaries and lagoons.**
Pandion haliaetus	**Osprey**	**Migratory Wetland (Commonwealth), International agreement (Bonn)**	**Coastal habitat, terrestrial wetlands, offshore islands.**

Commonwealth is where the species is protected under the Environmental Protection, Biodiversity and Conservation Act 1999 (Commonwealth)

Table B6 Potential groundwater-dependent ecosystem values of the Irwin study area identified through the Mid-west values spatial layers

Site	Features	Value
Yardonago Nature Reserve	Vegetation	*Litoria adelaidensis* at most northern extent (Fauna – Water Dependent). Nature Reserve important for Recreational purposes – Geocaching.
Six Mile Swamp	Swamp	Recreational – area of interest for the public.
Ejarno Spring	Spring	Recreational – area of interest for the public.
Eight Mile Well	Vegetation/Wetland	Recreational – public walking trails with interpretive signage.
Irwin River	River	Social – historical droving occurred at this site.

Appendix C — Priority Ecological Communities and Threatened Ecological Communities

The Department of Biodiversity, Conservation and Attraction's *Threatened and priority ecological communities* (DPaW 2016a) database includes ecological communities throughout Western Australia that are categorised as:

- presumed totally destroyed
- critically endangered
- endangered
- vulnerable
- priority 1-5
- lower risk and
- not evaluated.

Communities are based on various life-forms including plants, invertebrates and micro-organisms.

Table C1 Threatened ecological communities and priority ecological communities in the broader Midlands region

Threatened ecological community	Conservation status	Characteristics^
Species and communities in bold are potentially groundwater-dependent		
Assemblages of organic mound springs of the Three Springs area	**Endangered**	**Peat layers built up over an extended period, supply of permanent fresh spring water.**
Coastal sands dominated by *Acacia rostellifera*, *Eucalyptus oraria* and *E. obtusiflora* (Geraldton area)	Priority 1	Dominated by mallee eucalypts occurring on limestone ridges, limestone soil, and swales of dunes.
Ferricrete floristic community (Rocky Springs type)	**Vulnerable**	**Red and brown sandy loams over ferricrete (reliant on water processes for formation of ferricrete).**
Herbaceous plant assemblages on bentonite lakes	Endangered	Bentonite substratum on perched ephemeral fresh water playa lakes and clay pans (unlikely groundwater-dependent ecosystem based on being a perched system).
Lesueur-Coomallo Floristic Community A1.2 (Species-rich heath with emergent *Hakea obliqua*)	Endangered	Well-drained grey sand, over pale yellow sand on lateritic uplands, dominated by *H. obliqua* with *Allocasuarina humilis.*

Threatened ecological community	Conservation status	Characteristics^
Species and communities in bold are potentially groundwater-dependent		
Lesueur-Coomallo Floristic Community D1 (Species-rich low heath dominated by *Allocasuarina microstachya*)	**Critically Endangered**	**Species rich low heath on well-drained lateritic gravels, dominated by *A. microstachya.***
Lesueur-Coomallo Floristic Community	Priority 1	Mixed species-rich heath on lateritic gravel.
Lesueur-Coomallo Floristic Community M2 (*Melaleuca preissiana* woodland)	Priority 1	Woodland dominated by *M. preissiana* along sandy drainage lines.
Petrophile chrysantha low heath on Lesueur dissected uplands (Gp200-170)	Priority 2	Low heath dominated by *P. chrysantha* on dissected uplands.
Plant assemblages of the Inering System	Vulnerable	Various plant assemblages including *Allocasuarina campestris* scrub over chert and granite hills.
Stromatolite community of stratified hypersaline coastal lake – Lake Thetis	**Vulnerable**	**Microbialite (*Calothrix* and *Scytonema spp.*) community associated with alkaline, nutrient-poor water of Lake Thetis.**
Subtropical and Temperate Coastal Saltmarsh	Vulnerable (Commonwealth)	Saltmarsh dominated coastal areas under regular or intermittent tidal influence. May also include areas that have groundwater connectivity to tidal water bodies.
Vegetation associations on ridges and slopes of the chert hills of the Coomberdale Floristic Region. (Old name: Heath community on chert hills of the Coomberdale Floristic Region)	Endangered	Various shrublands including *Allocasuarina campestris* shrubland and *Allocasuarina microstachya* scrub on ridges and slopes of chert hills/quartzite ridges.
Banksia Woodlands of the Swan Coastal Plain*	**Endangered (Commonwealth)**	**The ecological community is a woodland associated with the Swan Coastal Plain of southwest Western Australia. A key diagnostic feature is a prominent tree layer of *Banksia*, with scattered eucalypts and other tree species often present among or emerging above the *Banksia* canopy.**

^Characteristics as per Department of Parks and Wildlife (2014) and Department of Environment (2016c)

**Not identified in the database request, however, recently listed as a Threatened ecological community see Department of the Environment (2016a)*

Note – No communities were identified in either study area other than the Banksia Woodlands of the Swan Coastal Plain (identified in the Dinner Hill study area)

Commonwealth is where the species is protected under the Environmental Protection, Biodiversity and Conservation Act 1999 (Commonwealth)

Appendix D — Irwin River site visit

A field visit to the Irwin Spring, Mendara Spring, and Irwin River was undertaken on 21-22 of June 2016. The springs have not been extensively studied, and as such specifics on fauna and flora in the springs are limited. The purpose of the visit was to document environmental values and ground truth values identified through previous literature.

During the field trip the springs appeared to be serving a dual purpose in providing suitable habitat for a range of fauna as well as serving as a stock watering point with noticeable use of the spring by cattle Table D1. These lists are not exhaustive as surveys were not undertaken to identify all flora and fauna, they only represent species noted from visual observations during walkthroughs of the springs.

Riparian vegetation at the spring was not fenced and the area was substantially modified. River Gums (*Eucalyptus camaldulensis*) form an open woodland in the riparian zone of the spring, with an understory of both introduced and native herbs and shrubs. A noteworthy observation was the presence of the introduced Spiky/Spiny Rush (*Juncus acutus)* forming large groups on the outer rim of the spring (Figure D1 and Figure D2). Similar to the native Sea Rush (*Juncus kraussii*) this species is commonly observed in waterlogged and saline areas (DPIRD 2005; Greenwood & MacFarlane 2009), which may warrant further investigation to confirm the spring's level of salinity.

*Figure D1 Spiky Rush (*Juncus acutus*) observed at the Mendara Spring*

*Figure D2 High density of Spiky Rush (*Juncus acutus*) on the outer edge of the Mendara Spring*

The dominance of the introduced Spiky Rush (*Juncus acutus*) on the edges of the spring may be due to the water quality at the springs providing optimum habitat for the species (this requires a survey for verification), however, it may also be due to the presence of stock utilising the springs. Disturbance to soil and existing vegetation creates voids in the landscape and optimum conditions for introduced species to colonise. The Spiky Rush is a hardy and spiky plant, allowing it to deter and/or withstand disturbance by stock, whereas more delicate native understory shrubs and herbs are not likely to withstand the same disturbance.

The presence of this species on the outer rim may now be protecting the native flora in the spring by deterring stock from entering the inner parts of the spring. It may however, eventually outcompete the remaining native species. The uncertainty surrounding the potential implications would require further investigation to determine its impact on the native flora and fauna of the spring.

Table D1 Fauna observed during field visit

Species name	Common name	Conservation status	Preferred habitat
Crinia pseudinsignifera	Bleating froglet	Least Concern	Farm dams, lakes, temporary swamps, flooded fields
Limnodynastes dorsalis	Western banjo frog	Least Concern	Permanent and temporary water (inclusive of farm dams and wetlands)
Threskiornis molucca	Australian white ibis	Listed marine (Commonwealth)	Swamps, lagoons, floodplains, grasslands
Tadorna tadornoides	Australian Shelduck	Least Concern	Freshwater
Poliocephalus poliocephalus	Hoary-headed grebe	Least Concern	Open waters, freshwater, estuarine, brackish
Anas superciliosa	Pacific black duck	Least Concern	Freshwater, pools, tidal mud flats, lakes, wetlands
Chenonetta jubata	Australian wood duck	Least Concern	Grasslands, open woodlands, flooded pasture, dams, wetlands
Egretta novaehollandiae	White-faced heron	Least Concern	Freshwater, tidal mudflats, flooded grasslands
Barnardius zonarius	Australian ringneck	Least Concern	Lightly timbered areas, open woodlands, and tree-lined watercourses
Cacatua sanguinea	Little Corella	Least Concern	Along watercourses, seeding grasses
Coracina novaehollandiae	Black-faced cuckoo-shrike	Listed marine (Commonwealth)	Wooded habitat
Eolophus roseicapillus	Galah	Least Concern	Widespread, timbered habitats, often near water
Falco cenchroides	Nankeen kestrel	Listed marine (Commonwealth)	Lightly wooded areas, open agricultural land
Rhipidura leucophrys	Willie wagtail	Least Concern	Open forests, woodlands, often associated with watercourses
Grallina cyanoleuca	Magpie lark	Listed marine (Commonwealth)	Widespread across range of habitats
Missulena occatoria	Red-headed mouse spider	Not assessed	Semi-arid shrub lands, banks of rivers and creeks
*Vulpes vulpes**	European fox	Introduced/ Pest species	Widespread, agricultural land, forest, urban, semi-urban, woodland

**Introduced species*
Commonwealth is where the species is protected under the Environmental Protection, Biodiversity and Conservation Act 1999 (Commonwealth)

Appendix E — Pre-European Vegetation Codes (Beard 1979)

Table E1 Beard vegetation complexes across the two study areas

Code	Vegetation complex	Groundwater-dependent ecosystem study area
b1,2Li	Low woodland; *Banksia attenuata* & *B. menziesii*	Dinner Hill
b3Li	Low woodland; *Banksia prionotes*	Dinner Hill
bLi	Low woodland; banksia	Dinner Hill
c6e6Mi	Medium woodland; York gum & *Casuarina obesa*	Dinner Hill
dZc	Shrublands; dryandra heath	Dinner Hill
e18Mi	Medium woodland; river gum	Dinner Hill & Irwin
e3,18Mr	Medium woodland; marri & river gum	Dinner Hill
e3,5Mi	Medium woodland; marri & wandoo	Dinner Hill
e3Mi	Medium woodland; marri	Dinner Hill
e3Mr/dZc	Mosaic: Medium open woodland; marri/ Shrublands; dryandra heath	Dinner Hill
e5,6Mi	Medium woodland; York gum (*Eucalyptus loxophleba*) & wandoo	Dinner Hill
e6,8Mi	Medium woodland; York gum & salmon gum	Dinner Hill
e6Mi	Medium woodland; York gum	Dinner Hill & Irwin
e6Mr eSi	Shrublands; mallee with scattered York gum	Dinner Hill
e6Mr m5Sc	Shrublands; *Melaleuca thyoides* thicket with scattered York gum	Dinner Hill
eMr b1,2Li	Medium open woodland; eucalypts (e2?), with low woodland; *Banksia attenuata* & *B. menziesii*	Dinner Hill
hSZc/dZc	Mosaic: Shrublands; hakea scrub-heath/ Shrublands; dryandra heath	Dinner Hill
m5Sc k3Ci	Succulent steppe with thicket; *Melaleuca thyoides* over samphire	Dinner Hill
sl	Bare areas; salt lakes	Dinner Hill
x14SZc/dZc	Mosaic: Shrublands; scrub-heath on the Swan Coastal Plain/ Shrublands; dryandra heath	Dinner Hill
x8SZc	Shrublands; scrub-heath on yellow sandplain banksia-xylomelum alliance in the Geraldton Sandplain & Avon	Dinner Hill
a23,32m3Sc/ a26	Mosaic: Shrublands; *Acacia rostellifera*, *A. cyclops* (S) & *Melaleuca cardiophylla* (N) thicket/ Shrublands; *A. lasiocarpa* & *M. acerosa* heath	Irwin
a23Sc	Shrublands; *Acacia rostellifera* thicket	Irwin

Code	Vegetation complex	Groundwater-dependent ecosystem study area
a23m3Sc	Shrublands; *Acacia rostellifera* & *Melaleuca cardiophylla* thicket	Irwin
a23m3Sc/ e44Lp	Mosaic: Shrublands; *Acacia rostellifera* & *Melaleuca cardiophylla* thicket/ Sparse low woodland; Illyarrie	Irwin
abSi	Shrublands; acacia & banksia scrub	Irwin
ds	Bare areas; drift sand	Irwin
e18Mr m5Sc	Shrublands; Melaleuca thyoides thicket with scattered river gum	Irwin
e43Si	Shrublands; mallee scrub, *Eucalyptus dongarrensis*	Irwin
m5Sc	Mallee; Eucalypt shrubland, *Eucalyptus eremophila*, *E. redunca* and *spp.*	Irwin
x3SZc	Shrublands; scrub-heath on sandplain	Irwin
x4SZc	Shrublands; scrub-heath on lateritic sandplain in the central Geraldton Sandplain Region	Irwin
x5Szc	Shrublands; scrub-heath with scattered *Banksia spp*., *Eucalyptus todtiana* & *Xylomelum angustifolium* on deep sandy flats in the Geraldton Sandplain Region	Irwin
x6SZc/e44Lp	Mosaic: Shrublands; scrub-heath on limestone in the northern Swan Region/ Sparse low woodland; Illyarrie	Irwin
xZc	Pindan woodland; Acacia thicket with eucalypt woodland over spinifex	Irwin

Appendix F — Guidance for using this report to set groundwater objectives and assess drawdown impacts

The guidance provided in this section assumes that current in-situ values of groundwater are to be maintained at a low level of risk (WRC 2000, DoW 2009), in order to achieve outcomes that are 'environmentally acceptable' and that support 'current and future needs for water'[10] (see also Section 6).

A framework for setting objectives, as a basis for drawdown impact assessment

Figure F1 proposes groundwater management objectives to deliver environmentally acceptable outcomes at a low level of risk in the Dinner Hill and Irwin study areas.

Applying a low level of risk to define environmentally acceptable outcomes for each of these three ecosystem components:

- aquatic habitats
- wetland vegetation and
- groundwater-dependent trees

is considered appropriate, given that each of these ecosystem components is likely to support a significant or protected environmental value in the Dinner Hill and Irwin study areas (Figure F2). Figure F2 is informed by the values supported by these three ecosystem components, outlined in Figure 9 (Dinner Hill) and Figure 14 (Irwin).

Recommended steps to using this report for drawdown impact assessment

Figure F3 recommends steps to define environmental objectives for specific groundwater-dependent ecosystems in the Dinner Hill and Irwin study areas for a drawdown impact assessment.

Figure F3 refers the user to tables and figures in this report to identify significant or protected values. It also prompts the application of existing guidance on environmental considerations for groundwater management in the Northern Perth Basin (DoW 2009).

It is recommended that these steps are used in context of state-wide guidance outlined in Figure F2 and with DoW 2009. Where drawdown is predicted to have more than a low level of risk at an environmentally significant or protected site, supporting information will be needed to demonstrate, in the context of relevant policies, that environmentally acceptable outcomes can be achieved, for a licence to be granted.

[10] Among the considerations for the grant/refuse a water licence under the *Rights in Water and Irrigation Act 1914*.

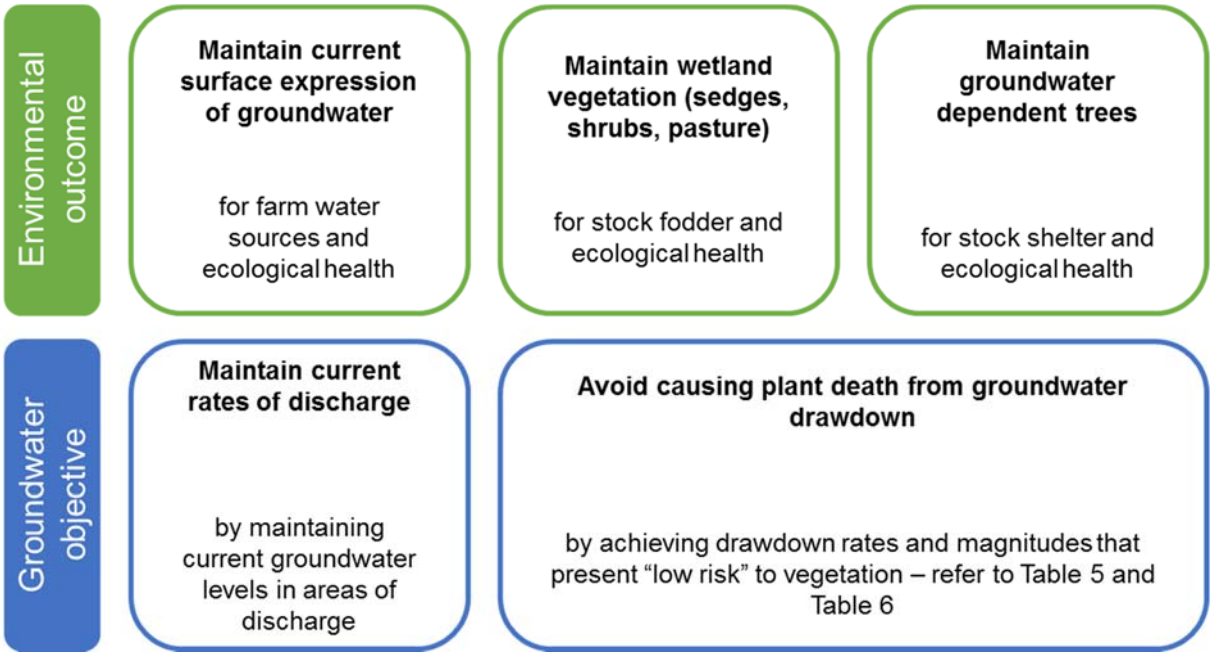

Figure F1 *Groundwater management objectives to deliver acceptable environmental outcomes at a low level of risk at groundwater-dependent ecosystems in the Dinner Hill and Irwin study areas*

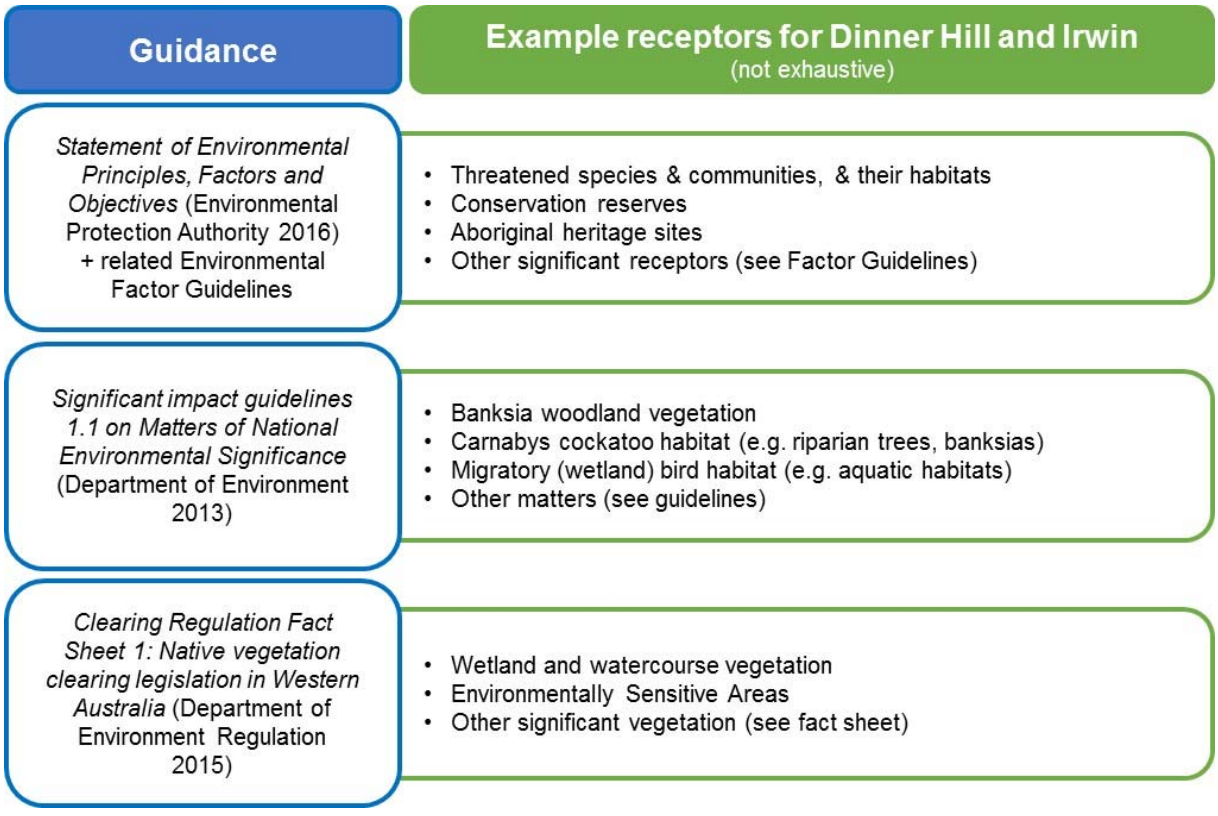

Figure F2 *Guidance to identify significant or protected groundwater-dependent ecosystems in the Dinner Hill and Irwin study areas*

1	Use potential groundwater-dependent ecosystem mapping and aerial photography to identify sites which may experience drawdown
2	Use Table 3 (Dinner Hill) or Table 4 (Irwin) to identify the in-situ groundwater values of sites which may experience drawdown
3	Use Figure 9 (Dinner Hill) or Figure 14 (Irwin) to identify the ecosystem components which support the values at those sites
4	Use Figure 15 to identify the groundwater management objective for each site
5	Where vegetation is among the ecosystem components, apply the guidance in this appendix to determine drawdown thresholds to maintain vegetation at a low level of risk

Figure F3 Recommended steps for setting groundwater management objectives for sites in the Dinner Hill and Irwin study areas

Drawdown thresholds to maintain vegetation

Vegetation growing in areas with shallow depth to groundwater were reported to be more sensitive to fluctuations in the water table than those with deeper roots (DoW 2009). Depth to groundwater categories help to define potential impacts from changes in groundwater levels (see Table F1 and Table F2). These categories vary in their thresholds for groundwater decline, beyond which vegetation is at risk of being impacted.

The groundwater drawdown thresholds for vegetation presented in DoW (2009) are relevant to the Midlands project area. Excerpt tables are provided below, with the 'low risk' category highlighted to align with advice in Figure F1; however we recommend referring to the full guidance document. There are two thresholds that affect environmental outcomes from drawdown. The rate at which drawdown occurs is important, because it determines whether plant roots are able to track a receding water table. The total magnitude is important because the final position of the water table will influence the species composition.

*Table F1 Influence of drawdown magnitude on risk of impact to groundwater-dependent vegetation (*DoW *2009)*

Pre-abstraction depth to groundwater category	Total drawdown magnitude			
	Low	Moderate	High	Severe
0-3 m (wetland)	0-0.25	0.25-0.5	0.5-0.75	>0.75
0-3 m (terrestrial)	0-0.75	0.75-1.25	1.25-1.75	>1.75
3-6 m	0-1.0	1.0-1.5	1.5-2.25	>2.25
6-10 m	0-1.25	1.25-2.0	2.0-2.75	>2.75

*Table F2 Influence of drawdown rate on risk of impact to groundwater-dependent vegetation (*DoW *2009)*

Pre-abstraction depth to groundwater category	Drawdown rate (m/year, to maximum of five years)			
	Low	Moderate	High	Severe
0-3 m (wetland)	0-0.1	0.1-0.2	0.2-0.3	>0.3
0-3 m (terrestrial)	0-0.1	0.1-0.25	0.25-0.5	>0.5
3-6 m	0-0.1	0.1-0.25	0.25-0.5	>0.5
6-10 m	0-0.1	0.1-0.25	0.25-0.5	>0.5

Limitations

The drawdown thresholds in see Table F1 and Table F2 are not intended to indicate risks to:

- Ecosystem components other than vegetation, such as surface expressions of groundwater (i.e. aquatic habitats), which need site-specific assessment of changes in surface water regime (e.g. extent, depth, periodicity).
- Vegetation in saline environments (such as surrounding salt lakes), where the water table may not be an important plant water source.

Environmental assessment for development activities other than groundwater abstraction

The design and approval of future irrigation projects in the Dinner Hill or Irwin focus areas are likely to be subject to regulatory approvals other than environmental considerations of groundwater allocation. These other considerations are not addressed in this report. Examples include local government approvals, or clearing permits for land to be cropped. Despite its development for mining projects, the *Western Australian water in mining guideline* (DoW 2013) may provide useful guidance for approvals planning for complex proposals in Western Australia.

Shortened forms

Bonn	The Convention on Migratory Species, also known as the Bonn Convention
CAMBA	China-Australia Migratory Bird Agreement
DAFWA	Department of Agriculture and Food (Western Australia). Now DPIRD
DBCA	Department of Biodiversity Conservation and Attractions. Formerly DPaW
DER	Department of Environment Regulation (Western Australia). Now DWER
DEWHA	Department of the Environment, Water Heritage and the Arts (Commonwealth). Now Department of the Environment and Water Resources
DIWA	Directory of Important Wetlands in Australia
DoE	Department of Environment (Western Australia). Now DWER
DoW	Department of Water (Western Australia). Now DWER
DPaW	Department of Parks and Wildlife (Western Australia)
DPIRD	Department of Primary Industries and Regional Development (Western Australia). Formerly DAFWA, Department of Fisheries and Department of Regional Development
DPLH	Department of Planning, Lands and Heritage (Western Australia)
DWER	Department of Water and Environmental Regulation (Western Australia). Formerly DoW, DER and the Office of the EPA
EPA	Environmental Protection Authority or *Environmental Protection Act 1986*
GDE	Groundwater-dependent ecosystem
JAMBA	Japan-Australia Migratory Bird Agreement
RIWI	*Rights in Water and Irrigation Act 1914*
ROKAMBA	Republic of Korea-Australia Migratory Bird Agreement

References

Atlas of Living Australia 2016, *Atlas of Living Australia*, viewed May 2016, http://www.ala.org.au/species-by-location/

AWE 2016, *Xyris production facility (XPF) refurbishment environment plan summary document*, AWE Perth Pty. Ltd., Perth, Western Australia

Balleau W 1972, *Agaton project: Perth Basin geology and groundwater at Agaton exploratory bore field*, Records of the Geological Survey of Western Australia, Report 1972/11 (unpublished)

Beard J 1979, *Vegetation Survey of Western Australia: 1:250 000 Series*, Vegmap Publications, Applecross, Western Australia

Birdlife Australia 2012a, *First bird atlas*, Birds Australia, viewed May 2016, http://www.birdsaustralia.com.au/

——2012b, *Historical bird atlas: Birdlife Australia*, Birds Australia, viewed May 2016, http://www.birdsaustralia.com.au/

——2012c, *First bird atlas,* Birds Australia, viewed May 2016, http://www.birdsaustralia.com.au/

—— 2016, *The atlas of Australian Birds*, Bird data, viewed May 2016, http://birdata.com.au/

Campbell W 1910, *The Irwin River coalfield and the adjacent districts from Arrino to Northampton*, Geological Survey Bulletin no. 38, Perth

Casson N 2012, *Condensed descriptions of vegetation at Mid-West groundwater-dependent ecosystems sites*, report prepared for the Department of Water, Perth (unpublished)

Crook I 1984, *Nature reserves of the Shire of Dandaragan, volume one,* Western Australian nature reserve management plan no. 5, Perth, Western Australia

De Silva J, Wallace-Bell P & Ryan S 2015, *Perth regional aquifer modelling system (PRAMS V 3.4): conceptual model*, Hydrogeology report HR334, Department of Water, Perth (unpublished)

Dentith M 1999, 'Yallalie: a buried structure of possible impact origin in the Perth Basin, Western Australia', *Geological Magazine*, *vol. 136*, pp 619–632

Department of Environment and Conservation 2006, *Slender Andersonia (*Andersonia gracilis*) interim recovery plan 2006-2011*, Interim recovery plan no. 228, Department of Environment and Conservation, Perth

——2009, *Resource condition report for a significant Western Australian wetland: Lake Guraga*, Department of Environment and Conservation, Perth

——2010, *2009-2010 Yearbook*, Department of Environment and Conservation, Perth

Department of Infrastructure, Planning and Natural Resources 2005, *Salinity indicator plants*, Department of Infrastructure, Planning and Natural Resources, Hunter Region

Department of Parks and Wildlife 2014, *Approved interim recovery plans*, viewed April 2016, https://www.dpaw.wa.gov.au/plants-and-animals/threatened-species-and-communities/198-approved-interim-recovery-plans

——2016a, *Threatened and priority flora database*, Search for Midlands accessed on 21 March 2016, prepared by the Species and Communities Branch for Department of Water for *Water For Food* Investigation

——2016b, *FloraBase*, viewed April 2016, https://florabase.dpaw.wa.gov.au/

Department of the Environment 2016a, *Banksia woodlands of the Swan Coastal Plain in community and species profile and threats database*, Department of the Environment, Canberra. http://www.environment.gov.au/sprat

——2016b, *Environmental Protection, Biodiversity and Conservation Act 1999 protected matters report*, from Protected matters search tool, viewed April 2016 http://www.environment.gov.au/

——2016c, *Species profile and threats database*, viewed 2016, Department of the Environment http://www.environment.gov.au

Department of Water 2007, *Hydrogeology of the Dongara borehole line*, Department of Water, Perth

——2009, *Environmental considerations for groundwater management in the Northern Perth Basin*, Department of Water, Perth

——2010a, *Jurien groundwater allocation plan*, Water resource allocation planning series, report no. 27, Department of Water, Perth

——2010b, *Arrowsmith groundwater allocation plan*, Water resource allocation planning series, report no. 28, Department of Water, Perth

——2011, *Water allocation planning in Western Australia: A guide to our process*, Department of Water, Perth

——2013, *Western Australian water in mining guideline*, Water licensing delivery series, report no. 12, Department of Water, Perth

——2015, *Gingin groundwater allocation plan*, Water resource allocation planning series, report no 53, Department of Water, Perth

——2017, *Northern Perth Basin: Geology, hydrogeology and groundwater resources*, Hydrogeological Bulletin series, report no. HB1, Department of Water, Perth

Endemic 2012, *Revised wetland mapping and management, Mt Adams Road, Dongara*, report prepared for Tiwest Pty Ltd., Perth (unpublished)

Environment Australia 2001, *A directory of important wetlands in Australia, Third Edition*, Environment Australia, Canberra

Environmental Protection Authority 2005, *Cataby mineral sands project, Iluka Resources Limited, report and recommendations,* Environmental Protection Authority, Bulletin 1212, Perth

——2013, *Environmental assessment guideline for consideration of subterranean fauna in environmental impact assessment in Western Australia*, Environmental Protection Authority, Perth

Geoscience Australia 2016, *Water observations from space dataset*, Commonwealth of Australia (Geoscience Australia), Canberra, http://www.ga.gov.au/scientific-topics/hazards/flood/wofs

Gerritsen R, no date, *Factors influencing the adoption of Indigenous agriculture in Australia,* http://rupertgerritsen.tripod.com/pdf/unpublished/up4.pdf

Greenwood M & MacFarlane G 2009, 'Effects of salinity on competitive interactions between two *Juncus* species', *Aquatic Botany, Vol. 90, no. 1*, pp. 23–29

Halse S, Pearson G & Patrick S 1993, *Vegetation of depth-gauged wetlands in nature reserves of south-west Western Australia*, Technical Report no. 30, Department of Conservation and Land Management, Perth

HydroConcept Pty Ltd. 2015, *Preliminary groundwater assessment of the Midlands region*, HydroConcept Pty Ltd., Perth

IUCN 2016, *The IUCN Red List of Threatened Species*, viewed: April 2016, http://www.iucnredlist.org/

Kay T 2001, *A hydrogeological assessment of the Victoria Plains, Red Gully, Gingin Town site and Eclipse Hill subareas of the Gingin groundwater area*, Hydrogeology report HR156, Water and Rivers Commission, Perth

Land Insights 2014, *Irwin River Estuary Management Plan*, Land Insights, Mt. Lawley

Morgan D & Gill H 2004, 'Fish fauna in inland waters of the Pilbara (Indian Ocean) Drainage Division of Western Australia – evidence for three sub-provinces', *Zootaxa, Vol. 636, no. 1*, pp. 1-43

Morgan D, Beatty S, Klunzinger M, Allen M & Burnham Q 2011, *A field guide to freshwater fishes, crayfishes & mussels of south-western Australia*, South East Regional Centre for Urban Landcare (SERCUL) and Centre for Fish & Fisheries Research, Murdoch University, Perth

Rutherford J, Roy V & Johnson S 2005, *The hydrogeology of groundwater-dependent ecosystems in the Northern Perth Basin*, Hydrogeological Report Series, Report HG 11, Department of Environment, Perth

Schafer D 2015, *Allanooka-Casuarinas groundwater investigation*, Department of Water, Perth.

Schafer D & Hoare A 2018, *Review of the Leederville-Parmelia aquifer hydrogeology in the Dinner Hill groundwater sub-area*, Hydrogeological Record HR 384, Department of Water, Perth

Shire of Dandaragan 2004, *Shire of Dandaragan municipal inventory of heritage places*, Shire of Dandaragan, Dandaragan

——*Welcome to Dandaragan*, viewed 29 September 2016 https://www.dandaragan.wa.gov.au/visit-dandaragan.aspx

Shire of Irwin 2005, *Irwin Shire Council municipal inventory of heritage places*, Shire of Irwin, Dongara

——2016, *Part 2 Report: local planning strategy review*, Dongara Town Planning Urban Design and Heritage, http://www.irwin.wa.gov.au/profiles/irwin/assets/clientdata/document-centre/attachment-booklet-july-2016-part-2-pi-local-planning-strategy-review-red(125).pdf

South West Aboriginal Land and Sea Council 2012, *Noongar Wangkinyiny*, South West Aboriginal Land and Sea Council, Perth

Stuart-Street A 2005, *Greenough region catchment appraisal*, Report no. 268, Department of Agriculture and Food, Western Australia

Trocini S, Barret G, Howard K & Ramalho C 2015, *Rakali Community Survey 2014-2015*, Report prepared by WWF-Australia and the Western Australian Department of Parks and Wildlife, Perth

Warman C 2008, *Understanding the spatial and temporal variation in anthropogenically induced channel response in the Irwin River catchment*, PhD thesis, University of Western Australia

Water and Rivers Commission 2000, *Environmental water provisions policy for Western Australia*, Statewide policy no. 5, Water and Rivers Commission, Perth

Western Australian Museum 2014, *Western Australian Museum*, viewed May 2016, http://museum.wa.gov.au/research/databases/ozcam

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