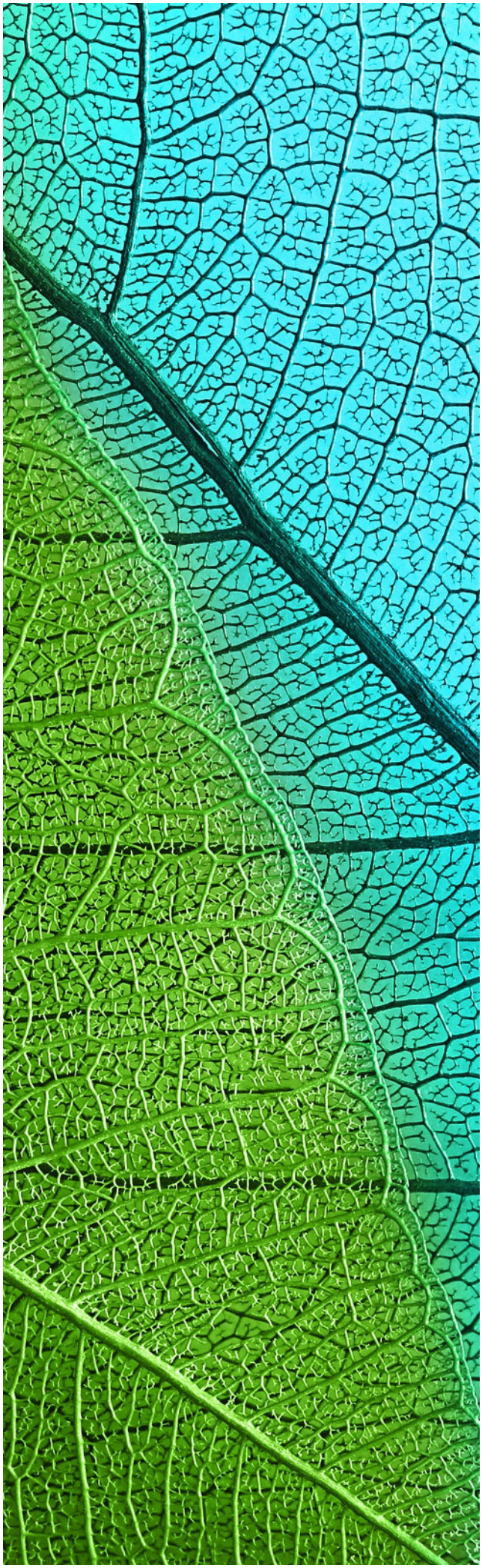

Hexham Wind Farm

Brolga Impact Assessment

Prepared for
Hexham Wind Farm Pty Ltd

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Report No. 18088 (8.16)

Nature Advisory
(Formerly Brett Lane & Associates Pty Ltd)
5/61-63 Camberwell Road
Hawthorn East, VIC 3123
PO Box 337, Camberwell VIC 3124
(03) 9815 2111
www.natureadvisory.com.au

Executive summary

Hexham Wind Farm Pty Ltd engaged Nature Advisory Pty Ltd (Nature Advisory) to assess the impacts on the state-threatened Brolga (*Antigone rubicunda*) from the proposed Hexham Wind Farm in south-western Victoria. This report has been specifically prepared to advise the Environment Effects Statement process, which is required under the *Environment Effects Act 1978 (EE Act).*

This assessment follows the *Interim Guidelines for the Assessment, Avoidance, Mitigation, and Offsetting of Potential Wind Farm Impacts on the Victorian Brolga Population 2011* (DSE, 2012), hereafter referred to as the 'Interim Brolga Guidelines' and includes an evolved approach to habitat assessment and determining the Brolga breeding home ranges following consultation between the proponent and the Department of Energy, Environment and Climate Action (DEECA) in 2024.

DEECA released the 'Handbook for the development of renewable energy in Victoria' in May 2025 including new species-specific guidance for onshore wind energy facilities regarding the Victorian Brolga (DEECA 2025). Under the transitional arrangements the Handbook does not apply if prior to the commencement of the Handbook the project has been referred to the Minister or Planning for assessment under the EE Act or an assessment under the EE Act has commenced for the project, both of these transitional arrangements apply to Hexham Wind Farm and as agreed in consultation with DEECA the project will be assessed under the Interim Brolga Guidelines.

A temporary on-site quarry is being investigated for the purposes of providing aggregate materials for access tracks and hardstand areas, and to minimise traffic movements on local roads during construction. Potential impacts to breeding Brolga have been considered in this report.

The proposed wind farm extends over approximately 16,000 hectares of land in the Moyne Shire. It comprises up to 106 turbines and associated access tracks. The access tracks on the project site will be permanent and will connect to the public road network in several places.

The Brolga is an iconic bird that is secure nationally but listed as endangered in Victoria under the *Flora and Fauna Guarantee Act 1988*. It has experienced a significant decline in Victoria since European settlement which is attributed to habitat loss from agriculture and wetland drainage, predation from foxes and collisions with fences and powerlines. Only one likely Brolga collision with wind turbines has been reported, due to most likely interaction with wind farms within the Brolga's range (Biosis 2023). The cause of death was indetermined as the body, neck and head of the bird was missing due to scavenging.

This report presents the methodology and results from the investigations required under the Interim Brolga Guidelines. It reports the results of fieldwork undertaken by Nature Advisory from 2018 to 2024 and earlier surveys by Ecology and Heritage Partners from 2010 to 2013. These investigations have been undertaken to help achieve the objective of the Interim Brolga Guidelines which is to ensure that each wind farm development has zero net impact on the Victorian Brolga population (DSE, 2012, p.6), thereby avoiding any cumulative impact on the species from the development of the wind energy industry in the state.

The Interim Brolga Guidelines require regular consultation with the state Department of Energy, Environment and Climate Action, which has been important in the development of this project. Extensive discussions have occurred since 2018 with key environment, planning and technical personnel to ensure that the Interim Brolga Guidelines have been applied as required.

Over the last decade, significant efforts have been made to assess Brolga and their habitat for the project. This has included reviewing existing database records and landowner consultation, field surveys during breeding and non-breeding periods, aerial surveys, and the assessment of habitat suitability based on field assessment combined with hydrological modelling.

This report focuses on avoiding and mitigating the impacts of the proposed Hexham Wind Farm on breeding Brolgas as the species does not use any wetlands near the project site during the summer to autumn flocking season. Regarding avoidance and mitigation measures for breeding wetlands, the Interim Guidelines state: *"…turbine siting would be used to exclude any significant reduction in breeding success caused by turbines" (Brolga Scientific Panel, 2008). This will be achieved by establishing turbine-free areas around all potential Brolga nesting sites sufficient to have no significant impact on the likelihood of successful reproduction*."

This assessment has been informed by the latest findings on Brolga movements around their breeding wetlands, much of which has arisen since the publication in 2012 of the Interim Brolga Guidelines.

The key findings from this assessment include:

- A significant proportion (62%) of wetlands in the radius of investigation (within and up to 10 km from the project site) have been permanently drained.
- A significant proportion of the radius of investigation, in particular the southern and north-western portions, lacks wetlands and the Brolga has not historically been recorded there.
- Eight breeding pairs of Brolga were confirmed to inhabit the radius of investigation during 2019. Breeding success and attempts were greater during this year due to good rainfall and related wetland availability, and therefore eight breeding pairs of Brolga have been assumed to be the maximum that would occur in the radius of investigation in any given exceptional year.
- No Brolga flocking activities have been recorded during the flocking season within the radius of investigation, with the closest flocking site being 20 km to the northwest near Penshurst.
- Based on the historical activity of the Brolga in the radius of investigation and the findings of this assessment, the focus has been on the use of the area for breeding. Little risk to the Brolga is considered to arise from the lack of use of the region during the flocking season.
- A level three assessment as per the Interim Brolga Guidelines has been undertaken due to Brolga breeding within the wind farm boundary and outside the northern and eastern boundaries.
- Twenty-two Brolga breeding wetlands are located within 5 km of the project site and are considered to provide Brolga breeding habitat now and into the future. Appropriate turbine-free buffers around those wetlands on and near the project site have been delineated to ensure the project does not significantly impact their breeding success.
- Collision Risk Modelling (CRM) has found that based on the most conservative avoidance rate of 90%, the residual impact of the wind farm on breeding Brolgas may lead to the loss of between one and 10 Brolga with an average of 5.3 Brolga over the 30-year life of the project.

- Implementation of the Interim Brolga Guidelines has ensured that the project does not contribute to the cumulative impact of the wind energy industry in southwestern Victoria on the Victorian Brolga population.

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1. Introduction

Hexham Wind Farm Pty Ltd engaged Nature Advisory to undertake an assessment of the impacts on the state-threatened Brolga (*Antigone rubicunda*) of the proposed Hexham Wind Farm (HWF) in western Victoria.

The proposed HWF site (project site) is approximately 16,104 hectares of private land and adjacent roadside in the western Victorian localities of Hexham, Caramut, Ellerslie, Minjah, and Woolsthorpe, 20 km west of Mortlake and 200 km west of Melbourne.

As a result of clearing for agriculture, native vegetation within the project site is largely restricted to roadside reserves and along watercourses. Hexham Wind Farm proposes to install up to 106 wind turbines with a maximum blade tip height of 260 metres, a minimum blade tip height of 40 metres and a rotor diameter of up to 190 metres. The associated access tracks on the project site will be permanent and will connect to the public road network in several places.

The region is characterised by an extensive flat to undulating basaltic plain with stony rises, old lava flows, numerous volcanic eruption points and scattered shallow wetlands, both saline and freshwater. Water filled maars and calderas are also common (e.g., Lake Bullenmerri, Lake Purdigulluc, and Tower Hill) (VicFlora, 2024).

This report presents the methods and results of the Brolga assessment based on fieldwork undertaken by Nature Advisory from 2018 to 2024 and earlier surveys by Ecology and Heritage Partners (EHP) from 2009 to 2013 in accordance with the Interim Brolga Guidelines (DSE, 2012).

Over the last decade, significant efforts to assess Brolga and their habitat for the project have been made. This has included a review of existing database records, landowner consultation, field surveys for Brolga during breeding and non-breeding seasons, aerial surveys, and the assessment of habitat suitability based on field assessment combined with hydrological modelling.

The investigation area encompassed the project site as well as a 10-kilometre zone around it referred to as the Radius of Investigation (RoI), as defined in the Interim Brolga Guidelines (p. 13).

This report focuses on avoiding and mitigating the impacts of the project on breeding Brolgas as the species does not use any wetlands near the project site during the summer-autumn flocking season. Regarding avoidance and mitigation measures for breeding wetlands, the Interim Guidelines state: *"…turbine siting would be used to exclude any significant reduction in breeding success caused by turbines"* (Brolga Scientific Panel, 2008). *This will be achieved by establishing turbine-free areas around all potential Brolga nesting sites sufficient to have no significant impact on the likelihood of successful reproduction*."

The results of the Brolga assessment are presented following the three-level approach prescribed in the Interim Brolga Guidelines. At this stage level one, level two and steps 1-3 of level three have been completed and are reported here to inform the Environment Effects Statement (EES) process. The Collisions Risk Model (CRM) and Population Viability Assessment (PVA) of the level three assessment will be updated once the layout has been finalised.

This report is divided into the following sections:

Section 2 provides an overview of the Brolga assessment approach.

Section 3 describes the level one assessment methods and results.

Section 4 describes the level two assessment methods and results.

Section 5 describes the level three assessment undertaken to date.

Section 6 provides an overview of findings from the assessments.

Eamon O'Meara (Zoologist), Elizabeth Browne (Zoologist), Guille Mayor (Zoologist), Lilith Armstrong (Zoologist), Jackson Clerke (Senior Zoologist), Khalid Al-Dabbagh (Senior Zoologist), Peter Lansley (Senior Zoologist), Curtis Doughty (Senior Zoologist), Kylie Patrick (Senior Ecologist and Project Manager), Inga Kulik (Director, Senior Ecologist and Project Manager) and Brett Lane (Principal Consultant) from Nature Advisory completed this investigation.

2. Brolga assessment overview

2.1. Species description

The Brolga is listed as *Endangered* under the *Flora and Fauna Guarantee Act 1988* (FFG Act; DEECA, 2023). Brolga belong to the family Gruidae (cranes), of which two species occur in Australia (Marchant and Higgins, 1993). Brolgas are very similar to other cranes in their general ecology and physiology, being large-bodied, long-legged, and long-lived. Adult Brolgas stand up to 1.8 m tall, have a wingspan of 2 m, and a weight range of 4–8 kg.

During the non-breeding season, Brolgas can form large flocks (occasionally as large as 200) but are typically seen in small groups (10 to 20 individuals). Breeding pairs can form long-term bonds and, if one of the pair dies, the remaining individual may take several seasons to find another mate (Marchant and Higgins, 1993). Brolga pairs will aggressively defend their breeding territory (Arnol et al., 1984) and have been observed destroying nests that other Brolgas have attempted to build within it. Typically, pairs only produce one or two offspring per breeding season and therefore recruitment into the population is low.

The Brolga's annual cycle is divided into two principal periods, as follows:

- A breeding season, (July to December), during which territorial pairs nest in shallow freshwater wetlands that are often ephemeral and hold water reliably in winter and spring.
- The flocking (non-breeding) season (December to June), when Brolga disperse from their breeding wetlands, which are drying up, to larger wetlands that are more permanent. Here, they form flocks that roost at the wetland and forage in adjacent terrestrial and wetland habitats (DSE, 2012).

Between the breeding and flocking seasons, Brolga move between their breeding and flocking sites during two migration periods that are roughly consistent with the seasons above although variations due to weather can be expected.

The Australian Brolga population numbers in the tens of thousands, giving it a secure conservation status (Marchant and Higgins, 1993). However, most of the population occurs in northern Australia. In Victoria, its range has contracted since European settlement due to wetland drainage and habitat loss related to agriculture, and predation of eggs and young by the introduced Red Fox (*Vulpes vulpes)*. Its former range included northeast Victoria, Gippsland, and the formerly extensive wetlands of the Melbourne region. Currently, Brolgas are found in the south-west and the north of the state in parts of the Murray River basin (Du Guesclin, 2003).

2.2. Brolga distribution in Victoria

The distribution of the Brolga in the main part of its Victorian range, the south-west, varies seasonally. In the breeding season adult pairs disperse to small and moderately sized seasonal or semi-permanent wetlands to breed as territorial pairs. At this time, small numbers of non-breeding birds can form flocks on larger wetlands. In the flocking season, birds congregate in larger wetlands as the smaller, seasonal wetlands dry out over summer.

Brolga movements in south-west Victoria are not yet completely understood. Seasonal movements, referred to as migration movements, occur in south-east Australia between flocking and breeding wetlands. Local movements can also take place when birds are moving between roosting and feeding sites. Long distance movements may take place in very dry years and populations may move from dry inland wetlands to wetlands associated with the Murray River (Marchant and

Higgins, 1993). In very wet seasons, birds may remain at breeding wetlands throughout the year and not move to flocking sites. Therefore, Brolga movements and distribution are heavily dependent on climate and foraging opportunities.

Consistent Brolga flocking sites in south-west Victoria that account for a significant proportion of the population occur in the locations listed below, based on information compiled by Sheldon (2004) and provided in consultations with the Department of Energy, Environment and Climate Action (DEECA):

- The Grampians region
- Strathdownie
- Cressy
- Streatham (mainly on Lake Wongan and in the Skipton area)
- Hamilton, Dunkeld, and Penshurst areas
- Edenhope area
- Toolondo
- Willaura and Stavely areas
- Darlington.

2.3. Brolga population size

The 1984 estimate of the Victoria brolga population was between 600 to 650 birds, with approximately 550 to 600 of these birds (around 92%) in south-west Victoria (Arnol *et al.,* 1984). This and subsequent estimates are noted in Table 1.

Table 1: Brolga population estimates, south-west Victoria

Month /year	Est. no.	% ≤2 yrs. old	Same day counts	Source
13/02/2025	856	20	Yes	http://swifft.net.au/cb_pages/sp_brolga.php (viewed June 2025)
24/03/2024	836	19	Yes, subset of main flocking sites	
22/04/2023	521	11		
Apr 2022	552	14	Yes	
Mar 2021	413	9	Yes	
Apr 2019	635	6	Partial	
Apr 2018	377	13	Partial	
Apr 2017	278	18	Partial	
Apr 2016	348	8	Partial	
Apr 2015	449	10	Partial	
Apr 2013	907	17	Yes	
2012	448	16	Partial	
2011	250	20	No	
2010	401	10	No	
2004	675	-	No	Sheldon (2004)
2002	402	-	No	DSE (2007)
1984	550-600	-	No	Arnol *et al.* (1984)

The estimates for 2021–24 (Table 1) are based on counts made at a subset of the main flocking sites in south-western Victoria. These included wetlands at or near Willaura, Penshurst, Lake Bolac, Streatham, Darlington, Cressy and Strathdownie.

The Department of Environment, Land, Water and Planning (DELWP) conducted the April counts for years 2012–19 at Dundonnell, Penshurst, Willaura, Strathdownie, Lake Bolac, Streatham, Bool Lagoon (South Australia; approximately 20 km from the Victorian border) and Lake Wongan. These counts were simultaneous, being undertaken on the same day to avoid re-counting flocks that may have moved.

Earlier counts (1984 to 2011) were non-simultaneous and, as such, are not directly comparable to later counts. Counts conducted over multiple days may record the same bird multiple times, resulting in overestimates

From 2010, more juvenile Brolga were observed in flocks than in previous years, which were drought years. Years with high rainfall result in more numerous breeding wetlands that stay inundated longer. This makes it more likely that breeding habitat remains suitable throughout the breeding and fledging periods.

The existing data indicates that the Victorian Brolga population has increased in 2024 and 2025. However, its recent *Endangered* status under the FFG Act is due to ongoing threats to its wetland habitats (DEECA 2023, Veltheim et al. 2022).

The population viability assessment (Section 5.3) assumes a Victorian population of 625 Brolgas.

2.4. Brolga habitat

In Victoria, Brolga occur in a variety of habitats and use different habitats in the breeding season compared with the non-breeding, or flocking, season (Arnol *et al*., 1984). During the breeding season, territorial pairs nest in shallow freshwater wetlands that are often ephemeral, holding water reliably only in winter and spring (Herring, 2005). During the non-breeding season Brolga congregate together at larger, often permanent waterbodies where they roost, drink and forage and from where they venture out across the landscape to forage in terrestrial habitats (Johnsgaard, 1983, Arnol *et al*., 1984). As Brolga do not flock within the HWF RoI, only breeding habitat has been considered in detail below.

Brolga rely on wetlands for nesting, food resources and night-time roosting sites (Johnsgaard, 1983). In the breeding season (July to December), they nest in shallow freshwater marshes less than 50 cm deep and with emergent vegetation and freshwater meadows less than 30 cm deep dominated by annual herbs, rushes or tussock grass (Marchant and Higgins, 1993). Emergent vegetation at these wetlands plays a crucial role in providing Brolga habitat as it provides nesting material, food resources (tubers, aquatic animals), provides shelter for prey (vertebrates and invertebrates) and cover from predators for young chicks (Johnsgaard, 1983). Dense, tall emergent vegetation over one metre in height is generally avoided (e.g., Cumbungi, *Typha* sp.), as Brolgas need to maintain a panoramic view of their surroundings (Herring 2007).

A Brolga family will spend most of its time in the nesting wetland foraging but will move to other wetlands nearby to forage and/or roost as the chicks develop and food resources are depleted. Brolga also forage in pasture and to a lesser degree (during the breeding season) in cereal and canola crops in the vicinity of the breeding wetland and night-time roost. Brolga roost at a wetland during the night and move about during the day within, around and between them to forage (Veltheim, 2018; Veltheim et al., 2019). Veltheim et al. (2019) found that a modelled utilisation

distribution to 2 km from a breeding wetland captured 95% of the likely movements of a Brolga family around that breeding wetland.

Suitable breeding habitat is dominated by aquatic vegetation, including sedges, rushes, annual herbs, Tussock Grass *Poa* sp., Sweet Grass *Glyceria* sp., Spike–rush *Elocharis* sp. or Common Sword Sedge *Gahnia* (Marchant and Higgins 1993). Nests are usually constructed within the shallows of wetlands from a variety of plant matter where a platform of vegetation is constructed approximately 1.5 m in diameter (White, 1987). Both breeding and nearby foraging wetlands provide food to support a successful breeding outcome and Veltheim *et al*. (2019) found that access to at least three wetlands was more likely to result in optimum breeding success.

Brolga are unlikely to breed in drainage lines flowing into and out of wetlands due to flooding risk and they prefer larger expanses of water to protect them from ground predators. They typically nest in large (30–200 ha) ephemeral wetlands (Herring, 2004), particularly in north-east Victoria, where breeding wetlands average 115 ha in size (Herring, 2001). In contrast, in south-west Victoria, Brolga nests occur in smaller wetlands (<10 ha; reviewed in Veltheim et al., 2019). Brolgas also generally do not breed in flowing creeks and rivers, though they may if they have been dammed and flows stilled.

The key threat to Brolga is the drainage and alteration of the wetland hydrology (Du Guesclin, 2003). Wetlands that have been partially or fully drained typically do not provide the physical and biotic resources needed to build nests, incubate eggs, feed and shelter young chicks from ground predators or feed older chicks until they fledge, as they may not hold water long enough for successful breeding (DEECA, 2025) or may reduce in size to the point that Brolgas are unlikely to select them for breeding (Veltheim et al., 2019). However, DEECA has advised that there are records of partially drained wetlands being used for nesting.

Based on discussions between DEECA and Wind Prospect since 2020, a wetland that is most likely to support a successful breeding attempt holds water for at least 120 days at least once every ten years. This is based on the approximate 30-day egg-laying and incubation period and the 90 days it takes hatched chicks to become independent (fledge), the measure of a successful breeding outcome. Given the role of multiple wetlands within a breeding brolga home range (Veltheim et al., 2019), where multiple wetlands occur nearby, a minimum 120-day inundation period provides habitat to support breeding given birds can move between wetlands. A hydrological investigation of the HWF and its surrounds (up to 1 km beyond the project site) has been undertaken (Appendix 4).

To avoid and mitigate wind farm impacts, the Interim Brolga Guidelines (p.8) define a Brolga breeding wetland as:

"*The nest of a Brolga breeding pair and the perimeter of the surrounding wetland. Also includes wetlands with previous records of Brolga nests from any relevant information source. A wetland remains a breeding site providing it has not been permanently drained and/or planted with trees. Wetlands that have been ploughed can still be breeding sites providing the wetland retains some level of filling.*"

To define a turbine-free buffer (the principal mechanism for avoiding and minimising impacts on Brolgas) in this report, the habitat that supports breeding includes nearby wetlands (within 2 km based on Veltheim et al., 2019 – see Section 6.1.1) around a confirmed breeding wetland despite there being no breeding records. These wetlands provide supplementary foraging habitat for a Brolga family as described above. They have been defined hydrologically (Water Technology 2024a, Appendix 4) or visually as holding water for at least 120 days at least once every ten years.

As per the Interim Brolga Guidelines, any previously recorded breeding wetland that has been permanently drained is not considered likely to support breeding in the future.

For the purpose of this assessment, a historical breeding wetland can be considered permanently drained if an excavated earthen channel has been constructed from the wetland invert to a connecting drain, downstream waterway or downstream wetland.

More than one line of evidence would be used as the evidence requirement and include:

1. Topographical imagery which demonstrates the drainage channel and connecting downstream wetland or waterway.
2. Historical satellite imagery of the wetland in the central month of the Brolga breeding season (Aug/Sep/Oct) over multiple years within a 10-year period evidencing the wetland area as drained and not capable of functioning as a wetland suitable for Brolga breeding.
3. Using a high-resolution Digital Elevation Model (DEM) in combination with water balance or hydrological modelling as the most precise and scientifically defensible method to assess whether a site can (or cannot) function as a wetland suitable for Brolga breeding.

This approach has been agreed to by DEECA via email (21/05/2025).

2.5. Threats

The Action Statement (Du Guesclin, 2003) identifies the following key threats to Brolga breeding wetlands:

- Drainage and disappearance of breeding wetlands
- Altered flood regime
- Modification of vegetation structure and species composition, water quality or soil structure at breeding wetlands and terrestrial foraging areas
- Widespread use of herbicides and pesticides especially near breeding wetlands
- Disturbance by hunting activities where young birds remain in the breeding wetland
- Introduced predators, feeding on eggs and chicks
- Wildlife and burning programs, which remove nest material
- Grazing by stock can degrade wetlands
- Subdivision and fencing of large private landholdings as chicks can get caught in fences
- Erection of structures such as overhead powerlines can cause collisions
- Use of wetlands for irrigation and/or reuse systems.

Some of the key threats impacting the Brolga flocking sites include:

- Disturbance by hunters during the duck season and deposition of lead shots in wetlands
- Loss of habitat due to changes in vegetation, for example, changes in agricultural practices
- Catchment degradation resulting in changes in water quality, including increased salinity, siltation or flooding
- Poisoning of agricultural pests e.g., crickets
- Erection of structures such as overhead powerlines.

2.6. Policy framework for wind farms

The planning guidelines for wind farms in Victoria (DTP, 2023) require that the potential impacts of wind farms on species listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) or the Victorian FFG Act be assessed. Clause 52.32 of the Planning Scheme also required impacts on FFG Act-listed species to be assessed.

One such species is the Brolga (listed as Endangered under the FFG Act but not on the EPBC Act), which occurs in the broader region around the project site. Responsible authorities must consider the impacts of wind farm developments on this species before making decisions on permit applications. The Victorian Government has provided guidance on how impacts to Brolga from wind farms can be avoided and mitigated (Interim Brolga Guidelines, DSE 2012), as described below. By using these guidelines, these policy directions have been followed.

DEECA released the 'Handbook for the development of renewable energy in Victoria' in May 2025 including new species-specific guidance for onshore wind energy facilities regarding the Victorian Brolga (DEECA 2025). Under the transitional arrangements the Handbook does not apply if prior to the commencement of the Handbook the project has been referred to the Minister or Planning for assessment under the EE Act or an assessment under the EE Act has commenced for the project, both of these transitional arrangements apply to Hexham Wind Farm and as agreed in consultation with DEECA the project will be assessed under the Interim Brolga Guidelines. The objective of the Interim Brolga Guidelines is to ensure that each wind farm development has *at a minimum a zero-net impact on the Victorian Brolga population* (DSE, 2012, p.6). To meet this objective, three levels of investigation may be required. Information is gathered at each investigation level to inform the impact assessment and mitigation strategies. Each level also informs the next and all three levels are applied if there is potential for a significant impact that requires informed mitigation and offset. This Brolga assessment follows the methods in the DSE (2012) Interim Brolga Guidelines.

This document outlines the investigations completed to date to address levels one and two of the assessment and provides the basis for discussions with key environment, planning and technical personnel in DEECA, HWF and Nature Advisory to ensure that the method of achieving the outcome of a zero-net impact on the Victorian Brolga population is acceptable. The level three investigation is a four-step process and the first three steps have been completed: avoid or mitigate potential impacts, collision risk modelling (CRM) and the Brolga population viability assessment (PVA). Step four of level three assessment from the Interim Brolga Guidelines, identifying compensation strategies will be undertaken later in the planning process as a separate Brolga Compensation Plan.

Further details on the levels of assessment and steps in the Interim Brolga Guidelines and their application in this work are summarised in Table 2. This also indicates where the relevant information can be found in this report, as well as the work that remains to be completed.

Table 2: Three-level assessment of wind farm impact on Brolga: current investigation

Level	Step	Assessment triggers (as per DSE 2012)	Current investigation: outcomes & actions
Level 1 Trigger		The presence of Brolga within the RoI (i.e., within 10 km of the proposed wind farm boundary). The presence of potential Brolga habitat within the RoI, OR The location of the proposed development is within an area that may be used by Brolga during seasonal movements between breeding and flocking habitats.	Level One Assessment triggered and conducted (see Section 3).
1	1	Undertake desktop studies into known and potential habitat areas for Brolga.	All available historical and recent Brolga records within the 10 km RoI have been collated and reviewed to identify the extent of Brolga occurrence in the RoI. (see Section 3.1 and 3.2).
	2	Initial field inspection and local community consultation.	A site inspection was undertaken to identify potential Brolga breeding habitat on and around the proposed project site. Extensive landholder consultation within the RoI has been undertaken to identify current and historical Brolga flocking and breeding wetlands that may not be in the available databases or accessible during field studies (see Section 3.1 and 3.2).
Level 2 Trigger		Records of breeding or flocking habitats within the RoI. The proposed development is located in an area which may be used by Brolga moving seasonally between breeding and foraging sites, and may potentially create a barrier reducing movements between these habitats OR The proposed location of new powerlines associated with the development may create new collision risks for Brolga.	Level Two Assessment triggered and completed (see Section 4).
2	-	The Level 2 Assessment collects comprehensive data about the location, nature and extent of Brolga habitats, and patterns of habitat use and behaviour at breeding, flocking and foraging sites within the RoI.	Site-specific investigations determined that the Brolga occasionally use the landscape within and around the proposed HWF. Breeding was recorded in wetlands in the RoI.

Level	Step	Assessment triggers (as per DSE 2012)	Current investigation: outcomes & actions
			The species does not flock within 10 km of the wind farm (see Section 4.2.3). Extensive site-specific field investigations have been undertaken during breeding and non-breeding periods in 2009 to 2011, 2013, and 2018 to 2024 to document the location of Brolga habitats in the RoI (see Sections 3 and 4).
Level 3 Trigger		Qualitative risk assessment (AusWEA 2005) of project following site design is greater than "low".	Potential for impact, level three triggered anyway (Section 5).
3	1	Avoid or mitigate all potential impacts to Brolga breeding and flocking home ranges within the RoI with turbine-free buffer areas.	The establishment of turbine free buffers around breeding sites has been agreed with DEECA (see Section 5.1.1).
	2	Develop a site-specific Collision Risk Model (CRM) for Brolga utilising or moving through the radius of investigation.	The Band – Nature Advisory Collision Risk Model has been used to estimate the number of bids affected by collision with turbines (see Section 5.2 and Appendix 7)
	3	Use DEECA (Melbourne University) Brolga PVA to estimate the impact of the proposed development on the population.	A PVA has been prepared based on outcomes of CRM (see Section 5.3 and Appendix 8).
	4	Identify appropriate compensation strategies to ensure a zero net impact on the Victorian Brolga population.	Based on the outcomes of the CRM and PVA (Section 5.4).

The remainder of this report is structured around the Interim Brolga Guidelines to enable the reader to follow how they have been applied.

3. Level one assessment

All three level one assessment triggers apply to the project. The level one assessment is described in this section.

3.1. Methods

3.1.1. Review of existing reporting and documentation

The existing documentation below, relating to the RoI was reviewed:

- *Preliminary Flora & Fauna Assessment for the Proposed Hexham Wind Farm, Hexham, Victoria*. Ecology Partners Pty Ltd, April 2011 (EP, 2011)
- Brolga Movements and Spatial Requirements During Breeding, south–west Victoria. Ecology and Heritage Partners Pty Ltd, November 2013 (EHP, 2013)
- *Fauna and Flora Assessment: Detailed Fauna and Flora Investigations: Hexham Wind Farm, Hexham, Victoria*. Prepared for Hexham Wind Farm Pty Ltd, Ecology and Heritage Partners Pty Ltd, June 2014 (EHP, 2014)
- *Breeding home range movements of pre-fledged brolga chicks, Antigone rubicunda (Gruidae) in Victoria, Australia – Implications for wind farm planning and conservation* (Veltheim *et. al.,* 2019)
- *Final Report - Biodiversity Assessment: Hexham Wind Farm, Hexham, Victoria*. Prepared for Hexham Wind Farm Pty Ltd. Ecology and Heritage Partners September 2018 (EHP, 2018)
- Breeding wetland home range mapping published in the EES Referrals for the Penshurst (Biosis Research, 2011) and Mount Fyans (Biosis, 2022) Wind Farms
- Correspondence from local landholders of Brolga sightings.

3.1.2. Brolga breeding and flocking records.

Databases were consulted to identify historic Brolga breeding, flocking and sighting records, including:

- Victoria Biodiversity Atlas (VBA) (DEECA, 2024) – high accuracy records for south-western Victoria were obtained in 2024
- The Atlas of Australian Birds and Birdata (BirdLife, Australia 2024) accessed 2024
- The south-west Victorian flocking site database (compiled by Sheldon (2004) and provided by the then Department of Sustainability and Environment (DSE))

These databases were reviewed for Brolga records in south-west Victoria, in the HWF RoI, and within the project site.

Several Brolga breeding records are not associated with wetlands due to the accuracy of the record. DEECA have provided a protocol for addressing Brolga breeding records greater than 100 m from a wetland. The following steps were applied in these circumstances:

- Attempt to confirm the record location using the location and observer details
- Buffer the record according to the accuracy field
- Attribute the record to the closest wetland within the accuracy buffer

- If there are no wetlands within the accuracy buffer, disregard the record
- If the accuracy attribute is >1 km, disregard the record.

All historical records of breeding associated with a wetland were assumed to indicate sites where breeding could occur in the future. Following the Interim Brolga Guidelines, the only exception was where the historical record of breeding was located at a wetland that had been permanently drained.

The Interim Brolga Guidelines state that a flock roost site must meet all three criteria listed below in Table 3 (DSE, 2012).

Table 3: Criteria used to identify a flock roost site (source: DSE, 2012)

Criteria	Justification
More than one year of recording.	To ensure the selection of traditional and regularly used sites.
One or more records of counts equal to or greater than 10 birds.	To include sites which have been used often or traditionally by flocking Brolga. The assumption is made that if more than 10 birds are recorded on a wetland, flocking behaviour is likely.
Recorded in more than one month.	To include sites where Brolga flock for periods greater than one day or one week, i.e. to include sites used traditionally for the majority of the flocking or non-breeding season.

For initial analysis and short-listing of possible flocking sites, including during the landholder surveys, sites that had supported ten or more birds were identified from existing records. These sites were divided into the following two categories:

1. **Traditional flocking sites** are not specifically defined in the Interim Brolga Guidelines but are referred to as the wetland to which Brolga flocks return each night to roost during the dry, flocking season 'year after year'.
2. **One-off flocking sites** are defined in the Interim Brolga Guidelines as sites where a flock of Brolgas has been observed on a single occasion, but the site is not a traditional and regularly used site. This includes single records of a flock or repeat records once within a month or less, and flocks observed foraging during the day away from wetlands.

Traditional flocking sites are considered to have much greater value for Brolga than one-off flocking sites, as they represent a key habitat used for safe overnight roosting after a day of foraging in the surrounding landscape. Movements to and from one-off sites are more likely to resemble the movements Brolga make in the migration season, movements that the Interim Brolga Guidelines state can be considered in determining the residual risk of the project to the Victorian Brolga population. One-off flocking records may also correspond to an observation of a flock foraging during the day away from its traditional flocking site and can often be of birds using non-wetland habitats, such as crops or pasture.

3.1.3. Initial surveys undertaken by EHP

EHP completed initial field surveys between 2009 and 2013. These surveys included:

- Brolga searches between November 2009 to February 2010. This included driving all roads within a 20-kilometre radius of the project area and searching for Brolga in a potential wetland habitat with the aid of binoculars. Where access could be arranged, all historical

Brolga breeding records were visited, and the habitat was assessed for its suitability for breeding habitat.

- Aerial survey for Brolga in October 2010 by flying a light aircraft over the project site and within a 20-kilometre radius to identify potential Brolga nests. Nest locations were then recorded and visited on the ground where this was possible.
- Initial community consultation in 2011 involved contacting landholders with historical records of Brolga to seek information about Brolga habitat and request permission to visit the location. Landowners involved in the project were surveyed and their neighbours were invited to participate via a mailout.
- Brolga breeding season searches during 2012-13 of 11 wetland areas within the project site to identify Brolga breeding activity.

3.2. Results

3.2.1. Historical flocking sites

Figure 1 indicates the NVR2017 Habitat Importance Modelling (DEECA modelled Brolga habitat) together with the Nature Advisory potential flocking sites that were surveyed and VBA Brolga flocking records with 1,000-metre accuracy or lower (up to 2nd February 2021). Nature Advisory identified potential flocking sites as areas that were either indicated in the literature as a flocking site or with records in the databases of three or more Brolga. F12 was added during the flocking surveys as a pair of Brolga was observed in that area during the flocking season monitoring period. All accessible wetlands across the RoI that held water during the flocking seasons were surveyed during the Brolga flocking surveys.

One VBA record within the RoI consisted of 18 Brolga and was located 2.5 km north of the proposed wind farm boundary. This record was from June 2008 and entered by a local landholder. The location description of the record states 'Blackwood Lake (Caramut-Dunkeld Road)'. Blackwood Lake is located 20 km from the proposed wind farm (outside the RoI) on a private property along Woolsthorpe Road between Caramut and Dunkeld. There is likely a co-ordinate error with this record and the record was intended to be at Blackwood Lake.

A review of the Brolga flocking database found one flocking record within the RoI (Sheldon 2004). In April 2003, 35 Brolga were recorded near Wetland 28243 which is located within the project site. The landholder, who was the property owner at the time of the record, has not observed Brolga flocking on his property (EHP, 2014). There was also a Brolga record at this site in May 1997 although the number of Brolga observed was not disclosed. Wetland 28243 fails to meet the criteria for a traditional flocking site and is considered to have supported a one-off flocking site.

No Brolga flocking activity was observed in the RoI during the Brolga flocking season surveys. Given the lack of flocking records and the lack of large, permanent wetlands in the RoI there is no evidence of any traditional Brolga flocking sites in the RoI.

The nearest flocking site is located near Penshurst, approximately 20 km north-east of the study area.

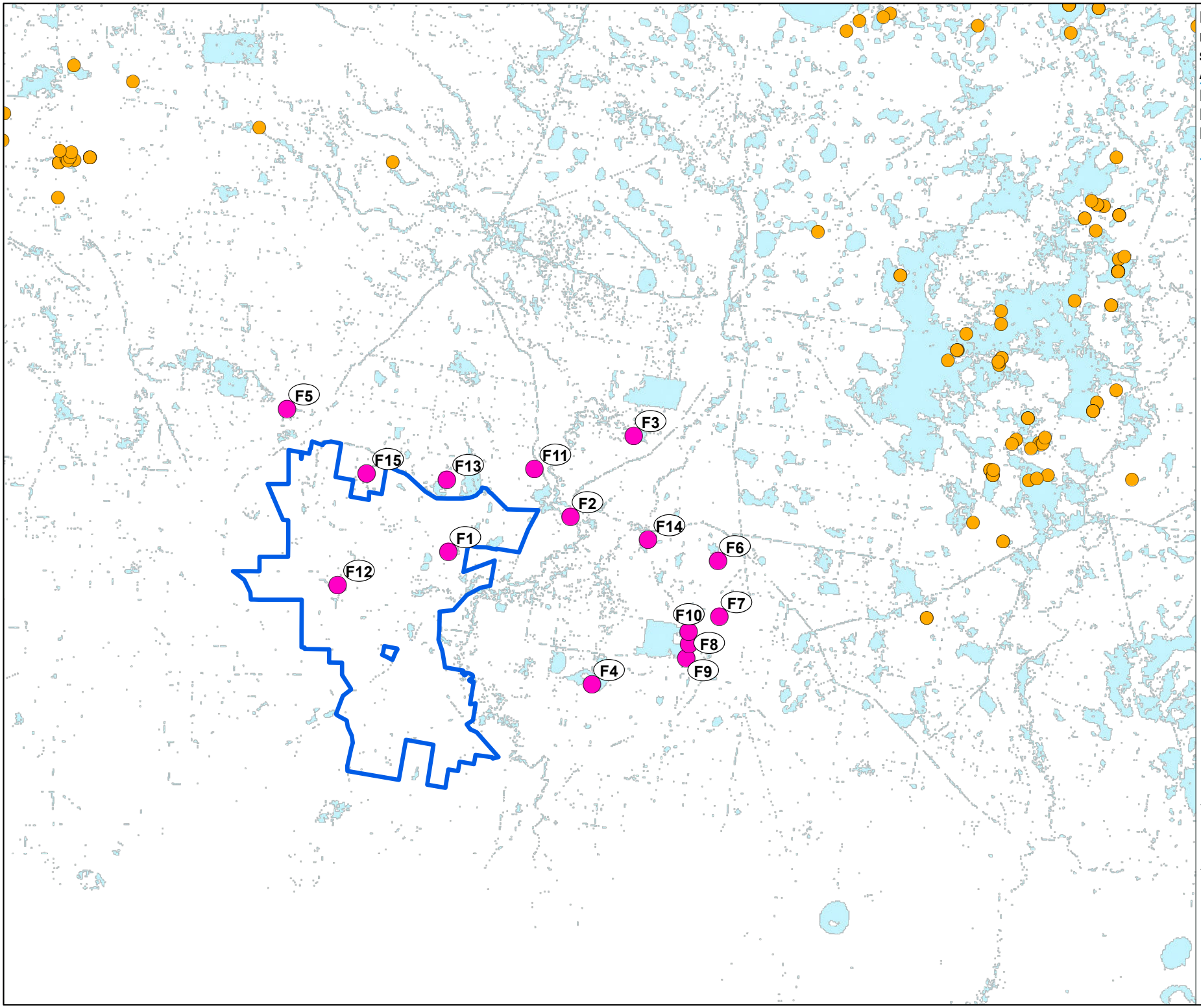

Figure 1: Brolga VBA flocking records and potential flocking sites surveyed by Nature Advisory

Project No: 18088_26
Project: Hexham Wind Farm
Date: 28/08/2025

Wind farm boundary

High accuracy Brolga VBA flocking records (up to date of 20/11/2024, <=1000m accuracy)

NA identified potential flocking sites surveyed

NVR2017 Habitat Importance Modelling (DELWP modelled Brolga habitat)

N

Kilometres

0 2 4 6 8 10

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3.2.2. *Historical breeding wetlands*

Figure 2 and Figure 3 present Brolga information from the VBA.

Figure 2 shows VBA records with an accuracy of 1,000 m or less and the Habitat Importance Modelling for Brolga prepared by DEECA for south-west Victoria. Figure 2 shows the following:

- The HWF site lies generally in the southern area of the distribution of Brolga records in southwest Victoria
- Several records are from within the project site
- Higher concentrations of records occur to the north-west, north-east and east of the HWF

Figure 3 focuses on the HWF RoI and details VBA records and the NVR2017 Habitat Importance Modelling (DEECA modelled Brolga habitat). Figure 3 shows the following:

- There are seven breeding records within the project site, two of which have been discarded
- There are scattered breeding records directly to the east and north-east of the project site
- Modelled Brolga habitat within the project site is patchy with larger areas in the north-east of the project site
- Larger patches of modelled habitat occur to the north and east of the project site

Table 4 presents an analysis of VBA breeding records within the RoI. Of the 22 breeding records reviewed, 16 were considered suitable for inclusion, which included 11 wetlands (due to duplicate records at some wetlands) considered to provide Brolga breeding habitat in the future.

Six of the VBA breeding records within the RoI have been disregarded (Table 4).

Five of these were excluded based on the criteria set out by DEECA for Brolga breeding records more than 100 m from a wetland (Section 3.1.2). These five records did not have any wetlands within the 900 m accuracy of the point (stated in the VBA record) and have been disregarded.

One of the breeding records was excluded because the nearest wetland, Wetland 28238, is considered permanently drained. According to page 8 of the Interim Brolga Guidelines, "*a wetland remains a breeding site provided it has not been permanently drained*". Given these conditions, Wetland 28238 does not qualify as a Brolga breeding wetland. For the purpose of this assessment and as agreed in consultation with DEECA, a historical breeding wetland can be considered permanently drained if an excavated earthen channel has been constructed from the wetland invert to a connecting drain, downstream waterway or downstream wetland.

More than one line of evidence would be used as the evidence requirement and include:

1. Topographical imagery which demonstrates the drainage channel and connecting downstream wetland or waterway.
2. Historical satellite imagery of the wetland in the central month of the Brolga breeding season (Aug/Sep/Oct) over multiple years within a 10-year period evidencing the wetland area as drained and not capable of functioning as a wetland suitable for Brolga breeding.
3. Using a high-resolution Digital Elevation Model (DEM) in combination with water balance or hydrological modelling as the most precise and scientifically defensible method to assess whether a site can (or cannot) function as a wetland suitable for Brolga breeding.

Wetland 28238 has not filled since Brolga monitoring commenced by Nature Advisory in 2018. A hydrologic assessment of this wetland, including a topographic review, shows it contains multiple drains that divert water into the nearby Limestone Creek, preventing water from accumulating. Additionally, an analysis of aerial and satellite imagery over the past 16 years including important Brolga breeding months of August, September, October and November confirms that the wetland has not been inundated during these periods (Appendix 5). In particular, satellite and aerial imagery (Sentinel-2) was reviewed between 2016 and 2024 for the months August, September, October and November and found that the largest amount of water was on 12th October 2022 as the wettest period for this wetland over 10 years. In October 2022 only Limestone Creek itself was inundated with no water in the wetland itself.

A high-resolution digital elevation model was developed for the project site to better understand wetland areas that could be suitable Brolga habitat. Modelling at this wetland area identified an excavated earthen channel had been constructed from the wetland invert to a connecting drain. As such the wetland was not suitable for 120-day inundation modelling (Water Technology 2025, Appendix 4). These multiple lines of evidence demonstrate that Wetland 28238 is classified as permanently drained. Consequently, the associated VBA record has been excluded, and the wetland is deemed highly unlikely to provide breeding habitat in the future.

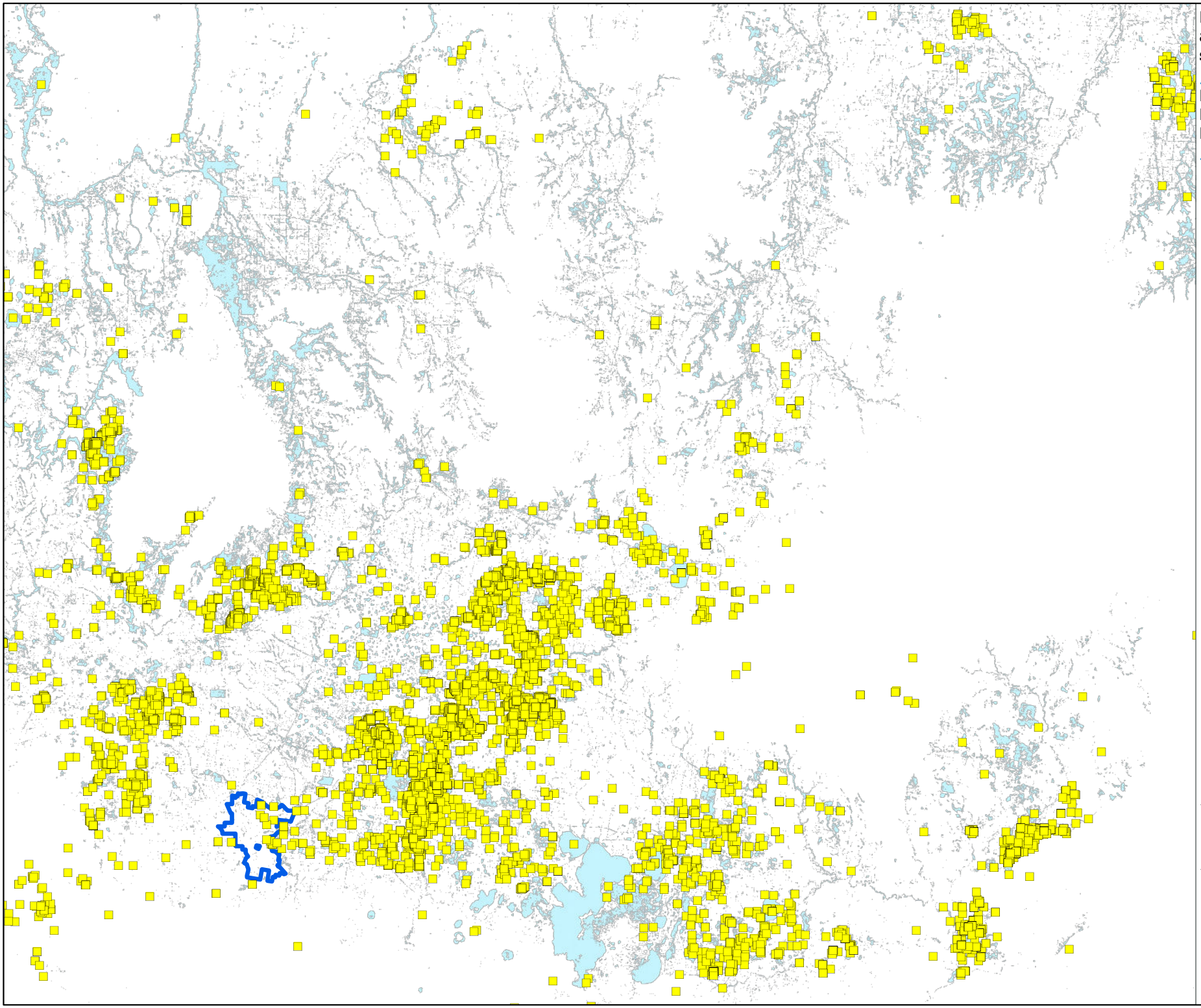

Figure 2: Brolga VBA records and modelled habitat southwest Victoria

Project No: 18088_26
Project: Hexham Wind Farm
Date: 12/06/2025

Wind farm boundary

Brolga VBA records (up to date of 20/11/2024, <=1000m accuracy)

NVR2017 Habitat Importance Modelling (DELWP modelled Brolga habitat)

N

Kilometres

0 10 20 30 40

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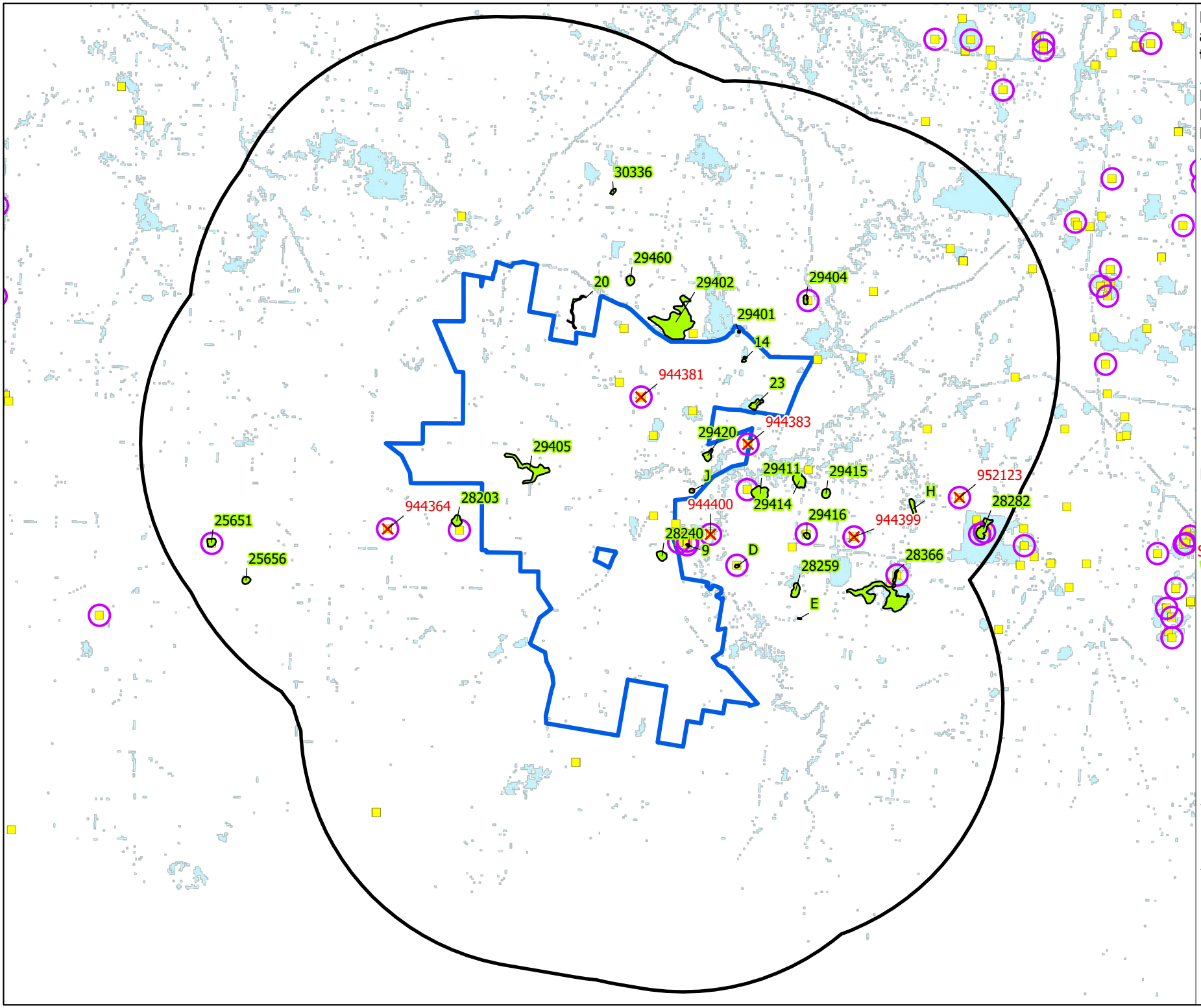

Figure 3: Brolga VBA records and modelled habitat with in the ROI

Project No: 18088_26
Project: Hexham Wind Farm
Date: 13/06/2025

Wind farm boundary

Radius of Investigation (10km)

Disregarded VBA Brolga breeding record

Brolga breading

Brolga VBA records (up to date of 20/11/2024, <=1000m accuracy)

NVR2017 Habitat Importance Modelling (DELWP modelled Brolga habitat)

Brolga breeding habitat

Confirmed Brolga breeding wetland

Survey observation number: 95123
Wetland number: 28282

N

Kilometres

0 2 4 6 8

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Table 4: Analysis of Brolga breeding records from the VBA within the RoI (10km)

VBA Survey Ob. No.	Start date	End date	Location description	Wetland No.	Comments	Accuracy (m)	Suitable for inclusion
944400	1/01/1984	31/12/1984	Mortlake		Location not situated at a wetland and there is no wetland within 900 m (record accuracy).	900	No
944364	1/01/1984	31/12/1984	Minjah		Location not situated at a wetland and there is no wetland within 900 m.	900	No
944381	1/01/1984	31/12/1984	Caramut	28238	Location not situated at a wetland. There is one wetland (28238) within 900 m. This wetland is deemed permanently drained and is not considered a Brolga breeding habitat (see Section 3.2.2 for the definition of permanently drained wetlands)	900	No
944382	1/01/1984	31/12/1984	South Caramut	28203	Location not at a wetland. It is situated next to Wetland 28203 and within 900 m.	900	Yes
944383	1/01/1984	31/12/1984	Hexham		Location not situated at a wetland and there are no wetlands within 900 m.	900	No
944385	1/01/1984	31/12/1984	Hexham	29411	Point located next to Wetland 28252.	900	Yes
944399	1/01/1984	31/12/1984	Mortlake		Location not situated at a wetland and there are no wetlands within 900 m.	900	No
856455	1/01/1987		Not provided	29404	Point located next to Wetland 29047.	100	Yes
854277	2/12/1991		Not provided	25651	Point located at Wetland 25651.	100	Yes
952123	1/01/2002	31/12/2002	Darlington/Dundonnell - BAP map-derived sites		Location not situated at a wetland and there are no wetlands considered to be suitable Brolga breeding habitat within 900 m.	900	No
954316	22/08/2007		Mortlake Common	28282	Located at Wetland 28282 (Mortlake Common), a confirmed Brolga breeding wetland.	900	Yes
954318	22/08/2007		Hexham district	9	Located next to Wetland 3, a confirmed Brolga breeding wetland.	900	Yes
952147	11/09/2007		Darlington/Dundonnell - map derived sites - BL & A; Ecology Partners	29416	Located at Wetland 28264, a confirmed Brolga breeding wetland.	900	Yes

VBA Survey Ob. No.	Start date	End date	Location description	Wetland No.	Comments	Accuracy (m)	Suitable for inclusion
952148	11/09/2007		Darlington/Dundonnell - map derived sites - BL & A; Ecology Partners	9	Located next to Wetland 3, a confirmed Brolga breeding wetland.	900	Yes
954358	1/10/2007		Thulborn Rd	28282	Located at Wetland 28282 (Mortlake Common), a confirmed Brolga breeding wetland.	900	Yes
954361	1/10/2007		Hexham - Ballangeich Rd	9	Located next to Wetland 3, a confirmed Brolga breeding wetland.	900	Yes
954333	18/09/2008		Mortlake	28366	Located at Wetland 28366, a confirmed Brolga breeding wetland.	900	Yes
954334	18/09/2008		Mortlake	D	Located at Wetland 4.	900	Yes
2340239	15/09/2020		10km SW of Hexham	9	Nature Advisory breeding record - confirmed breeding wetland at Wetland 3.	200	Yes
2340242	15/09/2020		3.8km SW of Hexham	23	Nature Advisory breeding record - confirmed breeding wetland at Wetland 28249.	200	Yes
2340240	15/10/2020		10.5km SW of Hexham	28240	Nature Advisory breeding record - confirmed breeding wetland at Wetland 28240.	200	Yes
2340243	15/11/2020		3.8km SW of Hexham	23	Nature Advisory - breeding record, confirmed breeding wetland at Wetland 28249.	200	Yes

Notes: Rows highlighted grey are Brolga breeding records at wetlands considered to provide future breeding opportunities.

3.2.3. *Initial Brolga surveys 2012-2013*

No Brolga flocking activity was observed or reported by any landholders during the initial survey period.

The results of the initial surveys are summarised below (EHP, 2013):

- Nine Brolga breeding wetlands were monitored within the broader search area:
  - Six breeding wetlands were located around the Darlington area to the east of the project site
  - Three breeding wetlands were located to the east of the proposed wind farm
- No Brolga breeding was observed within the RoI.

During the aerial survey on 8th October 2010 one breeding wetland was confirmed in the RoI at Wetland 28282 - Mortlake Common (EHP, 2014).

During the initial community consultation period, eight breeding wetlands were identified (EHP, 2014). Of these seven were considered to provide breeding habitat and likely to continue to be used in the future (Table 5, Figure 6).

One of the records, referenced as RW3 from EHP (2014), was initially identified as a breeding site based on information from a local landholder. However, after multiple consultations with him since 2014, he has not confirmed this area as a Brolga breeding site (Table 5).

Table 5: Breeding wetlands identified during initial community consultations.

EHP reference	Wetland no.	Redefined wetland no.	Comments	Suitable for inclusion
RW1	28252	29411	Wetland present.	Yes
RW2	28261	29414	Wetland present.	Yes
RW3	A	N/A	This area was included in previous reporting (EHP 2014) as a breeding area identified by a local landholder. More recent discussions with the local landholder clarified that the area was not flagged as a Brolga breeding site. The area is low-lying and has drains running through it. No wetland is present and it does not hold water. It is no longer considered a Brolga breeding site.	No
RW4	D	N/A	Wetland present.	Yes
RW5	28259	N/A	Wetland present.	Yes
RW6	28366	N/A	Wetland present.	Yes
RW7	E	N/A	Wetland present.	Yes
RW9	28267	29415	Wetland present.	Yes

3.3. Conclusions

Based on the level one assessment it was concluded that the project would meet at least the first and third trigger for a level two assessment as outlined in the Interim Brolga Guidelines. There were records of breeding habitats within the RoI (trigger one). The project site is in an area that may be used by Brolga for diurnal movements between foraging and roosting sites (trigger three). As such the Brolga assessment progressed to level two investigations, described in the next section of this report.

4. Level two assessment

The level two assessment collects comprehensive data about the location, nature and extent of Brolga habitats, and patterns of habitat use and behaviour at breeding, flocking and foraging sites within the RoI. Extensive investigations to meet the level two criteria were completed for the project between 2018 and 2020, and from 2022 to 2024.

4.1. Methods

The following methods were used in this assessment:

- Detailed consultation with landholders in the RoI
- A comprehensive aerial survey of the 10-km RoI for breeding Brolga
- Ground-based roaming observational surveys
- Review of previous data collected on Brolga flights and movements
- Hydrological assessments to show wetlands most suitable for Brolga habitat (breeding, foraging, and roosting)

These methods and relevant survey dates are summarised below.

4.1.1. Detailed community consultation

The results of detailed landholder consultations, when combined with historical data, enable a comprehensive and long-term understanding of Brolga activity in the RoI to supplement and provide context for the field investigations. The community questionnaire in Appendix 1 was used to gather information from landholders.

Landholders within the RoI were interviewed to identify additional flocking and breeding wetlands that may not be recorded in the available public databases. All landowners, including absent landowners within 10 km of the proposed wind farm boundary were contacted by newsletter and invited to participate. Where information was available, landowners within the RoI were also emailed or contacted by phone call encouraging participation. Not all the phone numbers were available, so not all landholders were contacted.

Extensive interviews were undertaken with landholders in 2018 at the Caramut Hall on 12th and 13th August and Ellerslie Community Hall on 15th and 16th August. During the sessions, each participant was interviewed for up to 30 minutes. Additional consultations were held by telephone and in person during the study period with landowners in the RoI. Where possible, landholders were also sent surveys via email when other methods of contact failed.

Table 6 presents the area of the RoI held by local landholders who participated in the consultations. Figure 4 shows the properties that participated in the community consultation process.

The landholders in the RoI were asked about their current and past farming history to provide an accurate picture of land use/type within the local landscape. In addition to the presence and location of Brolga activity on their property, landholders were queried about broader historical and current land uses, and other biodiversity values of their properties and surrounding land.

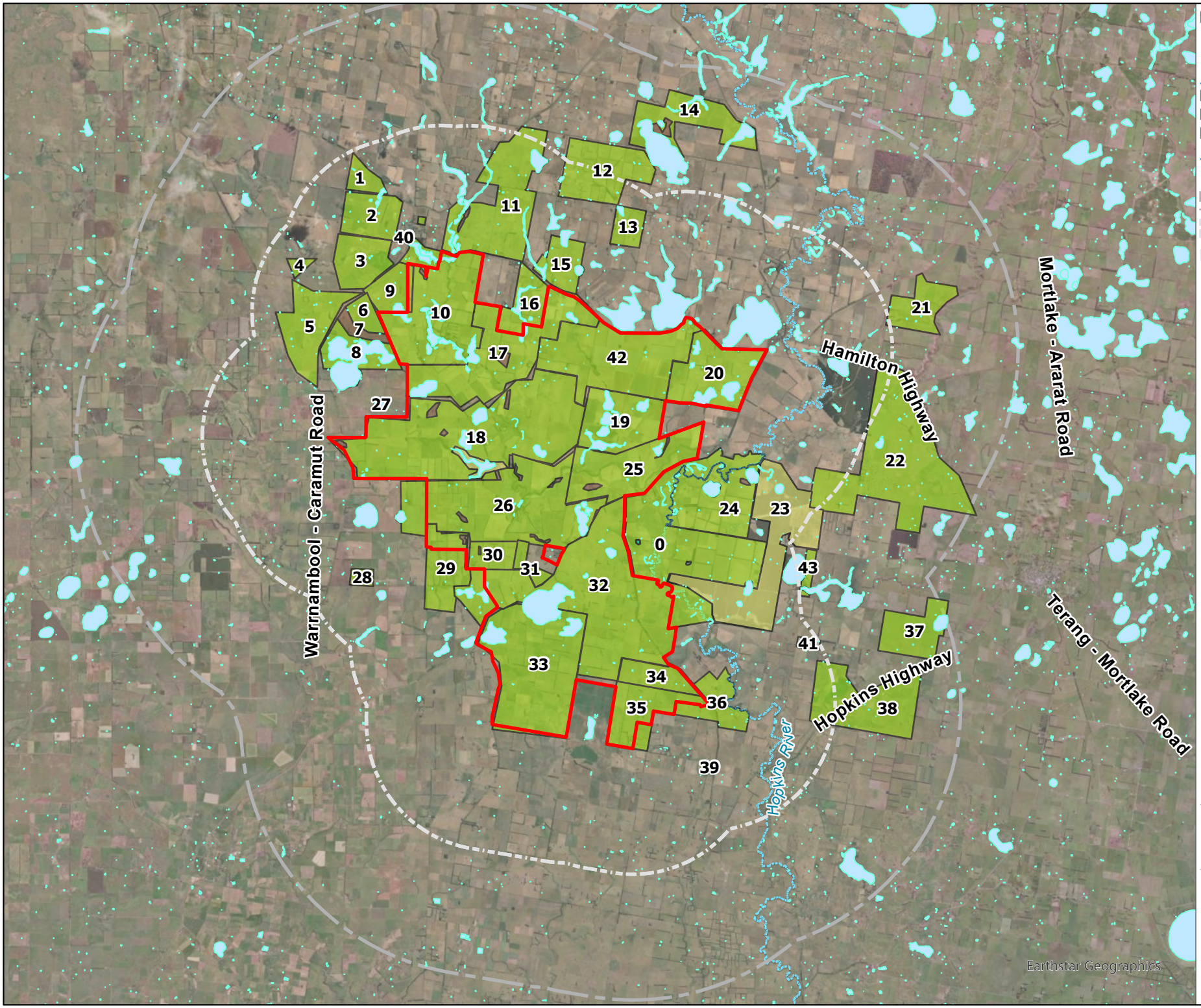

Figure 4: Landholder survey

Project No: 18088_26
Project: Hexham Wind Farm
Date: 13/06/2025

Wind farm boundary
Wind farm 10km buffer
Wind farm 5km buffer

LandType

Aquatic
Arable
Mixed
Other
Stony

N

Kilometres
0 1 2 3 4 5

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The quality of landholder survey data is likely to vary due to landholder interest and length of residency; however, the data obtained has added information to the overall picture of Brolga activity. Importantly, landholder surveys provided additional evidence on Brolga activity from a much longer period than the period of the current project-specific field investigations, or information on activity that may be missing from available databases.

Table 6: Percentage by area of wind farm and RoI surveyed by landholder interviews

Area	Area of land surveyed (ha)	Total area of land (ha)	% of area surveyed
Within the wind farm boundary	15,905	16,104	98.7%
Within 5 km of the wind farm boundary	26,076	58,862	44.3%
Within 10 km of the wind farm boundary	30,580	11,2974	27%

4.1.2. Breeding-season aerial survey

Nature Advisory completed an aerial survey to search for Brolga during fine weather conditions on 2, 3, and 14 October 2019. This is typically an optimal time to identify Brolga breeding. In the 2019 season, rainfall was average therefore observations were considered representative of an average Brolga breeding-season.

The aerial survey covered the complete RoI to 10 km from the wind farm. The aerial survey was designed to detect Brolga and to identify breeding wetlands within the proposed project site and in the RoI. In preparation of the survey, north-south flight lines were defined throughout the study area at 500 m (east-west) intervals.

The survey was undertaken in a fixed-wing, four-seat Cessna 182 RG flying between 90 and 120 m above ground, at a speed ranging between 209 and 240 km/hr. Variations were made in height and speed dependant on flight safety and regulatory requirements near powerlines and towns.

The survey team comprised the pilot, a navigator and two observers. The two observers (Curtis Doughty and Brett Lane) are experienced aerial wildlife surveyors. Transect details were provided to the observers by the navigator (Eamon O'Meara or Jackson Clerke). One observer was located on each side of the plane. Observers scanned an area of approximately 250 m on either side of each transect, using binoculars when necessary. When Brolga were observed, their location was recorded on an aerial photograph and transect information was noted. This included the transect number, the direction and distance of the birds from the observer and a general description of the habitat and the wetland number (Victorian Wetland Inventory number) on which the Brolga was sighted. Evidence of breeding, such as birds standing next to or incubating on nests was also recorded.

Limitations of aerial surveys

Aerial surveys can miss individuals of targeted species. Flight speed means that some nests and birds may be missed; the distance at which aerial observers operate may miss birds hidden in vegetation. Notwithstanding this, at 250 m most Brolga are visible in wetlands. Furthermore, the observers involved in the survey are experienced at detecting birds during aerial surveys which contributes to survey accuracy.

The aerial survey added a few additional breeding wetlands not previously documented. The combination of the initial on-ground surveys, the aerial surveys (to overcome access limitations) and landholder interviews, combined with historical information on breeding wetlands in public databases, has generated

representative data on breeding locations and Brolga numbers on the project site and in the surrounding RoI. This combination of information sources is consistent with the requirements of the level two assessment in the Interim Brolga Guidelines.

4.1.3. Brolga surveys

Brolga flocking season assessment

To provide information on the likelihood of Brolga using any area in the search region as a flocking site a Brolga flocking survey was undertaken in the RoI by Nature Advisory observers over two- to four-day periods monthly from May to June 2018, January to June 2019 and January to June 2020. The surveys focused on areas that had records from databases of more than two Brolga within the wider area and at permanent wetlands that held water throughout the year.

The dates the Brolga flocking surveys were undertaken were:

2018:

- 1-4 May
- 29 May– 1 Jun

2019:

- 9-11 and 21-23 Jan
- 7-8 and 26-27 Feb
- 27-29 Mar
- 23-24 Apr
- 23-24 May
- 19-21 Jun

2020:

- 21-24 Jan
- 17-21 Feb
- 10-13 Mar
- 27 Apr – 1 May
- 19-22 May
- 15-18 Jun

Brolga breeding season assessment

Wetland quality was assessed for suitability for breeding Brolga. If a site had the potential to support breeding, based on the presence of water, surveys were conducted. From 2018 to 2023, two methods (ground-based surveys and aerial surveys) were used to detect the Brolga presence and their breeding status. Methods used for the ground-based surveys are outlined below.

Ground-based surveys

Between September 2018 and December 2024, Nature Advisory completed ground searches for breeding Brolga within the RoI. Brolga breeding activity and locations were recorded. Surveys were undertaken on the following dates:

2018:

- 25-27 Sep
- 24-29 Oct
- 14-16 Nov
- 17-20 Dec

2019:

- 23-26 Jul
- 5-8 Aug
- 2-5 Sep
- 14-17 Oct
- 11-14 Nov
- 9-13 Dec

2020:

- 27-28 Jul
- 29-31 Aug
- 27-29 Sep
- 27-29 Oct
- 16-17 Nov
- 14-15 Dec

2022:

- 21-22 Sep
- 24-26 and 28 Oct
- 22-24 Nov
- 28-30 Dec

2023:

- 17-19 Jul
- 15-17 Aug
- 13-15 Sep
- 16-18 Oct
- 21-22 Nov
- 11-13 Dec

2024:

- 29 Jul – 1 Aug
- 19-22 Aug
- 16-19 Sep
- 21-24 Oct
- 18-21 Nov
- 16-19 Dec

The 2020 surveys focussed on the wind farm site and the 5 km zone around it, hence the shorter duration of those surveys. If Brolga were recorded at a wetland, extended observations were made to determine if the Brolga had a nest or young.

Rainfall and runoff in autumn, winter and spring 2018 were below average and therefore most seasonal wetlands were dry by November 2018. For this reason, the survey period represents below-average conditions for breeding. Rainfall and runoff in autumn, winter and spring 2019 was average with most wetlands being inundated until December 2019. This was a wetter year than the previous with better breeding conditions for Brolga due to wetlands holding water for a longer period. Appendix 2 shows monthly rainfall totals compared with overall means recorded at a weather station near Mortlake (BOM 2021). The 2020 breeding season showed signs of an early start with pairs already observed in breeding wetlands in June. Nesting was confirmed in some wetlands however an above-average spring rainfall saw pairs losing their nests due to flooding, although some re-nesting occurred later in the season. The 2022 breeding season started late due to heavy rainfalls in early spring 2022 causing flooding of paddocks in low-lying areas, which prevented access to some areas of the RoI. Above-average rainfall in the first half of 2023 resulted in an initially high inundation of several of the wetlands and surrounding low-lying areas, but below-average rainfall in the second half of the year saw the water level across most wetlands fall significantly and caused some wetlands to dry out entirely. Below-average rainfall continued in 2024, and water levels remained low across the study area.

Further hydrological investigations were undertaken to make a definitive assessment of all wetlands on the project site for their suitability to provide Brolga habitat (Nature Advisory 2020, Water Technology 2024a). During this study, a LIDAR survey was undertaken across the project site to generate a digital elevation model (DEM - 10 cm vertical interval) and the past ten years of rainfall data was used to identify all areas in the project area that pooled water for an inundation period of at least once in ten years for a 120–day period. Wetlands meeting this criterium were considered suitable to provide Brolga habitat. The modelling and criteria have been developed in consultation with DEECA, over multiple years of engagement. Wetlands that were small (< 0.1 ha) and shallow (< 300 mm depth) or contained an excavated earthen channel connecting to a downstream drain, waterway or wetland, were excluded from the hydrological analysis as they would not be able to hold water for 120 days during the Brolga breeding season. This criterium was not used to rule out breeding wetlands with historical breeding records.

The survey area for the field inspection consisted of the project site and the surrounding 5 km of the RoI. All wetlands in this area not subject to private land access limitations were visited and surveyed. In addition, searches were undertaken between 5 and 10 km from the project site focussing on areas where breeding had been recorded in the past, e.g., Mortlake Common Reserve and nearby wetlands. All remaining wetlands that could not be visited in the field (mostly due to private land access limitations) were assessed using aerial photography and aerial survey to determine their suitability as Brolga breeding habitat.

Wetlands were visited multiple times throughout the survey period if they continued to hold water. Once they were dry, they were no longer surveyed for breeding Brolga during that season. If a wetland was initially classified as unsuitable for Brolga breeding due to the wetland having been permanently drained, it was not surveyed again for breeding activities.

4.1.4. Brolga habitat assessment

A wetland provides potential nesting/breeding, foraging and/or night-time roost habitat for Brolga, and encompasses 'breeding wetlands' (see Section 4.1.5).

The primary feature that influences the suitability of wetland habitat for Brolga breeding is hydrological function, such as depth and duration of inundation during the breeding season. Other factors such as

type and cover of vegetation, associated biological productivity, and total wetland size and basin shape (e.g., shoreline slope) were not considered for this study, although are generally recognised as contributing factors that influence the suitability of a wetland for Brolga breeding.

Methods to model potential Brolga habitat included assessment of mapped wetlands in the Victorian Wetland Inventory (VWI) and hydrological modelling.

Victorian Wetland Inventory (VWI)

Wetlands mapped in the VWI database were considered first for their potential suitability for Brolga habitat. The VWI database is administered by DEECA and shows the extent and types of wetlands in Victoria, incorporating local and regional wetland datasets. Wetlands in the VWI database are categorised based on the following:

- Wetland system type (lake, marsh/swamp, marine, estuarine)
- Salinity regime (e.g., fresh, saline)
- Water regime (permanent or periodically inundated)
- Water source (e.g., groundwater, river)
- Dominant vegetation
- Wetland origin (naturally occurring or human-made).

Hydrological wetland assessment

Two years of monitoring noted that many of the VWI wetlands were inaccurate in terms of size, shape, or presence of water. Hydrology investigations were commissioned to develop a surface water model to redefine accurately the location and extent of wetlands (Appendix 4, Water Technology 2024a). The wetlands included in the assessment are indicated on Figure 5.

This process included:

- A LiDAR survey was undertaken across the project site with a vertical accuracy of 10 cm; and
- The surface water hydrological model was developed to assess which wetlands can hold water at least once in ten years for a 120–day period, which is what the Brolga requires to breed successfully (see Section 2.4).

Shapefiles were provided to Nature Advisory with the results of the hydrology assessment. The assessment generated a list of wetlands and farm dams that were potentially suitable for Brolga breeding or night-time roosting, including 27 farm dams and 19 wetlands.

Farm dams – habitat assessment

Farm dams within 2 km of known breeding wetlands were identified and their habitat was assessed (Figure 5). The assessment collected the following information relating to Brolga habitat quality:

- Presence/absence of wetland-dependent flora (fringing, floating, emergent)
- Evidence of excavation
- Presence of drains
- Surface water cover
- Presence/absence of steep banks
- Presence/absence of shallow swampy end

- Land use (e.g. grazing)
- Presence/absence of trees close to the dam/wetland.

Dams that showed evidence of earthworks together with a lack of wetland-dependent flora, presence of heavy grazing and steep banks, were assessed as low-quality Brolga habitat and unlikely to support breeding or foraging. Those with shallow, swampy areas adjacent to the dam that may support wetland dependent flora and hold water for 120 days once every ten years (i.e. wet years) were considered to provide Brolga habitat. An overall assessment based on the detailed characteristics of the dams and their immediate surroundings was based on the criteria listed above.

The farm dams were photographed during the September 2024 survey, as a record of their current condition and a baseline reference in the event of future changes. Photograph 1 provides an example of a farm dam that is unlikely to support Brolga breeding or foraging. In contrast, Photograph 2 shows an example of a farm dam that is likely to provide suitable habitat for Brolga.

Photograph 1: Farm dam unlikely to provide Brolga habitat

Photograph 2: Farm dam likely to provide Brolga habitat

The limitation of this assessment was that 2024 was a drier-than-average year (Mortlake data; BOM, 2024) up to the time of the survey in November. Many wetlands visited were dry or had water levels much lower than usual for the time of year. To account for this, the assessment considered the presence or absence of wetland-dependent flora and the presence of low-lying swampy ground at each dam, which could become suitable for Brolga in a wet year when wetland vegetation may grow quickly in response to inundation.

4.1.5. Breeding wetlands

A Brolga breeding wetland has had confirmed Brolga breeding activity either during the current investigations or in the past. Past records were collated from wildlife databases (VBA and BirdLife Australia) or the community consultation.

The results of all field surveys of the project site were included in the Brolga breeding wetland assessment and all breeding activities observed at a wetland (nest building, incubation, etc.) were considered confirmed Brolga breeding attempts, whether they were successful (i.e. fledged young) or not and the wetland considered a Brolga breeding wetland.

Wetlands within 2 km of Brolga breeding wetlands were included in the Brolgas home range as habitat that supports breeding, also defined in Section 2.4.

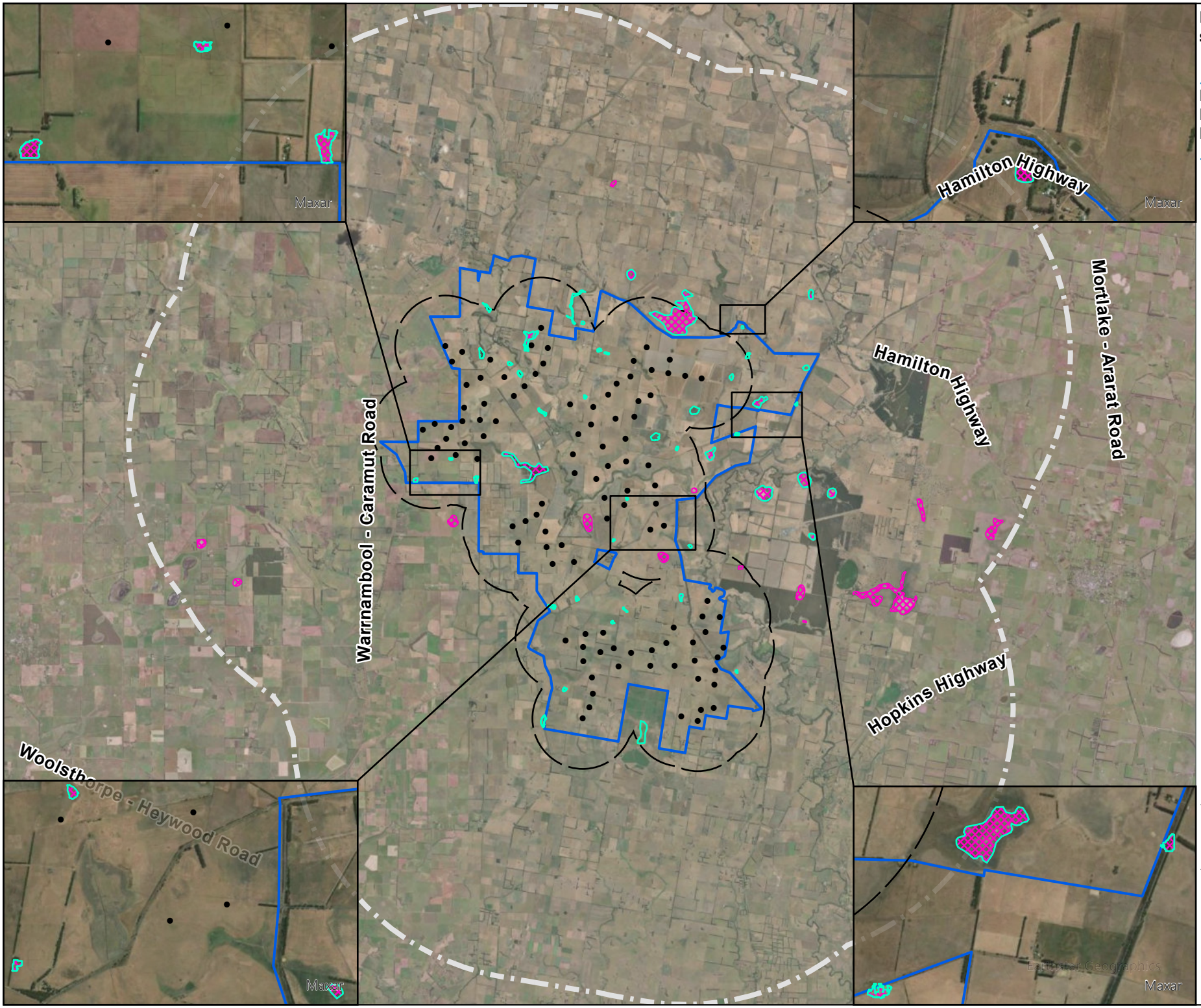

Figure 5: Habitat assessment survey effort

Project No: 18088_26
Project: Hexham Wind Farm
Date: 13/06/2025

- Wind farm boundary
- Turbines
- 2km buffer from turbines
- Radius of Investigation
- Hydrology assessment wetlands
- NA assessed wetlands

N

Kilometres
0 1 2 3 4 5

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Nature Advisory
PO Box 337, Camberwell, VIC 3124, Australia
www.natureadvisory.com.au
03 9815 2111 - info@natureadvisory.com.au

4.2. Results

4.2.1. Detailed community consultation

Thirty-three landholders/managers participated in the interviews, occasionally representing multiple properties or multiple family owners of properties. Brolga observations are summarised below:

- Twelve landholders reported not having seen a Brolga on their property.
- Nine landholders reported observing breeding events on wetlands, or being aware of a historical breeding wetland, on their property or their neighbour's property (total of six wetlands).
- Five landholders reported larger groups (three to five birds) but no flocking events on their property. One landholder recorded a one-off flocking event in which 10 to 15 birds were observed near a dam approximately a decade ago. An additional one-off flocking event was reported by a landholder directly to the north of the HWF where 10 Brolga were observed on their property in November 2020
- Twelve landholders reported general observations of Brolga occurring on their property but no breeding or flocking.

The results from these interviews and informal discussions with other landholders identified additional Brolga sightings within the RoI. Most landholders commented that when recorded, Brolga foraged in their paddocks over several days and then dispersed elsewhere.

The dominant land use within the RoI is grazing by sheep and cattle with some mixed cropping.

4.2.2. Breeding-season aerial survey

The three-day aerial survey in 2019 identified five Brolga pairs and three nests. A zoologist later ground-truthed the pairs and nests.

In addition, the aerial survey undertook a wetland assessment that included the following:

- Identification of VWI wetlands
- Assessment of whether the wetlands were drained or otherwise unsuitable (e.g., planted with trees)
- Identification of additional wetlands that were not included in the VWI wetlands.

This information was included in the wetland assessment outlined in the following sub-sections.

4.2.3. Brolga surveys

Brolga flocking survey results

No traditional Brolga flocking sites were identified through the desktop study, community consultations or the 2018-20 field assessments. Two one-off flocking events have been reported by landholders.

- The first was reported on a property in the north of the project site where 10 to 15 Brolga were observed at a farm dam south of the Hamilton Hwy circa 2011 (F13 on Figure 1).
- The second was reported on a property located north of the project site where 10 Brolga were observed north of the Hamilton Hwy in November 2020 (F15 on Figure 1).

During the non-breeding season, a small number of Brolga pairs remained at or near their breeding wetlands outside the wind farm boundary, and in one case two neighbouring pairs (four birds) were seen foraging together in the overlapping area of their territory to the north of the proposed wind farm at wetland 28966.

Brolga flocking field surveys were undertaken between May 2018 to June 2020. No evidence of Brolga flocking was observed over this period, therefore, there is no evidence to suggest that the project site or surrounds is used as a traditional flocking area. The closest documented traditional flocking site is 20 km north-east from the proposed wind farm near Penshurst.

Brolga breeding survey results

Extensive site-specific field investigations have been undertaken during breeding seasons in 2018, 2019, 2020, 2022, 2023 and 2024 to document the extent of Brolga activity and spatial patterns of activity in the RoI. The roaming field survey periods occurred during various weather conditions, including high and low rainfall seasons. As part of the breeding surveys, landowners and neighbours were consulted on Brolga activity. Table 7 summarises the survey results (see also Figure 6).

Table 7: Summary of Brolga roaming surveys during breeding seasons

Year	Brolga breeding observation	Other Brolga observations (non-breeding)
2018	A local landholder reported a pair breeding at wetland H. A local landholder reported a pair breeding at wetland 30336.	A pair observed in May and June at wetland 30369. This is a non-breeding season foraging and roosting site. A pair observed in September and October at wetland 29420 (VWI 28245). Breeding unconfirmed though likely attempted. A pair observed in October and December foraging in open paddocks at the northern end of wetland 29405. A pair observed in November foraging at drained wetland 29402 (VWI 28966). A pair observed in November foraging along the Mustons Creek.
2019	Nesting attempt in July at wetland 28366. The pair failed to raise any chicks though stayed in the area until November. Nesting attempt in August at wetland 29420 (VWI 28245). Breeding attempt failed; no chicks raised. Observed nesting in August at wetland 28282. Successfully reared one chick. Brolga confirmed nesting at wetland 25656 during aerial survey in October. Nesting attempt in October at wetland 29460 (VWI 28916). The pair was present in November though no chicks were confirmed. Sight was limited by tall grass. Nesting attempt observed during November at wetland 30336. The landholder reported Brolga raising a chick at wetland 20 (VWI 30330). A local landholder reported a pair breeding at wetland H.	A pair observed in January foraging in paddocks near wetland 29405. A pair observed in March and June at wetland 30369. This is a non-breeding season foraging and roosting site. Three individuals seen in the vicinity of the Mortlake sale yards in July. Flew from the east side of Hamilton in a westerly direction. A single Brolga observed at wetland 18 (VWI 28236). A pair observed in October foraging at wetland 23 (VWI 28249). No breeding activities observed. A pair was observed during aerial surveys in October at wetland 28269. No breeding activity observed. Likely to be the pair that nest to the east at wetland 28366. A pair observed in July and August foraging at a drained wetland number 28890. No breeding here, likely to be the pair that nest at wetland 30336. A pair reported by local landholder in November foraging at wetland 29402 (VWI 28966). Likely

Year	Brolga breeding observation	Other Brolga observations (non-breeding)
		the pair the nested at wetland 29460 (VWI 28916).
2020	Nesting observed in September at wetland 9. No chicks raised. Nesting observed in September at wetland 23 (VWI 28249). Nesting observed in September at wetland 29420 (VWI 28245). Heavy rains flooded the nest. The pair nested again in November. Unknown if the pair raised any chicks. Nesting attempt in October at wetland 28240. No chicks raised. A pair observed nesting in October at wetland 29460 (VWI 28916).	Two pairs observed during the non-breeding season in January and one pair in February, March, May and June foraging at wetland 29402 (VWI 28966). A pair with their fledgling observed in February foraging at wetland 28278. A pair observed foraging in May in the overflow swampy area of wetland 29405. During the breeding season a pair observed foraging in November at wetland 29402 (VWI 28966). No breeding activity observed. A local landholder reported 10 individuals foraging in November at an adjoining property to the north of the wind farm.
2022	Brolga observed breeding at northern end of wetland 28282 in September and October, approximately 10km east of the HWF site. Nesting observed at wetland 9 in November. Two adult Brolga observed at wetland 28240 in December, appeared to be nesting. A pair of Brolga was observed at wetland 14 throughout December. No young were observed due to long vegetation in wetland though breeding behaviour was observed including adult sitting on ground during stormy conditions indicating it was brooding young.	Two adults were observed walking/ foraging at wetland 29402 in October and by landowner in December. A Brolga was heard trumpeting behind Blue Gums west of wetland 29416, but not seen.
2023	Brolga pairs were confirmed to be attempting breeding at wetlands 9, 14, 23, 28259, 29402 and 29420. Nest incubation was observed at wetland 9 in August, but no adult Brolga or chicks were observed in September, hence it was likely a failed attempt. Nest incubation was observed at wetland 14 in September, and adults feeding chicks in October. Breeding was recorded at wetland 23 in July and August. Nesting was observed in July. Adults and two chicks were observed in August. Nesting of a pair was observed at wetland 28259 in August. In September, a single adult was observed once. A landowner reported seeing a pair of Brolga with a chick at wetland 29402 in November. Courtship behaviour was observed at wetland 29420 in October.	Non-breeding records occurred at wetlands 29411, 29416, and nearby wetland 29460. An individual was seen at wetland 29411 in November. Additionally, the landowner observed a pair foraging in a paddock to the southeast of this wetland in August. A pair were seen foraging in wetland 29416 in August. An individual was observed foraging in a paddock <500 m from wetland 29460 on two separate days in August. It is possible that a breeding attempt was made at this wetland but could not be confirmed due to lack of landowner permission.

Year	Brolga breeding observation	Other Brolga observations (non-breeding)
2024	A pair was observed nest building at wetland 28259. A pair with a juvenile were seen in a paddock adjacent to wetland 30336 in September.	A pair were observed at wetland 28966 with a juvenile individual in July. A juvenile was observed at wetland 28966 in October, no adults were seen. A pair and juvenile were observed in a cow paddock 100m from wetland 30336 in September. A pair were seen at wetland 28259 in August, September and October, but not in November and December. A pair were seen at wetland 9 in August, September and October. A landholder reported seeing a pair at various locations on their property east of the Hopkins River in July and August. A landholder reported seeing a pair in a paddock 1km north of wetland 9. A landholder reported hearing Brolga in wetland 28966 in early August and December. A landholder reported seeing Brolga at wetland 28259 in early August. A landholder reported seeing Brolga at wetland 30330 in October. Two Brolga were observed standing in wetland 28236 in November.

Based on the results of the breeding season surveys, it is estimated that the RoI supports up to eight breeding pairs of Brolgas, the most simultaneously observed breeding pairs at different sites during surveys.

4.2.4. Brolga behaviour and movements

Veltheim *et al*. (2019) used satellite-tracker generated point data to determine movement patterns of Brolga pairs with pre-fledging chicks based on locations of chicks (assumed to be accompanied by adult birds). The satellite recordings were made every six hours from midnight. This study showed that 95% of Brolga observations were within 1,369 m from night roosts[1] to daytime foraging areas and that their home range varied from 70 to 523 ha. A spatial model was then used to determine the likely 'utilisation distribution' of a Brolga family.

The 95% utilisation distribution was found to be within 2 km of the night roost/breeding wetland. This is the zone predicted by statistical modelling within which 95% of Brolga movements would occur. For previous projects DEECA have indicated a preference to use this 95% utilisation distribution distance as a basis for determining which wetlands to encompass within a Brolga breeding wetland home range.

[1] A night roost was the wetland in which adults and chicks spent the night. This was not always the same wetland in which the nest had been constructed if that was no longer suitable and an alternative was used.

It is noteworthy that the average distance Brolgas moved from breeding wetlands found by Veltheim *et al*. (2019) was 442 m, with 50% of observations being less than 315 m.

4.2.5. Brolga habitat assessments

Wetland assessment

The interim Brolga guidelines require a field inspection in step 2 of the level 1 assessment to field-verify the nature and extent of known and potential Brolga habitats. Hence, all potential breeding sites have been investigated for their suitability regarding habitat criteria. Nature Advisory assessed 206 wetlands in the RoI (100% of total VWI). The results of the habitat assessment within 5 km of the project site are presented in Appendix 3. A map showing the shape and locations of the VWI is presented in Figure 6.

A summary of the results from the wetland assessment is presented in Table 8. Sixty-two per cent of the assessed wetlands were deemed unsuitable as Brolga habitat as they were inaccurately mapped or permanently drained, with no confirmed breeding records. Drained wetlands included those that had been dry for many years as they had been drained and converted for agricultural use. Seventy-nine wetlands (38%) were identified as suitable Brolga habitat, which also included partially or permanently drained wetlands with confirmed breeding records. Hydrological assessment of wetlands within the project site enabled a more refined wetland assessment to inform the development of turbine-free buffers to avoid and mitigate impacts on Brolga.

Table 8: Summary of wetland assessment

Wetland assessment	No. of wetlands	% of wetlands
Drained or inaccurately mapped	127	62
Brolga habitat	79	38
Total	**206**	**100**

Many wetlands in the RoI were dry during the survey, or had been dry for many years, as they had been drained and converted to agricultural use. These sites no longer held water and were considered drained and unsuitable as Brolga habitat. Brolga were observed once foraging at a drained wetland next to a breeding wetland. No other drained wetlands were observed to be used by Brolga. This criterium was not used to rule out breeding wetlands with existing breeding records.

Hydrological wetland assessment

The undulating landscape of the project site and its surrounds created challenges in reconciling the landscape with the VWI. As the study progressed it became apparent that the VWI layer was inaccurate and did not represent the wetlands that were observed in the field and from aerial imagery. Water Technology (hydrological specialists) were engaged to develop a surface water model to redefine the wetland boundaries more accurately within the project area and areas close to the boundary (Figure 6).

Wetlands were redefined using a digital elevation model from a LIDAR survey, an inundation model for the area based on the 1:100 ARI (72-hour) rainfall event, rainfall data for a ten-year period (from 2009 to 2019) to identify wetland filling and inundation duration to locate wetlands that remain inundated for at least 120 days (Water Technology, 2024a) as per the parameters above. The Water Technology (2024a) report is presented in Appendix 4.

While water depth is also a critical factor that influences the suitability of wetlands for Brolga breeding, this factor was excluded from the hydrological modelling in response to feedback from DEECA making the hydrological modelling a conservative model of wetlands suitable for Brolga breeding (i.e., more likely to overestimate than underestimate suitability). It should be noted that no wetlands with existing Brolga

breeding records have been excluded if they did not meet the 120-day inundation criteria (see Section 4.2.6).

The more accurately defined wetland boundaries meant the movement of Brolga could be more accurately predicted. This helped to develop turbine-free buffer zones around wetlands that the Brolga was likely to use while traversing across the landscape to other foraging areas from the breeding wetland. Figure 6 presents the wetland layer used for this assessment and identifies whether wetlands were Brolga habitat (i.e., meets the 120-day inundation criteria; Water Technology, 2024a).

The hydrology assessments found that within, or close to, the project boundary there were 21 wetlands that met the hydrological criteria (Water Technology, 2024a, Appendix 4). Nature Advisory (2020) further assessed these wetlands focussing on the size of the wetlands and the presence of emergent vegetation that is crucial for nest building and foraging (Herring, 2001; Myers, 2001), as well as cover for chicks from predators. However, after further consultation with DEECA and as a conservative measure, wetland size and presence of emergent vegetation was not considered in the assessment suitable Brolga habitat.

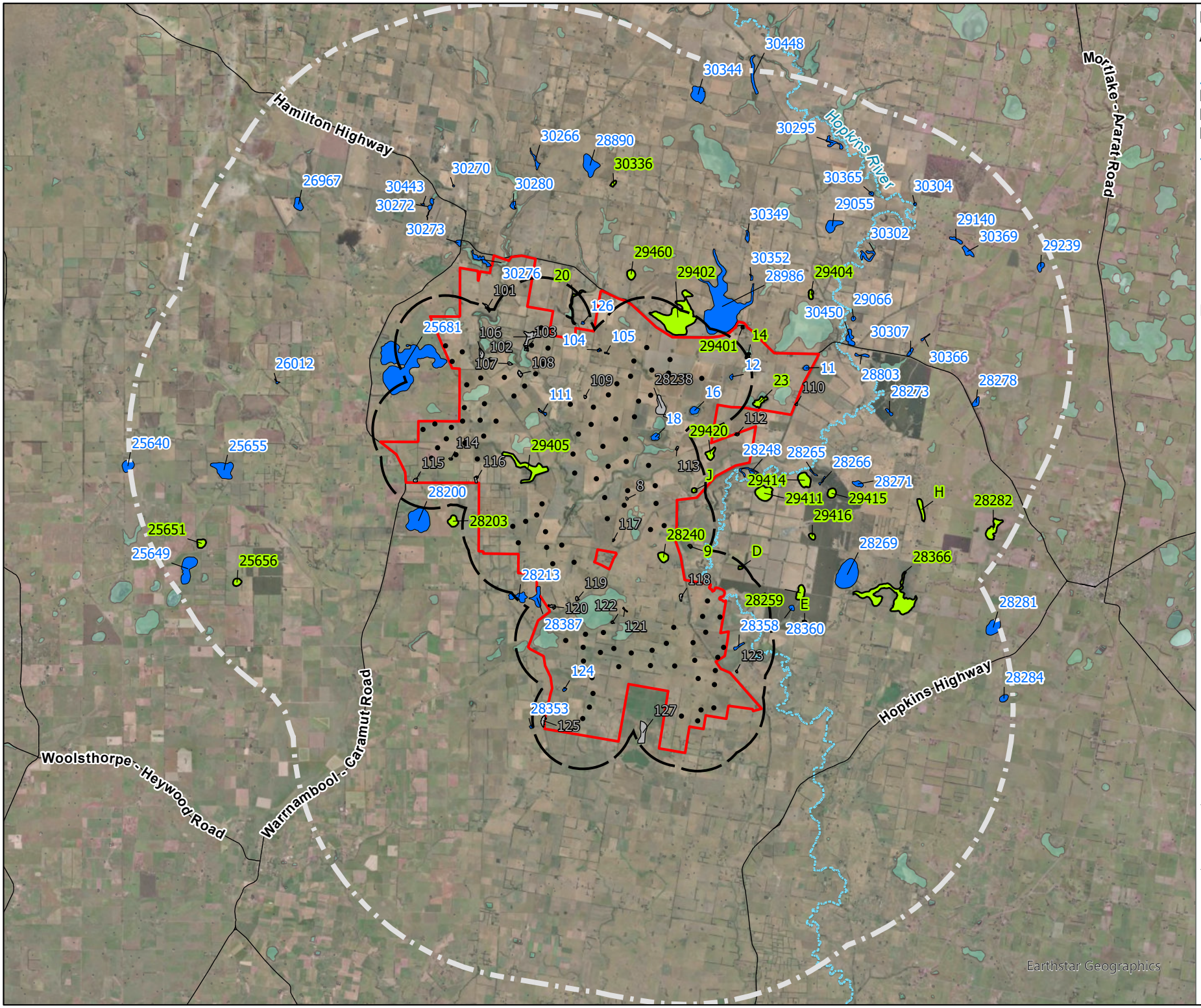

Figure 6: Brolga Wetland Assessment

Project No: 18088_26
Project: Hexham Wind Farm
Date: 28/08/2025

- Wind farm boundary
- Turbine
- 2km buffer from turbines
- Radius of Investigation
- DEECA wetland

Brolga breeding habitat

- Confirmed Brolga breeding wetland
- Brolga habitat
- Unsuitable

N

Kilometres
0 1 2 3 4 5

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Nature Advisory
PO Box 337, Camberwell, VIC 3124, Australia
www.natureadvisory.com.au
03 9815 2111 - info@natureadvisory.com.au

Farm dams –habitat assessment

The Brolga habitat assessment of farm dams and similar waterbodies was carried out from 23 to 24 September 2024 (Figure 7). None of the 11 dams assessed were considered Brolga habitat at the time of the assessment (Table 9). Ten sites completely lacked Brolga habitat features, such as vegetation and shallow areas for nesting or foraging. One site (dam 126) was considered potentially suitable habitat in wet years when inundation and vegetation increased. A vegetated bank in the centre of the wetland may present suitable habitat for Brolga. All these sites were within 2 km of known Brolga breeding wetlands. All sites were photographed.

Table 9 presents the results of the farm dam habitat assessment. Note that, although most of these areas are not formally identified as potential Brolga breeding habitat, Brolgas can be observed in any location and may be considered Brolga habitat in general terms if sightings have occurred (e.g., Dam 112 in Table 9; see also Appendix 3). Brolgas are known to be highly flexible, foraging across a variety of landscape features, including paddocks, cultivated areas, and multiple wetland types, even when these areas are not used for nesting (Archibald et al., 2020; Scambler et al., 2023).

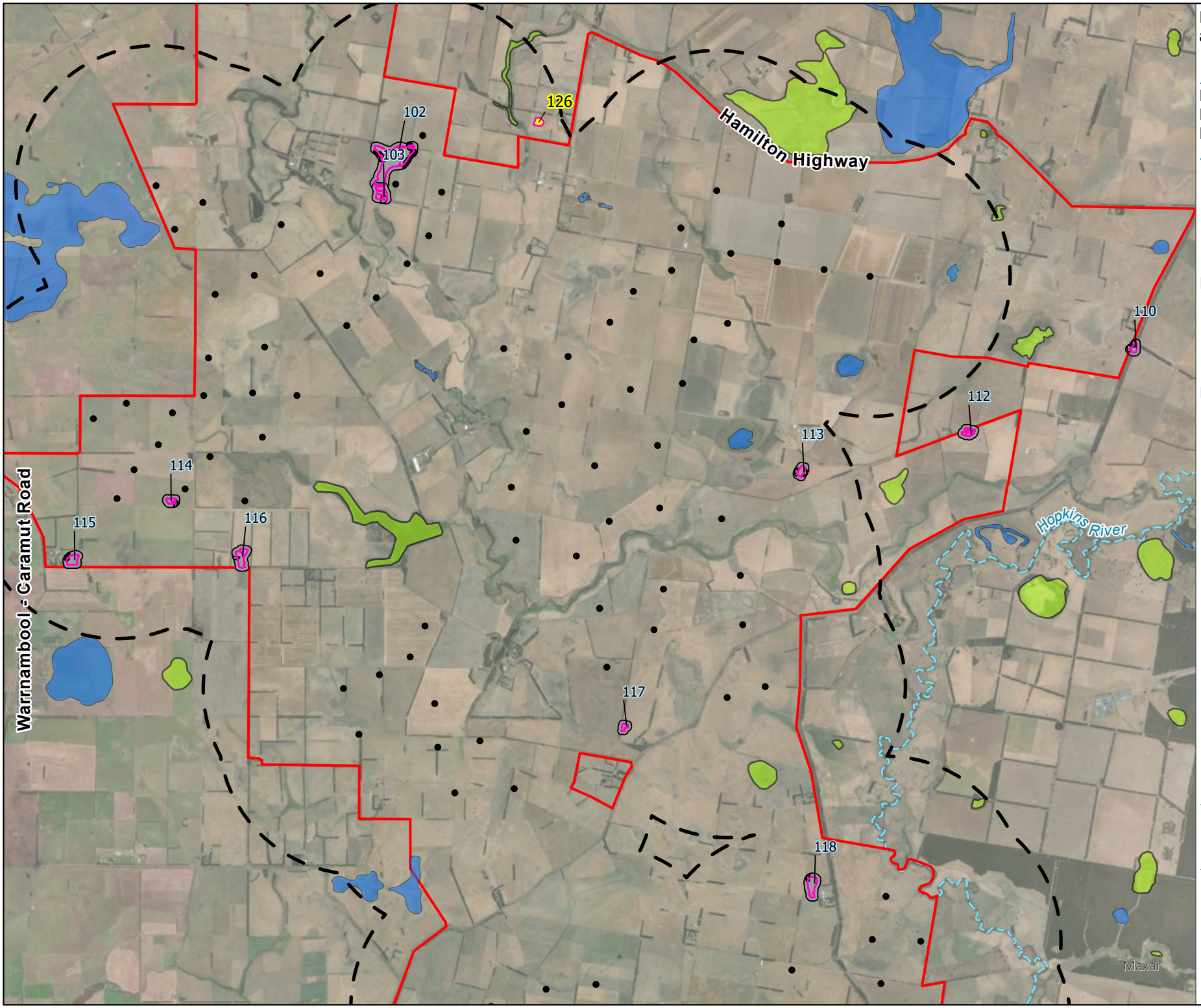


Figure 7: Farm dam assessment

Project No: 18088_26
Project: Hexham Wind Farm
Date: 26/06/2025

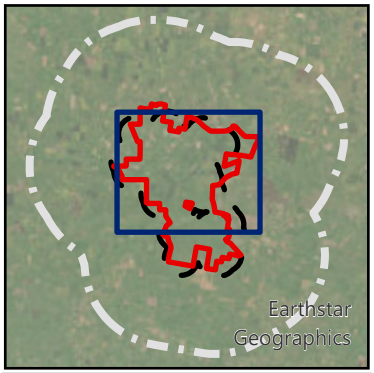
- Wind farm boundary
- Turbine
- 2km buffer from turbine
- Radius of Investigation

Farm dam assessment

- Potential Brolga habitat
- Unsuitable
- Wetlands assessed

Brolga breeding habitat

- Confirmed Brolga breeding wetland
- Brolga habitat



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Kilometres

0 0.5 1 1.5 2 2.5

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Nature Advisory
PO Box 337, Camberwell, VIC 3124, Australia
www.natureadvisory.com.au
03 9815 2111 - info@natureadvisory.com.au

Table 9: Summary of farm dam habitat assessment, September 2024

Dam no.	Aquatic vegetation (type and extent)	Evidence of excavation	Steep banks	Shallow end with suitable habitat	Drains	Surface water cover (%)	Land use	Overall habitat description	Brolga habitat
102	No - two willows on island only.	Yes	Yes	Unlikely to support Brolga - see overall description.	Faint drainage line at north end.	70	Likely grazed but not at the time of assessment	Steep-sided to south; swampy area in north dominated by *Malva* sp. and *Trifolium* sp. higher up; lacked water plants except herbs; no trees; buckshot in substrate - unlikely to hold water sufficient for Brolga habitat even in a wet year.	No
103	Minimal – some grass, mostly bare earth.	Yes	Yes	No shallow end.	Shallow drain to north-west leading from Dam 102.	90	Likely grazed but not at the time of assessment. Electric fence around dam.	2 willows and long grass on an island but unlikely to provide Brolga habitat. No aquatic plants.	No
110	No	Yes	Yes	Yes. Swampy area in road reserve connected by drain could be suitable in an exceptionally wet year.	Yes	80	Grazed	Treeless apart from line of subadult cypress parallel to the eastern road reserve.	No

Dam no.	Aquatic vegetation (type and extent)	Evidence of excavation	Steep banks	Shallow end with suitable habitat	Drains	Surface water cover (%)	Land use	Overall habitat description	Brolga habitat
112	No	Yes	Yes	No	No	90	Grazed - sheep.	Typical small farm dam with bare earth edges scraped out on two sides. Recent shelterbelt establishing parallel with road reserve - comprising Blackwood, other *Acacia* spp. and *Eucalyptus* sp. No significant swampy ground surrounding the dam that might provide Brolga habitat.	No
113	No	Yes	Yes	No	Yes - drain on west side, shallow drain on east side (neither directly intersecting dam).	80	Grazed – sheep (not currently), 2 horses in next paddock west.	Larger fam dam with bare edges. Some Juncus on the upper bank east side. Row of Ash (*Fraxinus* sp.) to 10 m height on the north side.	No
114	No	Yes	Yes	No	Shallow drain to east and west.	80	Grazed.	Treeless; typical square farm dam with bare earth edges.	No
115	No	Yes	Yes	'Shallow end' minimal. No aquatic plants.	No	60	Grazed (not currently).	One dead tree on the northern side, no aquatic plants.	No
116	No	Yes	Yes	No	No	90	Grazed.	Treeless; typical square farm dam with bare earth edges.	No

Dam no.	Aquatic vegetation (type and extent)	Evidence of excavation	Steep banks	Shallow end with suitable habitat	Drains	Surface water cover (%)	Land use	Overall habitat description	Brolga habitat
117	No	Yes	No	Minimal - area of swampy ground to southwest with Juncus present.	No	85	Grazed - sheep.	A couple of Willows on the west side. Row of cypress <50 m to north-west. Planted native shelterbelt running north-south ~50 m west of dam.	No
118	No	Yes	Yes	No	No	80	Grazed - sheep.	Treeless close to dams. No aquatic plants present	No
126	Scattered fringing Juncus.	Yes. Raised bund at west end and island created in middle of dam.	No	Dam is currently shallow with exposed mud; no obvious shallow end.	No	35	Grazed - sheep.	No trees adjacent to dam. No aquatic plants present.	Unlikely, but potential; Brolga occasionally nest on raised islands in farm dams (I. Veltheim, pers. comm.)

4.2.6. Brolga breeding wetlands

After discounting two VBA breeding records due to inaccuracy and a further wetland being permanently drained (see Section 3.2.2) 26 wetlands within the RoI were accepted as Brolga breeding wetlands (Table 10; Figure 8).

Of the 26 breeding wetlands, 14 wetlands within the RoI had confirmed breeding activity between 2018 and 2024. 11 wetlands were confirmed by Nature Advisory and three wetlands by local landholders. Six of these wetlands were located within the wind farm project site; wetlands J, 29405, 29420, 28240, 23 and 14.

A landholder reported past breeding at Wetland A (EHP 2013), and it was initially included as a breeding wetland. However, the record was later revoked following further verification with the landholder (Section 3.2.2, Figure 8). Additionally, there is an absence of modelled habitat or a nearby wetland. Therefore, this area has been discounted as a breeding site and is excluded from Table 10.

Based on the field observations, up to eight Brolga pairs were breeding simultaneously within the RoI over the survey period (2019). Of the 26 Brolga breeding wetlands, at least eight of these wetlands will likely be used in any year, given the presence of the eight breeding pairs. In the Level Three assessment, wetlands that have been accepted as Brolga breeding wetlands (Figure 8) have had turbine-free buffers placed around them to avoid significant impacts on breeding success from collision or disturbance.

Table 10: Analysis of Brolga breeding wetlands

Wetland no.	Redefined wetland no.	Past breeding record	2018	2019	2020	2022	2023	2024
D		2008 (VBA and landholder)						
E		Landholder observation (no date specified)						
H			Landholder observation	Landholder observation				
J		Landholder observation (no date specified)						
C	9	2008 & 2007 (VBA, landholder)			Nature Advisory record	Nature Advisory record	Nature Advisory record	
B	29401	Landholder (no date specified)						
F	29405	2009 (landholder observation)						
25651		1991 (VBA record)						
25656				Nature Advisory record				
28203		1/01/1984 (VBA literature report)						
28240					Nature Advisory record	Nature Advisory record		
28245	29420			Nature Advisory record	Nature Advisory record		Nature Advisory record	
28249	23				Nature Advisory record		Nature Advisory record	

Wetland no.	Redefined wetland no.	Past breeding record	2018	2019	2020	2022	2023	2024
28252	29411	1/01/1984 (VBA literature report and landholder)						
28259		Landholder observation (no date specified)					Nature Advisory record	Nature Advisory record
28261	29414	Landholder observation (no date specified)						
28264	29416	Record from EHP report						
28267	29415	Landholder observation (no date specified)						
28282		2007 (VBA)		Nature Advisory record		Nature Advisory record		
28366		2008 (VBA and landholder)		Nature Advisory record				
28801	14					Nature Advisory record	Nature Advisory record	
28916	29460			Nature Advisory record	Nature Advisory record			
28966	29402	Landholder record from EHP report					Landholder observation	
29047	29404	1/01/1987 (VBA and landholder)						
30330	20			Landholder observation				Nature Advisory record
30336			Landholder observation	Nature Advisory record				

Note: Grey-shaded rows indicate wetlands inside the wind farm boundary

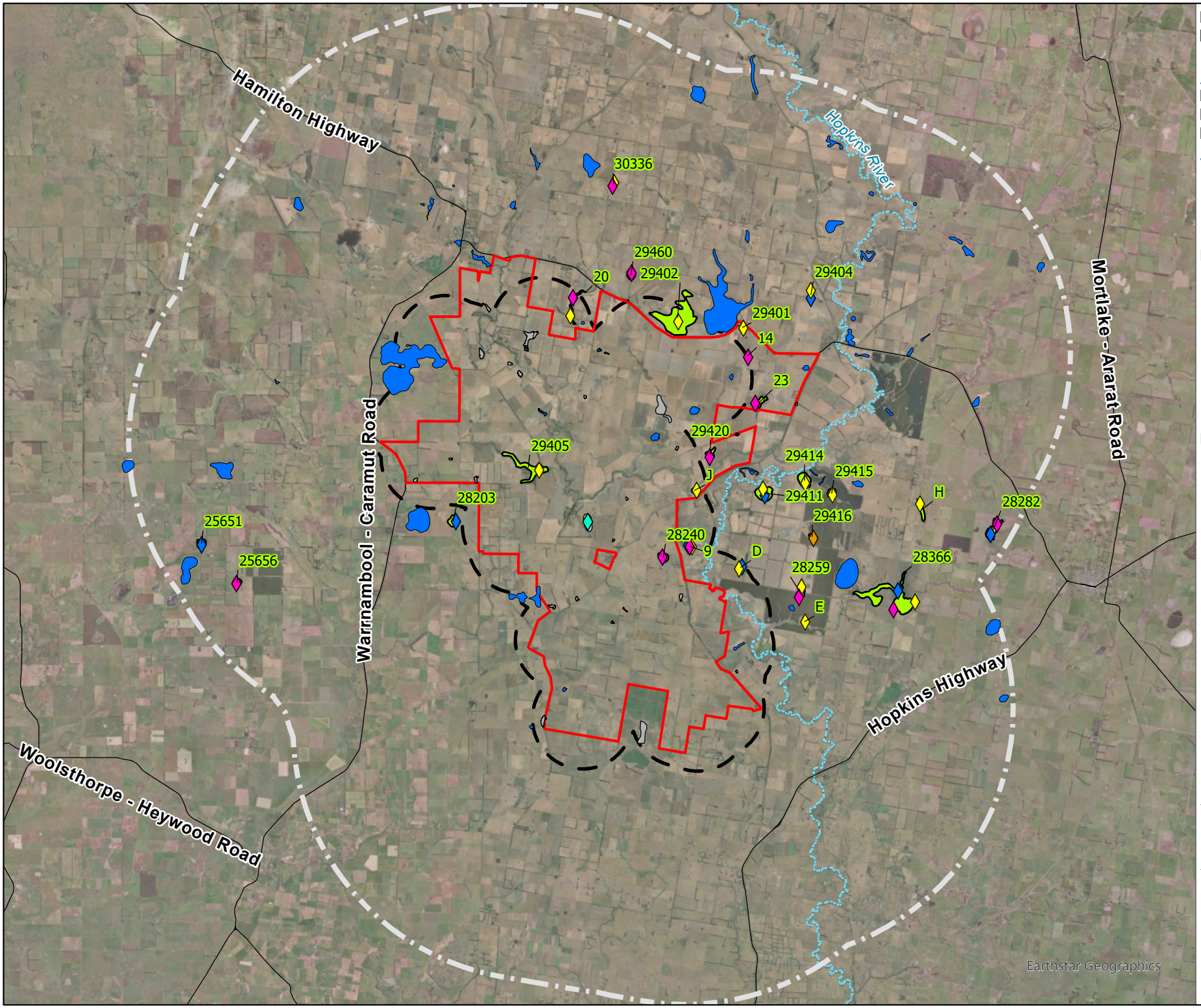

Figure 8: Confirmed Brolga breeding wetlands

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- Wind farm boundary
- 2km buffer from turbine
- Radius of Investigation

Brolga breeding records

- Landholder record - disregarded
- EHP
- Landholder
- Nature Advisory
- VBA

Brolga breeding habitat

- Confirmed Brolga breeding wetland
- Brolga habitat
- Unsuitable

N

Kilometres
0 1 2 3 4 5

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5. Level three assessment

A level three assessment involves four steps (Table 2), and each step is described below.

Step One: Avoid and mitigate impacts on the Brolga.

Avoiding or mitigating the impact of a wind farm on the Victorian Brolga population is primarily based on establishing turbine-free buffer zones surrounding breeding wetlands. Turbine-free buffers avoid or mitigate the impacts of turbines on these home ranges to achieve the objectives outlined below.

The Interim Brolga Guidelines require that turbine-free buffers be established to avoid impacts within Brolga breeding and flocking home ranges such that:

- For **breeding wetlands**, "turbine siting would be used to exclude any significant reduction in breeding success caused by turbines" (DSE, 2012, p. 8); and
- For **flocking wetlands**, "turbine-free buffers should be designed to exclude any significant impact on the survivorship of Brolga whilst occupying that flocking site" (DSE, 2012, p. 8).

Brolga do not use every breeding (or flocking) wetland every year or even for long periods. Thus, generating site specific approaches for every breeding (and flocking) location within and near a wind farm is not possible. Home ranges and turbine-free buffers must be based on assumptions drawn from evidence and observations about bird activity in and around these sites.

As no flocking sites occur within 10 km of the project site, mitigation needs only to address impacts on breeding wetlands.

Step Two: Collision risk model (CRM)

The objective of CRM is to estimate the residual number of Brolga flights that have the potential to interact with wind turbines on the proposed site and, from this estimate, the annual collision rate is then extrapolated to the assumed 30-year operating life of the project.

Step Three: Population Viability Analysis (PVA) model

The site-specific collision risk output is then used in the PVA to model the potential impact of the proposed wind farm on the Victorian Brolga population. The PVA has been undertaken for the development application by Dr Michael McCarthy of Melbourne University, who prepared the PVA for DEECA's predecessor some years ago. It indicates the impact of the wind farm on the future population size of the Brolga in Victoria.

Step Four: Compensation to achieve zero net impact on the Victorian Brolga population.

Improving Brolga breeding habitat to enhance breeding success is considered an appropriate compensation strategy to replace the birds lost to the population because of the proposed wind farm (DSE, 2012).

5.1. Potential impacts

Wind farms may impact on Brolgas in four ways listed below.

- Direct effects, particularly mortality resulting from collision with turbines or powerlines
- Indirect effects including:
  - Habitat avoidance
  - Disturbance from construction activities

- Barrier effects

Collision with turbines or powerlines

Only a single, likely Brolga collision with a wind turbine has been recorded to date[2]. Brolga collisions with powerlines have been reported from Victoria (Goldstraw & Du Guesclin, 1991; Herring, 2005). While wind turbines are not a key threat to the Victorian Brolga population, it has been suggested that they may be vulnerable to collision due to their large size and relatively low mobility.

In the absence of extensive and replicated observations on the interactions of flying Brolga with wind turbines, international research from closely related species was considered. The Brolga belongs to the crane family and wind turbine interactions have been observed for two other crane species: the European Common Crane (*Grus grus*) and the North American Sandhill Crane (*G. canadensis*).

In the United States of America, Navarrete and Griffins-Kyle (2016) monitored the Sandhill Crane migratory route in Texas. Sandhill Crane increasingly conflict with wind turbines during migration as the associated infrastructure expands across the landscape. The study area was the High Plains and the area has experienced a large increase in project sites where the cranes use this area during migration and part of winter where they forage in agricultural areas and roost at night in playas[3]. Sandhill Crane collision with turbines was reported twice in these foraging and roosting areas.

In Germany, Stübing and Korn (2006) observed cranes near wind farms on 88 occasions over seven years in Rhineland. They found that in-flight cranes never approached closer than 100 m to turbines, with distances usually between 300 and 700 m. In summer, after breeding, the cranes approached wind farms to within 150 to 250 m but no closer. This contrasts with Wood's (2014, 2017) observations at least twice of Brolga flying low directly under operating turbines at the Macarthur Wind Farm. This may be because flocking birds (European Crane observations) react collectively and more significantly to turbines than individuals or pairs of breeding birds.

Langgemach (2013) found that avoidance action by flying cranes in response to operating wind turbines was observed for individuals and small flocks up to 750 m from turbines while for larger flocks, turbines were avoided by greater distances, between 1,000 and 1,350 m.

The observations of Gerjets (2006) for European Crane, again at a wind farm in northern Germany, are summarised below:

- Cranes avoided flying close to wind turbines.
- Cranes have been observed flying within 200 m of operating wind turbines where turbine lines are oriented parallel with the direction of flight.
- The range of distances from turbines that cranes were observed flying in one systematic study was between 150 and 670 m, with a median distance of 300 m, where turbines were not parallel with the direction of flight.
- In another, less systematic study, crane flocks flew around operating wind turbines at distances of between 400 and 500 m where turbine lines were not parallel with the flight direction.

[2] Second year BAMP report – Dundonnell WF (Biosis 2023).
[3] A shallow, seasonally dry wetland or lakebed in the High Plains region.

- Flocks of cranes have been observed flying quite close to turbines, in one case about 100 m from one and in another between two operating turbines, quite close to the rotor tips.
- Another observation involved a "V" formation flock breaking up, possibly due to downwind turbulence from a wind turbine, at 750 m from the turbine. The flock eventually flew around the turbine and regrouped after 1.5 km.

The reaction of cranes to wind turbines therefore varies but they generally avoid wind turbines when in flight.

Habitat avoidance

There is strong circumstantial evidence that Brolgas can adaptively respond to the indirect impacts of wind turbines. For instance, observations on the impacts of wind turbines on Brolga behaviour from Wood (2014, 2017) and Veltheim *et al*. (2019) are informative. Nesting Brolgas at the Macarthur Wind Farm (approximately 45 km west from the HWF) were monitored in 2018, 2019 and 2021 for a separate project by Wind Prospect as part of the level two investigations for the project. The same breeding wetland and presumably pair were again observed in all three years breeding within 400 m of operating wind turbines. Veltheim et al. (2019) also observed Brolgas as close as 150 m from turbines. This information indicates that at the Macarthur Wind Farm, Brolga have bred within 400 m of constructed and operating turbines for at least six out of the last ten years and that they will forage consistently within 100 m of the base of operating turbines (Wood 2014 & 2017, Nature Advisory data). Maps showing this are provided in Appendix 6.

The Interim Brolga Guidelines provide for an additional 300 m disturbance buffer around the Brolga breeding home range. This distance was chosen based on anecdotal evidence from the observed reactions of Brolgas to human and vehicle disturbance. Wind turbines are a static, fixed source of disturbance, and the foregoing evidence indicates that continued deterrence from the 300 m zone around a turbine is unlikely to occur consistently, suggesting that it is a conservative measure. Notwithstanding this, the additional 300 m disturbance buffer is adopted for the HWF.

The main access track to the wind farm site south of Hamilton Highway leads partially through a Brolga buffer along an existing farm track between cultivated fields (inset in Figure 11). The buffered breeding wetland is located to the north of Hamilton Highway and as such already impacted by traffic along Hamilton Highway. No additional disturbance is expected from this access track. No other wind farm infrastructure including proposed overhead powerlines (Figure 11) are located within Brolga breeding buffers.

Disturbance from construction activities

The Brolga is susceptible to disturbance from frequent human activity. Habitat selection away from farmhouses and nearby sheds reflect this (Veltheim *et al*. 2019). Construction activities, including making tracks, erecting turbines, increased traffic and activities at the quarry have the potential to impact on the Brolga.

The Brolga Scientific Panel recommend a minimum indirect disturbance buffer of 300 m from breeding home ranges (DSE, 2012) to prevent such disturbance and just one access track is located within a Brolga breeding buffer (see above).

A temporary quarry is located in the northwestern part of the site east of Warnambool-Caramut Road (BCA Consulting, 2025) (Figure 11). This quarry and its access track have been sited outside any Brolga breeding site buffers. Almost weekly blasting is expected from the quarry operations during the construction of the wind farm, but airblast overpressure and ground vibration are controlled to minimise impacts on sensitive sites (BCA Consulting, 2025). The commonly observed response of birds located

within a few hundred metres of a blast is to take flight, the same response as from any sudden, loud noise (Terrock 2025). The closest Brolga breeding wetlands are wetland 29405, approximately 1.4 km southeast of the quarry site and wetland 29203, which lies 4km south of the quarry site. This distance is considered sufficient that Brolga are not expected to be impacted by blasting and quarry traffic.

Barrier effects

Long rows of turbines have the potential to create partial barriers to some bird movements; this, in turn, forces birds to travel further and increases their energy requirement (Drewitt and Langston, 2006). Layout, orientation and spacing of wind turbines are important factors to reduce barrier effects. Occasional gaps between turbine clusters may be appropriate to facilitate movement of Brolga from high density breeding areas to flocking sites (DSE, 2012).

The design of the proposed HWF has avoided long rows of turbines. These gaps between turbines effectively mitigate any potential barrier effects, regardless of whether an additional wind farm is constructed nearby.

5.1.1. Turbine-free buffers

The main measure implemented during the project design to avoid or mitigate impacts to the Victorian Brolga population has been the development of turbine-free buffers around confirmed or valid historical Brolga breeding wetlands. Turbine-free buffers represent the area around a Brolga breeding wetland, beyond which a wind turbine tower can be placed to avoid impacts on Brolga breeding success from collision or disturbance. The turbine-free buffer areas were designed to protect Brolga breeding wetlands from potential impact both during construction (i.e., disturbance) and operation (i.e., collision with wind turbines).

The Interim Brolga Guidelines state that turbine free buffers should avoid the Brolga breeding home range identified in the Level two assessment or use the generic guideline of a 3.2 km Brolga breeding home range. The turbine-free buffer design proposed for this project has incorporated the most recent research on Brolga behaviour in south-west Victoria undertaken by Veltheim *et al*. (2019). This research was undertaken so that land managers and decision makers can inform the development of turbine-free buffer zones around Brolga breeding and flocking sites. Information on the movement of birds around breeding wetlands is relevant to the HWF project. A site specific approach has been developed in consultation with DEECA including the Veltheim et al. (2019) research data. This provides the most robust evidence base to inform the turbine free buffers at the project.

Turbine-free buffers encompass a habitat-based home range developed for the project that considers the key habitats that support breeding, as listed below:

- Confirmed or valid historical breeding wetlands used for breeding and night roosting
- Non-wetland areas around breeding wetlands used for foraging
- Wetlands providing habitat used for foraging and/or alternate night-time roosting within two kilometres of breeding wetlands
- Movement corridors between breeding wetlands and other wetlands.

The home range around each breeding wetland was informed by:

- Recent satellite tracking studies undertaken by Veltheim *et al.* (2019)
- Known Brolga movements around breeding wetlands from several observational studies of Brolga flight behaviour by Nature Advisory
- Observations of the movements of Brolga breeding at the Macarthur Wind Farm since 2012

- Breeding wetland home range mapping published in the EES Referrals for the Penshurst (Biosis Research, 2011) and Mount Fyans Wind Farms (Biosis, 2017)

Turbine-free buffers include the following:

- The home range of the Brolga (defined based on movement patterns of the species according to Veltheim *et al*. (2019) and based on flight data collected on breeding pairs in south-western Victoria – see below); and
- An extra area comprising a 300 m disturbance buffer plus the 95 m turbine blade length buffer.

The buffer begins from the blade tip, which is assumed to be 95 m from the turbine location. This extra 95 m has been mapped for completeness.

Brolga breeding and night-roosting wetlands

Wetlands used as Brolga habitat and breeding wetlands were identified as part of level two assessments (see Section 4). These have been identified in Figure 6 and confirmed Brolga breeding and habitat wetlands are presented in Figure 8.

Brolga habitat wetlands that did not have Brolga breeding records associated with them were considered potential sources of food and, therefore, likely to form part of the home range around the breeding wetland. Such wetlands were more likely than others to support a productive wetland ecosystem as post-filling ecological succession progresses through winter and spring, producing increased emergent plant and algal cover and associated fauna populations, including frogs. Combined with their inundation duration, these wetlands would, therefore, be disproportionately important sources of food and potentially alternate night-time roosts.

The hydrological investigation by Water Technology (2024a, Appendix 4) identified and mapped wetlands that are inundated for 120 days or more at least once in 10 years (Brolga habitat). These are most likely to provide habitat that supports breeding (i.e. either nesting or productive foraging wetlands). Home ranges have been generated for each confirmed breeding wetland within these complexes. The combined home ranges across wetlands in these parts of the site were used as the basis for a turbine-free buffer for wetland complexes.

Non-wetland foraging areas and movement corridors

Based on the satellite tracking of Brolga chicks (Veltheim *et al.* 2019), it is important to include multiple wetlands within the breeding home range. Veltheim *et al* note that both breeding wetlands and non-wetland habitat should be incorporated into turbine-free buffers to allow barrier-free movement between wetlands and non-wetland foraging areas. They also stress the importance of ensuring habitat elements of breeding wetlands, night roosts, foraging areas, and movement corridors, are incorporated into buffers at each site, based on their spatial arrangement in the landscape, as opposed to applying estimates of distances moved or home ranges alone.

Veltheim *et al.* (2019) found that 2 km from a nesting or roosting wetland or, in the case of multiple wetlands, the 'centroid' of the wetlands used encompassed foraging habitat and movement corridors represented the 95% utilisation distribution for a Brolga family. This distance from the edge of breeding wetlands was therefore used to map home ranges and develop turbine-free buffers, as described in the next subsection. All Brolga breeding wetlands located within 2 km of proposed turbines (Figure 9) have had a habitat-based home range and turbine-free buffers mapped protecting them (discussed later in this section).

The Brolga breeding wetlands and other wetlands (Brolga habitat) that are within 2 km of each other are included in the home range for that breeding wetland. A single turbine-free buffer was created around

these wetland complexes to allow barrier-free movement between breeding wetlands, other wetlands and non-wetland foraging areas.

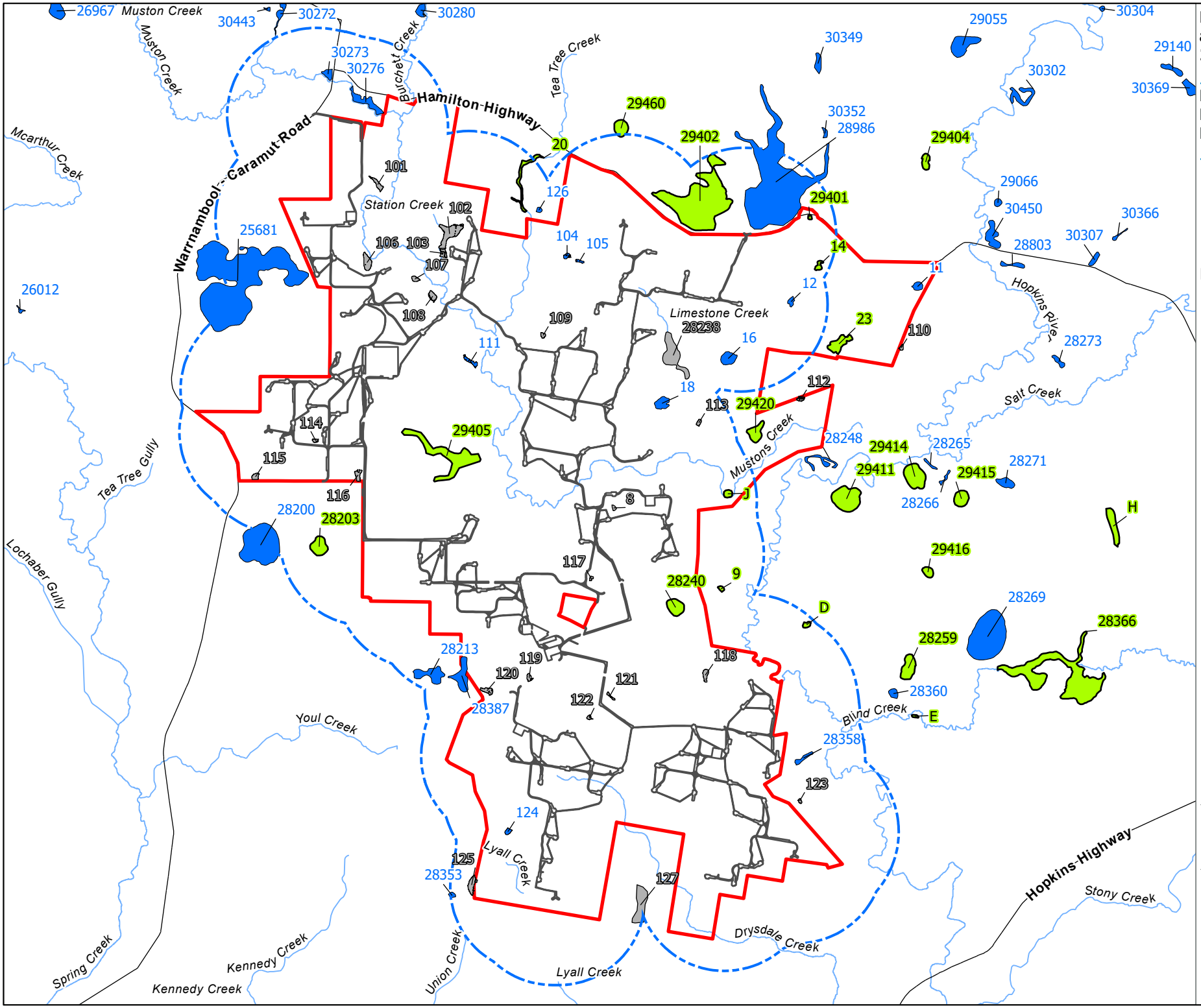

Figure 9: Breeding wetlands and habitat located within 2km of proposed turbines

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Wind farm boundary
Develpment footprint
2km radius of proposed turbines

Brolga breeding habitat

Confirmed Brolga breeding wetland
Brolga habitat
Unsuitable

N
Kilometres
0 1 2 3 4
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Defining Brolga breeding home ranges

This subsection describes how Brolga breeding home ranges were delineated. The home range includes the first two components of the turbine-free buffer and represents the area within which Brolgas are to occur more frequently throughout their breeding season. It includes two components:

- Grouping of wetland habitats within 2 km of confirmed Brolga breeding wetlands that form a wetland complex; and
- A 600 m buffer around each wetland within a complex.

These components are described below.

As wetlands provide greater food resources for Brolga, wetland complexes combined with the intervening non-wetland terrestrial habitat are considered sufficient to provide adequate resources for successful breeding and formed the core of the defined home range. The method for determining Brolga home range for wetland complexes is based on distances moved within, between and around wetlands by Brolga families from Veltheim *et al*. (2019). It represents an update of the habitat modelling method used by Nature Advisory (formerly Brett Lane & Associates Pty Ltd) at Dundonnell and Golden Plains Wind Farms.

Based on the Veltheim *et al.* (2019) findings, all wetlands within 2 km of confirmed Brolga breeding wetlands that meet the 120-day inundation criteria at least once in ten years based on the hydrological modelling (Water Technology, 2024a) were included in the home range (Figure 10).

Brolga will move out to these wetlands particularly when young Brolga are getting larger and can move greater distances and when resources at their breeding wetland become depleted. These wetlands and the terrestrial habitat between them were considered the areas in which Brolga was most likely to move to forage or roost (as illustrated in Figures 2 & 3 of the Veltheim *et al.* (2019) study). Drained wetlands holding water less than 120 days are less likely to provide season-long food supplies for Brolga.

To provide for Brolga movements around wetlands, a 600 m buffer is provided that encompasses most Brolga flights from nesting wetlands based on discussions with DEECA. The 600 m value is considered a conservative approach to wetland buffering and was adopted in ongoing consultation with DEECA.

Based on the Veltheim *et al.* (2019) findings, an average of 2.82 wetlands were used within a Brolga home range. The home ranges mapped from the 22 confirmed and valid breeding wetlands on or within 5 km of the wind farm boundary have an average of 3.6 wetlands within each home range. This ensures ample food resources are available to maximise breeding success.

Home ranges also encompass non-wetland habitat areas between these buffers for wetlands that are 2 km or less apart. Wetlands that are greater than 2 km apart are unlikely to have Brolga movements directly between them (Veltheim *et al*., 2019) so the home range boundary is drawn between the outer limits of the 600 m buffers to delineate the home ranges between wetlands within 2 km of one another. This explains why the home range map in Figure 10 does not follow straight lines encompassing all wetlands associated with the wetland complex breeding wetlands. Rather, it follows the zones of greatest between-wetland movement (i.e. wetlands within 2 km and their associated 600 m buffers).

Non-wetland habitat that Brolga are most likely to use is either within 600 m of a wetland or between two wetlands within 2 km of one another (as observed in Figures 2 & 3 of the Veltheim *et al.* (2019) study). The above method ensures that non-wetland areas most likely to be used by Brolga are included in the breeding home range.

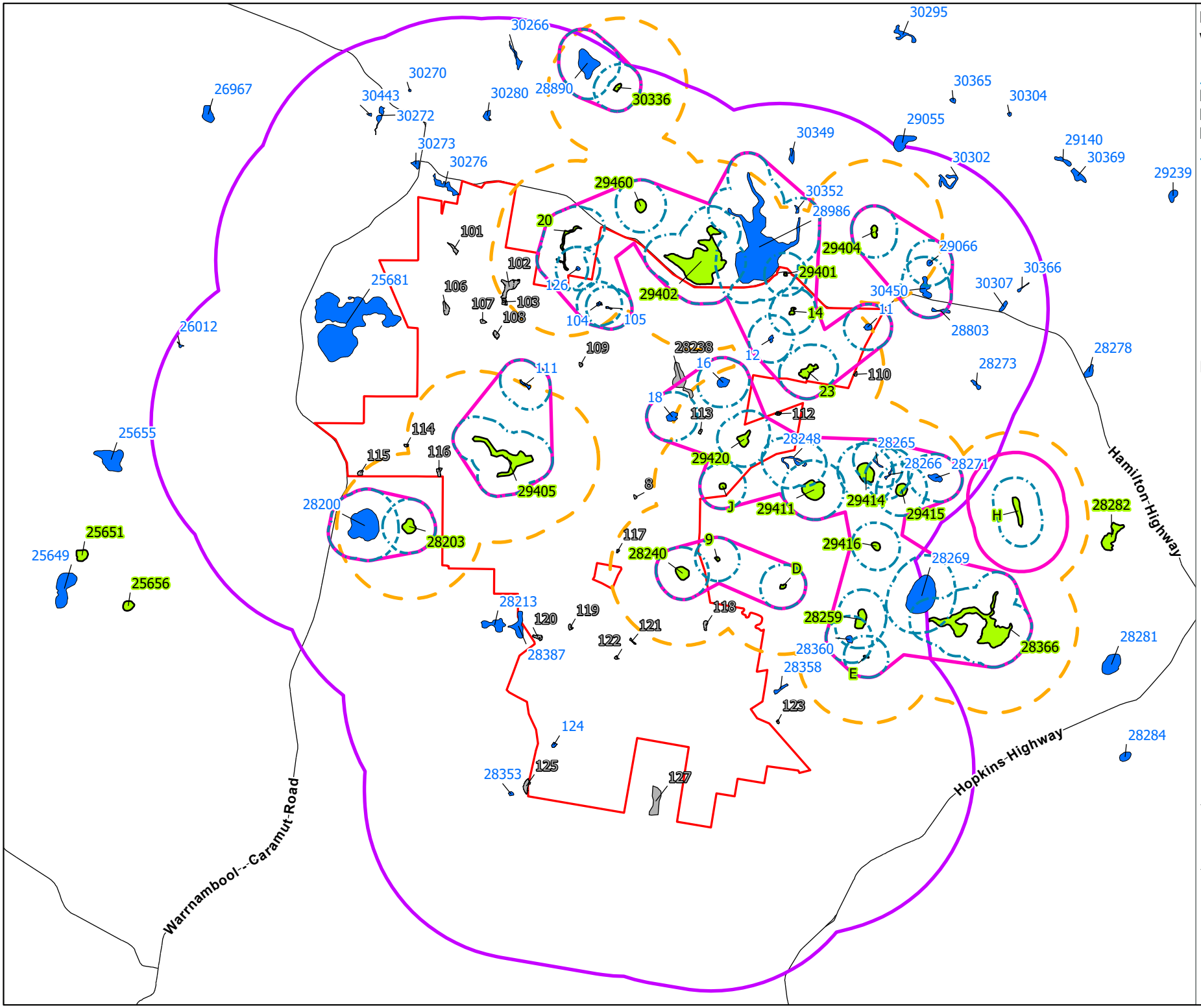

Figure 10: Brolga breeding wetland home ranges

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- Wind farm boundary
- 5km buffer from wind farm boundary
- 600m buffer around suitable wetlands
- Brolga homerange
- 2 km buffer from confirmed wetland in homerange

Brolga breeding habitat

- Confirmed Brolga breeding wetland
- Brolga habitat
- Unsuitable

N

Kilometres
0 1 2 3 4

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Brolga home range extent

Table 11 summarises the extent of the Brolga home ranges delineated for the HWF using this technique.

Table 11: Area of predicted home range for each confirmed Brolga breeding wetland

Breeding Wetland (home range)	Area (ha)
14, 20, 23, 29460, 29401, 29402	3,796
28203	560
D, 9, 28240	639
29404	648
29405	906
E, J, 28259, 29411, 29414, 29415, 29416, 29420	3,659

Veltheim *et al*. (2019) found Brolga home ranges vary in extent from 70 to 523 ha. The home ranges mapped for the breeding wetlands at HWF are more than 523 ha, with the largest at 3,796 ha. As all the Brolga home ranges calculated for this assessment exceed the largest home range identified in the Veltheim *et al.* (2019) study, the delineated home ranges used to define turbine-free buffers at the HWF are considered conservative.

In summary, the home ranges determined for the 22 breeding wetlands used by Brolgas that breed near the HWF provide more options for wetland food resources (i.e. number of wetlands) and are considerably larger in area than observed home ranges based on research on the species to date. Hence, the risk of Brolgas not breeding successfully under favourable rainfall conditions within such home ranges is considered low.

Final turbine-free buffers

The final turbine-free buffer proposed for Brolga breeding wetlands is a combination of the Brolga breeding home range plus:

- an additional disturbance buffer of 300 m
- a turbine blade length buffer of 95 m

The Interim Brolga Guidelines recommend a 300 m buffer to prevent disturbance to breeding Brolga. This has been applied around each Brolga home range.

The final component of the turbine-free buffer is an additional distance to account for the turbine blade length specific to the HWF project, which is a maximum of 95 m.

The outer edge of these additional zones around the home range represents the turbine-free buffer for Brolga breeding wetlands. This is shown for all breeding wetlands on and near the HWF in Figure 11, which also includes in different colours the various wetlands and buffers that make up the turbine-free buffer for the project.

Disturbance buffers

The following is an overview of Brolga observations at Macarthur Wind Farm between 2012 and 2021 (Veltheim *et al*., 2019, Wood,, 2014, Wood 2017, Nature Advisory data).

Brolgas have been observed breeding at two wetlands at the Macarthur Wind Farm in the past decade, including wetlands 25650 and 25699 (Appendix 6).

At Wetland 25650, breeding occurred during the 2012, 2013, 2016, 2018 and 2021 breeding seasons (Veltheim *et al*., 2019, Wood, 2014, Wood, 2017, Nature Advisory data). No monitoring occurred in 2015,

2017 and 2020, so Brolga activity in these years is unknown. The wetland is surrounded by three turbines at distances of 200, 280 and 290 m each from the edge of the wetland.

One chick was satellite tracked as part of the Veltheim *et al*. (2019) study and was recorded within 80 m of the base of a turbine. Tracking results are presented spatially in Appendix 6 (Figure 3 of the Veltheim *et al*. (2019) report).

During the 2018 breeding season, Nature Advisory, as part of its Brolga breeding season surveys for the proposed Willatook Wind Farm, monitored the adult pair at this wetland and plotted their location as they moved across their home range. The pair was observed as close as 150 m from the base of operating turbines. Similar behaviours were observed as those documented in the Veltheim *et al*. (2019) study, with the pair foraging close to the breeding wetland early in the breeding season and then moving further to the northwest later in the breeding season.

At Wetland 25699, a pair of Brolgas was observed breeding at this wetland in 2013 and 2014 (Wood, 2014). This wetland has six turbines surrounding it located between 50 and 420 m from its edge. The Brolga were observed foraging as close as 50 m from a turbine in the 2014 breeding season (Wood, 2014) and within 90 m of a turbine during the 2016 breeding season (Wood 2017). Spatial images of the Brolga monitoring are presented in Appendix 6.

The recommended disturbance buffer in the Interim Brolga Guidelines was applied to develop turbine free buffers for the HWF. Based on actual behavioural observations of Brolgas near wind turbines, this buffer is considered conservative and appropriate for determining turbine-free buffers.

The Veltheim *et al.* (2019) recommendations acknowledge that Brolga home range variations can make it challenging to apply generic buffers, based on average home range size or movement ability of pre-fledged chicks. It states that it is more appropriate to ensure that habitat elements, including breeding wetlands, night roosts, foraging areas and potential movement corridors between these habitats are incorporated into buffers at each breeding wetland, based on their spatial arrangement in the landscape. The proposed turbine-free buffers for HWF are consistent with this and are considered appropriate to ensure continued Brolga breeding success.

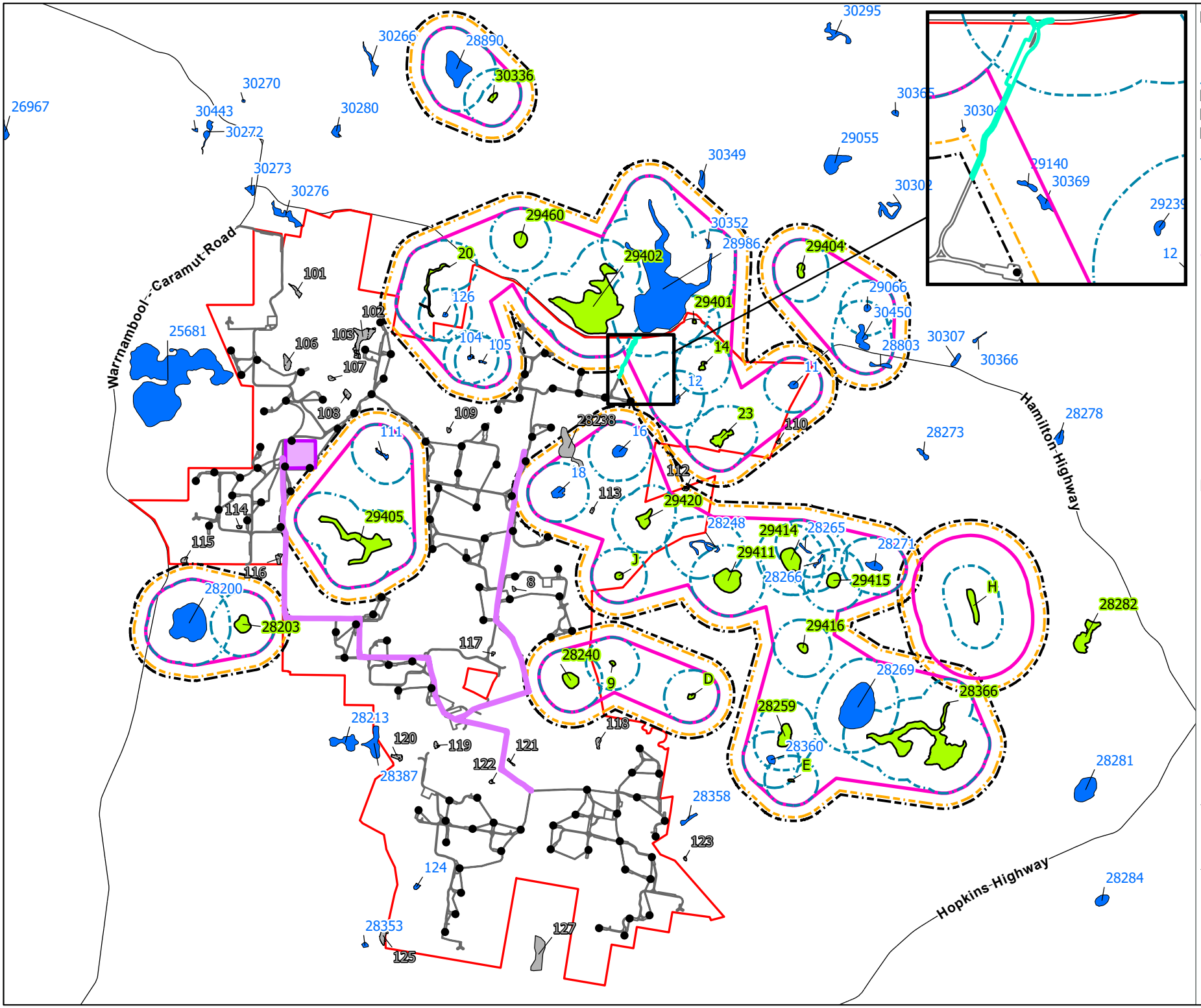

Figure 11: Turbine free buffer

Project No: 18088_26
Project: Hexham Wind Farm
Date: 28/08/2025

- Wind farm boundary
- Develpment footprint
- Turbine
- Overhead line
- Access track inside turbine free buffer
- Quarry site
- 600m buffer around suitable wetlands
- Brolga homerange
- Disturbance buffer - 300m
- Turbine free buffer - 95m

Brolga breeding habitat

- Confirmed Brolga breeding wetland
- Brolga habitat
- Unsuitable

N

Kilometres

0 1 2 3 4

GDA2020 MGA Zone 54

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Comparison with other approved wind farms

Turbine-free buffers are implemented to reduce collision risk and disturbance from turbines and wind farm operations to avoid any significant impact on Brolga breeding success. A formalised approach to buffering Brolga breeding wetlands has been adopted at three large wind farm projects in south-western Victoria that have been issued a planning permit. These methods have evolved and been informed by Brolga research, extensive site-specific field surveys and engagement with specialists, including DEECA. Table 12 summarises some statistics for these projects and presents the same statistics for HWF.

Table 12: Brolga breeding statistics for different wind farms in south-west Victoria

Project	No. Brolga breeding wetlands within 10 km	Est. No. breeding Brolga pairs within 10 km	No. sites requiring turbine-free buffers
Stockyard Hill	60	7	23
Dundonnell	44	7	12
Golden Plains	28	8	17
Hexham	**26**	**8**	**22**

The comparison in Table 12 shows that the overall Brolga risk profile for this wind farm is comparable with other approved wind farm projects, with less than 3% of the southeast Australian Brolga population breeding within the 10 km RoI around the proposed HWF. Several Brolga pairs breed within or close to the wind farm project boundary, triggering the requirement for turbine-free buffers. All other breeding pairs during the monitoring period were more than 5 km away from any proposed wind turbines. This information indicates that Brolga pairs may use up to 22 breeding wetlands on or near the project site for breeding.

5.2. Collision Risk Modelling

The Interim Brolga Guidelines indicate that the objective of collision risk modelling is:

> *"to estimate the residual number of Brolga movements which have the potential to interact with wind turbines on the proposed site and from this estimate the annual collision risk."*

Appendix 7 details the CRM method applied. The techniques involved are used regularly for the same purposes and have been published and peer-reviewed in relevant professional journals (Band *et al*., 2007; Band, 2012). An overview of how the model works and its results are provided here.

The Nature Advisory application (NA-BAND) updates the model to accept spatial data inputs. This modification extends the Band *et al*. 2007 and Band 2012 to calculate the probability of collision more correctly after interaction is a geometric calculation. The NA-BAND has previously been applied and accepted for various other wind farms in southwest Victoria, including Dundonnell and Golden Plains wind farms.

5.2.1. Model inputs

Inputs include both the wind farm layout and turbine specification, as well as the findings of where Brolga breeding wetlands were and the number of pairs using the RoI. Appendix 7 provides more details.

Details of the turbine layout and turbines to be used were provided by the proponent and factored into the application of the model (see Appendix 7). The turbine specifications include:

- A total of 106 turbines in the final layout, reduced from 109 turbines
- Rotor swept area (RSA) between 40 and 260 me above the ground

- Three blades per turbine
- Blade length of 110 m (conservative approach as the maximum blade length proposed is 95 m)
- Hub height of 150 m
- Maximum chord of 5.5 m
- Rotation period of 4.96 seconds
- All turbines operating 24 hours per day, 365 days per year, at top speed including all daylight hours when Brolga are active.

The inputs used for the model were conservative and were the same as inputs used in other projects such as Golden Plains Wind Farm described in BL&A (2018), Section 4.2.4 and in Appendix 7. The final input is particularly conservative as there will be times when the turbines are not operating due to low wind speed and when they will be rotating slower than their maximum period of 4.96 seconds.

The breeding season scenario has been developed based on observations of flights from and back to 31 breeding wetlands throughout south-western Victoria by Nature Advisory in the past 15 years (BL&A, 2018). The scenario involved the following assumptions:

- Twenty-four confirmed breeding wetlands have been used.
- A maximum of eight pairs of Brolga using each wetland with equal probability each year (this allows for breeding events that have not been documented for each site in the historical record).
- Each member of the breeding pair makes a flight to foraging habitat around the breeding wetland once per day (a total therefore of two outward and two inward flights per day), in accordance with the behaviour documented in BL&A (2018).
- A proportion of the flights are at a height and distance where turbine interaction is possible, being 40 m above the ground (see Appendix 7).
- An average breeding event of 120 days for each pair comprising 30 days of incubation and 90 days of chick rearing until fledging (Marchant & Higgins, 1993).

The final assumption is conservative. Nature Advisory has estimated the duration of a breeding wetland occupation (and therefore the number of assumed flights by that pair from the breeding wetland) as averaging 50 days as most breeding attempts fail due to predation of eggs or chicks by foxes, flooding or the rapid drying of the breeding wetland.

Three avoidance rates were modelled: 90%, 92% and 95%. Determining an appropriate wind turbine avoidance rate for the Brolga is challenging given the lack of past interactions between Brolga and wind turbines. Apart from the Macarthur Wind Farm, there are no operating wind farms in areas where Brolga could regularly interact with turbines where their interactions have been observed. Such rates have not been measured at Macarthur. Therefore, information on the behaviour of other crane species has been referred to.

Before discussing avoidance behaviour, it is worth considering definitions of avoidance. Cook *et al.* (2012) highlight the difference between 'macro-avoidance' and 'micro-avoidance'. Macro-avoidance refers to changes in flight behaviour that result in a bird avoiding a wind farm altogether. Micro-avoidance refers to the flight behaviour of a bird to avoid a turbine once within a wind farm. In practice, if birds avoid a turbine at 100 m distance, they could do so at the edge of a wind farm or several turbine 'rows' into a wind farm, where they might come across the first turbine in front of their flight path, so the distinction is not necessarily always useful for collision risk modelling.

In a mathematical sense, avoidance is dealt with in the collision risk model as micro-avoidance. The avoidance rate includes both forms of avoidance. In practice, the only available evidence for similar species combines both forms of avoidance, with an emphasis on macro-avoidance. What these studies show is that cranes can avoid wind turbines at a range of scales. In acknowledgement of the uncertainty of estimating the exact proportion of flights that will avoid turbines, a range of avoidance rates is presented. This is an accepted way of dealing with this uncertainty in Australian wind farm impact assessments and is discussed in Appendix 7.

A small number of observations of flying Brolgas reacting to wind turbines have been made at the Macarthur Wind Farm (Wood, 2014), indicating that they are aware of turbines and actively avoid them, although they appear not to be deterred by them (even flying low under them). Apart from that, the only other relevant observations are from crane species in Europe and North America. These observations refer to flocking and migrating birds rather than breeding birds. This information is presented for completeness.

Langgemach (2013) reviewed the impact of wind farms throughout Germany and found that up to 2013 there were seven recorded instances of cranes colliding fatally with wind turbines, mostly during night-time autumn migration, from a population numbering in the thousands in an area with many more turbines (e.g. in 2000, Germany had around 9,300 operating wind turbines; by 2012 this figure had risen to 23,000). It is noteworthy that, unlike European Crane, Brolga do not undertake long-distance night migration. It is well known that night-migrating birds are more susceptible to collision with wind turbines and other structures (Drewitt and Langston, 2008, Erickson *et al.,* 2001).

Observations of Sandhill Crane in North America are also informative[4]. Observations at a wind farm in South Dakota showed that out of 66 flocks that approached wind turbines, totalling more than 4,000 individuals, 92% of birds showed an avoidance response (https://cleanpower.org/blog/ windpower-report-whooping-cranes-may-avoid-wind-farms-more-research-ahead/ viewed 2nd February 2022).

A review (Nations *et al.,* 2012) suggested a turbine avoidance rate of between 90 and 95% for collision risk modelling for the Whooping Crane.

The true turbine avoidance rate for the Brolga is unlikely to be determined anytime soon, given the small number of wind farms operating and being monitored specifically for Brolga impacts in south-western Victoria. An informed assumption is therefore unavoidable and has been used in previous wind farm studies in Victoria (e.g. Stockyard Hill, Mortlake, Dundonnell, Golden Plains) and has been found by decision-makers to be informative. Based on the foregoing information, it was considered appropriate to use avoidance rates of 90%, 95%, and 99% and to present the collision risk modelling results for this range of avoidance rates.

Flight speed is another key input to the CRM. A literature review on the flight speed of cranes showed the average flight speed range is between 48 to 64 km/hr (Table 13). Given that the average weight of Brolga (6.15 kg) lies between the average weight of Whooping and Common Cranes, an average speed of 60 km/hr (or 16.7 m/s) was assumed for Brolga for the CRM input.

Table 13: Flight speed of Cranes

[4] Note that a recent study of Sandhill Cranes at four Texas wind farms by Navarrete (2011) has not been used, as a review of its statistical design found it to be flawed as it used parametric statistical tests on frequency and category data, thereby violating the assumptions of the statistical methods.

Species	low weight kg	high weight kg	av. Weight kg	low speed km/hr	high speed km/hr	av. Speed km/hr	Source	estimated speed range km/hr	av. Speed/ av. weight
Sandhill Crane	2.7	6.4	4.55	40	56	48	Journey North 2014	40 - 56	10.5
Sandhill Crane	2.7	6.4	4.55	23	83	53	Melvin & Temple 1982	23 - 83	11.6
Whooping Crane	6.4	7.7	7.05	56	72	64	Journey North 2014	56 - 72	9.1
Common Crane	4	6	5	40	80	60	LPO 2014	40 - 80	12

To summarise, key model inputs concerning the Brolga's flight behaviour were as follows:

- Flight speed: 60 km/hr
- Wingspan: 2 m
- Total length: 1.65 m
- Typical flight: flapping.

5.2.2. Model results

Using the NA-BAND collision risk model, the number of possible Brolga collisions with operating wind turbines at the proposed Hexham Wind Farm was estimated for the 90%, 92% and 95% avoidance rates (Table 14, Appendix 7).

Table 14: Results of Brolga CRM

Avoidance Rate	Collisions/year	Expected Collisions (30 years)	95% predicted Interval (30 years)
90%	0.176	5.3	[1, 10]
92%	0.141	4.2	[1, 9]
95%	0.088	2.6	[0, 6]

For the conservative 90% avoidance rate, between one and eleven birds (95% confidence limits,) may be affected over the 30 years life of the project, with an average of 0.176 collisions per year, resulting in potentially 5.3 Brolga colliding over 30 years. This equates to up to one bird every 3 years assuming a worst case of 10 birds over 30 years, with a mean of one every 5.6 years. This represents about 1.6% of the lower estimated population of 625 birds over thirty years, or a mean of 0.85%.

A PVA has been prepared to examine the population consequences of modelled mortality for the three avoidance rates (Section 5.3; Appendix 8).

5.3. Population Viability Analysis

Step three of the level three assessment in the Interim Brolga Guidelines requires that a PVA be undertaken. Dr M. McCarthy of Melbourne University was commissioned by DELWP (then DSE) to develop the PVA for the southeast Australian Brolga population. He was commissioned to apply this model to determine the impact of the HWF, without compensation, on the future population size of the Brolga in south-eastern Australia.

The PVA is a widely accepted modelling method (DSE, 2012) that attempts to predict the trajectory of the population of a plant or animal and calculates the quasi-extinction probability. Quasi-extinction is not actual extinction but a reduction in population size to a point where recovery of the population is very challenging. Table 15 summarises the results and Appendix 8 provides more detail for the Brolga PVA for the proposed HWF.

Table 15: Results of Brolga PVA (109 turbine layout, RSA height range 40 to 260m)

Brolga population size	Expected natural change in population size*	90% avoidance	92% avoidance	95% avoidance
Expected minimum southwest Victorian population (625 birds)	548.2	545.7	546.2	546.9
Change in population (birds)	-76.8	-2.5	-2.0	-1.3

* In the absence of losses to wind turbines and power lines

The PVA relies on inputs about baseline or current population levels (numbers), population age structure, reproduction rate and survival rate. Using this information, the PVA can predict the population of a species at a range of future times and how this might alter if any parameter changes (e.g. increased reproduction rate or declining adult survival rates). Predictions are made based on an iterative sampling method that averages the findings from 10,000 runs of the model.

The purpose of the Victorian Brolga PVA is to model population scenarios given estimates of the impacts on Brolga survival rate of wind farm developments (using collision risk modelling results) and to set targets for compensation and offset measures to ensure zero net impact on the Victorian Brolga population.

Dr McCarthy applied the Victorian Brolga PVA to the results of the collision risk modelling for the proposed HWF, specifically to the scenario of a Rotor Swept Area (RSA) height range of 40 to 260 m above the ground. The PVA report is provided in Appendix 8, and the results are summarised in Table 15, which estimates the population size after 30 years of operation of the proposed HWF.

In the absence of losses to wind turbines and powerlines, the expected minimum population size over the next 30 years was estimated as 548.2 Brolgas when the initial population size was 625. Based on an expected minimum population of 548.2 birds, the PVA predicts without compensation that after 30 years (the planned life of the wind farm project), the population size will be between 545.6 birds (90 percent avoidance rate) and 546.9 (95 percent avoidance rate), a reduction of between 2.6 and 1.4 birds compared with baseline conditions. The predicted result for a 90% avoidance rate is considered the most conservative collision rate and represents a reduction of about 0.005% of the Victorian Brolga population.

The PVA will be updated once the layout is finalised.

5.4. Compensation measures

The Interim Brolga Guidelines require that the impacts on the Victorian Brolga population predicted in Step Three (i.e. the PVA) are 'fully offset'.

Fully offset would mean that the Victorian Brolga population should have as a precautionary approach 10 more breeding adult Brolgas after offsetting has occurred. Using the conservative 90% avoidance rate scenario for wind farm impacts, a total of 10 new breeding adult Brolgas should be in the population by the end of the 30-year life of the wind farm project. This will ensure that the expected minimum population size remains the same.

A Brolga Compensation Plan will be prepared for HWF in consultation with DEECA, the Glenelg Hopkins CMA, Moyne Shire Council, as well as participating private landowners.

6. Overview of findings

The findings from the level one and two assessments of the Interim Brolga Guidelines are summarised below.

Brolga Flocking

- No Brolga flocking activities were observed in the RoI during the flocking season survey in 2018 to 2020. The proposed wind farm is approximately 20 km from the nearest known flocking site.
- No traditional flocking sites were identified in the RoI through the desktop study or community consultations.
- There is currently no evidence that Brolga use the RoI regularly as a flocking site and therefore no impact on Brolga flocking sites from the project is likely.

Brolga Breeding

- There is evidence of Brolga using wetlands within the RoI for breeding.
- Two pairs of Brolga were observed breeding within the RoI during the 2018 Brolga breeding surveys, eight pairs in 2019, five pairs in 2020, four pairs in 2022, six pairs in 2023 and two pairs in 2024.
- In 2018 to 2024, four wetlands were used by Brolga for breeding within the wind farm boundary, including:
    - Wetland 29420 – August 2019 (incubating) and October 2023 (courtship)
    - Wetland 28240 – October 2020 (nesting) and December 2022 (nesting)
    - Wetland 23 – September 2020 (nesting) and July/August 2023 (nesting, chicks)
    - Wetland 14 – December 2022 (incubating) and September/October 2023 (nesting, chicks)
- Two additional wetlands within the wind farm have previous Brolga breeding records observed by landholders (Wetlands 29401 and 29405). Brolga were sighted at wetland 29405 during the monitoring period however breeding activities were never confirmed. These two wetlands are likely to continue providing Brolga breeding habitat
- Location A (Figure 8), within the wind farm boundary was previously reported to have been used historically for breeding Brolga by a landholder. On review of the location the landholder has advised that this location is not consistent with previous reporting and the area has not been used for Brolga breeding. This area is considered highly unlikely to provide Brolga breeding habitat and was not considered a true breeding wetland.
- Of the 11 farm dams within 2 km of known Brolga breeding wetlands, one dam (farm dam 126) was considered potential Brolga habitat, primarily in wet years (i.e. one in 10) when vegetation growth and water depth are adequate. The remaining ten were considered unlikely to provide Brolga habitat as they lacked Brolga habitat characteristics. None were considered as Brolga habitat when surveyed in September 2024.
- Eighteen wetlands outside the wind farm boundary and within the RoI were confirmed as having Brolga breeding activities or had previous records of Brolga breeding at them and were considered likely to provide Brolga breeding habitat.

- Given that there are Brolga breeding at wetlands within and outside the wind farm boundary, particularly to the north and east, a level three assessment was triggered.
- Of the 79 modelled wetlands, 26 were considered breeding wetlands as they are likely to continue providing breeding habitat. Of these, 10 were located within 2 km of proposed turbine locations.
- Up to eight breeding pairs were estimated within the RoI.
- Brolga risk mitigation involves the establishment of habitat-based turbine-free buffers around 22 breeding wetlands on or near the wind farm.
- Residual Brolga impacts have been determined using the NA - BAND collision risk model, which found:
    - For the conservative 90% avoidance rate, between one and eleven birds (95% confidence limits, mean 5.5) may be affected over the 30 years life of the project, equating to 0.184 collisions per year.
- The PVA estimated that after 30 years at a 90% avoidance rate the reduction of the Brolga population due to the HWF will be 2.6 birds.

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Appendices

Appendix 1: Community Questionnaire

Community Survey Questionnaire- Hexham WF

Date:_____

Landholder's Name:_____

Property Address:_____

The aim of the following survey is to establish a broad-scale understanding of the environment on and around local landholder properties in the region through acquiring information such as; land use, historical land use, management practices, habitats and what flora and fauna are present. This information will inform the design and operation of Hexham Wind Farm.

LAND USE

What is the primary use for your land? E.g. cropping, grazing, mixed, alternating (indicate areas on map) – use attached spreadsheet

What broad land types exist on your land? E.g. arable, stony, aquatic, mixed, cleared (indicate on map) – use attached spreadsheet

How long have you owned or farmed the land?

_____

History / previous land use? – use attached spreadsheet

(If sheep grazing) When and where does lambing typically occur?

_____

_____

Do you remove the carcasses of dead stock? If so, what is the process?

_____

_____

Do you artificially feed stock on your property? - use attached spreadsheet

FLORA

Are there native plant communities / habitats on your property you are aware of?

Yes / No

What type? E.g. wetlands, woodlands, grasslands, rocky outcrops (indicate on map)

_____

How do you manage these areas? (i.e. fencing stock, weed control)

_____

_____

Has there been changes to wetlands in and around your land? When, what caused this? (i.e. drainage for cropping purposes)

_____

_____

_____

_____

Are you aware of any of the following threatened flora species on your property?

Matted Flax Lily Yes / No

Spiny Rice Flower Yes / No

Others?

_____

FAUNA

Are you aware of feral animals on your land? E.g. Rabbits and warrens, foxes, deer etc…

_____

_____

Do you manage feral animals on your land?

Yes / No

Are you aware of any of the following species on your land?

Wedge-tailed Eagle	Yes / No	Nests present?	Yes / No
Fat-tailed Dunnart	Yes / No		
Striped Legless Lizard	Yes / No		
Swamp Skink	Yes / No		
Growling Grass Frog	Yes / No		
Golden Sun Moth	Yes / No		
Brolga	Yes / No	Nests present?	Yes / No
Owl Species	Yes / No		

Bats (followed-up with all participants):
Supplementary question: Are you are aware of bat caves or bat daytime roosting areas in and around your property?

BROLGA SPECIFIC

Have Brolgas occurred on your land? Yes /no

Explain _____

_____

For each sub-area (paddock) of your land subject to different land use histories, how often and in what numbers have you seen Brolgas?

Area No (see map)	1	2	3	4	5	6	7
>10 birds*							
5-10 birds							
3-5 birds							
1-2 birds							
None							
Never							
>20 yrs ago							
10-20 yrs ago							
<10 yrs ago							

* If more than 10, estimate actual observed numbers or range of numbers.

If yes to the above - locate areas on maps

Have there been changes in the wetlands in and around your land?

When ? What was the cause ?

_____

_____

_____

Additional Comments on Brolgas

_____

_____

Appendix 2: Total and mean rainfall (mm) for the region taken from Mortlake (BOM 2024)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2010	23.6	78.8	57.2	50.8	31.8	51.4	40.6	167.0	65.6	70.2	64.8	129	830.8
2011	134.4	87.0	63.2	55.0	66.2	59.6	58.8	41.0	43.6	39.0	39.2	15.4	702.4
2012	17.0	3.6	45.0	30.2	55.8	57.0	92.4	74.6	55.0	46.0	26.0	45.0	547.6
2013	1.6	22.6	16.6	11.6	60.8	63.8	66.8	106.4	60.6	85.4	39.4	24.2	559.8
2014	30.4	7.2	19.0	69.4	35.6	100.4	59.2	39.4	23.6	18.0	36.6	20.8	459.6
2015	65.6	36.2	45.8	23.6	64.8	38.2	58.2	40.6	35.2	12.8	19.6	29.2	469.8
2016	37.0	17.6	31.6	37.6	102.4	62.8	103	51.4	119.8	95.4	38.0	32.6	729.2
2017	42.8	37.8	40.0	117.2	52.2	12.0	48.2	71.8	69.6	42.4	83.4	24.4	641.8
2018	13.0	17.0	21.2	23.0	104.4	61.8	65.4	57.4	23.4	14.8	39.6	39.0	480.0
2019	5.6	23.4	33.2	12.4	132.0	92.2	67.4	82.0	55.6	51.0	42.6	18.2	615.6
2020	19.2	75.2	18.6	67.6	88.4	49.6	27.2	74.6	94.0	101.6	71.2	42.6	729.8
2021	93.8	8.4	24.2	36.4	68.0	67.2	71.8	54.0	69.0	95.8	34.4	11.6	634.6
2022	83.6	2.0	57.8	24.0	27.4	82.6	55.0	79.0	70.4	146.8	86.8	41.0	756.4
2023	12.0	59.4	40.6	70.0	62.8	89.0	36.2	28.4	28.0	47.4	28.4	64.0	566.2
2024	57.2	1.6	3.6	63.4	20.8	24.6	87.6	30.8	47.8	31.2	37.8	53.2	459.6
Mean	**42.5**	**31.9**	**34.5**	**46.1**	**64.9**	**60.8**	**62.5**	**66.6**	**57.4**	**59.9**	**46.4**	**38.4**	**623.1**

Appendix 3: Summary of wetland site-assessments from 2018-2020 within 5 km of the project site (Nature Advisory)

Wetland No.	Redefined wetland no.	Past breeding record	Breeding	Wetland description summary
A		(Landholders)	No	No wetland present and does not hold water. The landholder has indicated that this is not a Brolga breeding site. It is no longer considered a Brolga breeding site.
B	29401	(Landholder)	Yes	A well-inundated dam. Contains an island with planted trees. No emergent vegetation. Possible breeding habitat in times when dam floods. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
C	9	2007(Nature Advisory VBA) and landholder 2020 (Nature Advisory)	Yes	Some emergent vegetation is present, with a reasonable coverage of water. Water >70% throughout breeding season.
D		2008 (Nature Advisory, VBA, and landholder)	Yes	Wetland is present.
E		(Landholder)	Yes	Wetland is present.
F	29405	2009 (landholder)	Yes	Permanent waterbody. Fenced off from stock. Contains planted eucalypts and associated vegetation on the fringes. Phalaris up to the edge. N arm of the wetland holds a suitable swampy area covered in emerging vegetation. Water levels in some areas may be suitable. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
H		2018 & 2019 (Landholder)	Yes	Large, drained wetland with scattered dams that holds water and vegetation in rainy years, allowing Brolgas to breed.
J		(Landholder)	Yes	Located in the floodplain of the Mustons Creek. May hold water in flooding events.
25681			Habitat	Large wetland, but currently the area of standing water is well below capacity and dry by October. Some emergent vegetation, but little in extent. Cattle are currently excluded from the site and are present in neighbouring paddocks.
28200			Habitat	Water below minimum capacity. Appears drained, with sheep present in the wetland area.
28203		1984 (VBA literature report)	Yes	No wetland at VBA point, though likely to refer to wetland 28203. A review of aerial photography of the wetland shows it has managed wetlands and seems permanently drained,

Wetland No.	Redefined wetland no.	Past breeding record	Breeding	Wetland description summary
				but this has not been confirmed on site. It has been included as breeding wetland as a precaution.
28213			Habitat	Drained wetland which currently only holds notable water within drainage channel. Reasonable amount of tussock cover present around the drainage line. Still held water at the time of aerial surveys.
28236	18		Habitat	This wetland was an open freshwater marsh with some emergent and extensive low fringing vegetation. Supports approximately 12 pairs of Black Swan, with potentially one old nest on site. Likely to be too shallow for Brolga nesting most years. Grazed by cattle. The wetland held water until the last survey in December. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28238				Wetland is permanently drained with multiple drains diverting water into a nearby creek.
28240		2020 (Nature Advisory)	Yes	Very good wetland covered in emergent vegetation (rush-water ribbon). Water was estimated at 70% in December. Drainage from the northern dam feeds this wetland. Tussock grasses and rocks are emergent in standing water across the site. Island of three trees present in centre. Pair foraging in the NW side of wetland. Large nest just E, close to the island.
28243	16		Habitat	Largely permanent waterbody. Little emergent vegetation present, only fringing. Would hold enough water for successful breeding. Down to 60% in December.
28245	29420	2019, 2020 (Nature Advisory)	Yes	A large marshy wetland, well vegetated with Poa Tussocks. Fenced (Landcare) and some sheep present but only lightly grazed. Breeding attempt in 2019. The wetland was still at 50% in December. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28248			Habitat	Aerial surveys located a swan nest. Habitat also includes billabongs.
28249	23		Yes	A shallow freshwater marsh containing extensive emergent vegetation for Black Swan to nest (5 nests and cygnets seen). A pair of Brolga were seen foraging, and a large empty nest was observed. Poa Tussocks extensive on western side but grazed. Waterbirds include Black Swan, Masked Lapwing, Yellow-billed Spoonbill, Black-winged Stilt, Pacific Black Duck, Grey Teal, White-faced Heron, Pink-eared Duck. Common Froglet also present. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.

Wetland No.	Redefined wetland no.	Past breeding record	Breeding	Wetland description summary
28252	29411	1984 (VBA literature report and landholder)	Yes	Ephemeral wetland that could provide nesting habitat in a wet year. Partially drained as determined by aerial survey. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28259		(Landholder)	Yes	Wetland half drained, the northern half looks to hold water and has emergent vegetation. Likely to provide breeding habitat.
28261	29414	(Landholder)	Yes	Wetland still present, likely to continue to provide breeding habitat for Brolga. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28263	11		Habitat	Appeared drained. Held 30% water by November and 10% by December. The extent is mostly pasture grasses with a small cluster of rush in the middle. A small creek flows through which held some water and vegetation and lined with River Red-gum. Confirmed drained by aerial survey. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28264	29416	Record from EHP report	Yes	Power line development piling soil on its W side and lots of machinery around. 50% water in December and good fringe vegetation of tussocks and high grasses. It may provide good habitat once work ceases. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28265			Habitat	No access. This wetland looks suitable from aerial photography, and forms part of a larger wetland system.
28266			Habitat	No access. This wetland looks suitable from aerial photography, and forms part of a larger wetland system.
28267		(Landholder)	Yes	Large wetland with some drainage. From aerial photography, it looks like it is a good breeding habitat for Brolga. One Black Swan was observed during the aerial survey. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28269			Habitat	No access. Two Brolgas were observed during the aerial survey. View is very restricted from the roadside due to trees. But wetland is currently a large body of water that appears to be free of stock. Little to no fringing or emergent vegetation present. Appears at least semi-permanent.
28271			Habitat	Initially not accessible. One Black Swan was observed during the aerial survey.

Wetland No.	Redefined wetland no.	Past breeding record	Breeding	Wetland description summary
28273			Habitat	Wetland has been permanently drained, and only a small dam remains. Currently surrounded by a plantation.
28348	107		No	Drained. Appears to be former flooded creek flats that would have flooded after major rain. Now supports 'improved' pasture. Part of the wetlands' original extent borders a creek. The creek mostly supports phragmites and planted eucalypts. The area is grazed by cattle.
28351	108		No	A large dam with steep banks and deep water. Does not support fringing, floating or emergent vegetation. Grazed in surrounding paddocks by sheep.
28352	102 & 103		No	River meander floodplain with good vegetation cover but no water. No standing water visible beyond large built-up dams with steep banks. Lacks most resources required for breeding. Cattle present. Both drained and dammed.
28353			Habitat	Small farm dam surrounded by trees and bushes.
28354	127		No	Appears at least semi-permanent. Steep banks, deep water, and lack of fringing and emerging vegetation. No waterbirds were present. A farmyard immediately overlooking the wetland/dam may be a source of disturbance. The wetland has experienced some drainage.
28358			Habitat	May hold water during wet years.
28360			Habitat	Black Swan was observed during the aerial survey.
28366		2008 (Nature Advisory, VBA and landholder) 2019 (Nature Advisory).	Yes	Brolga sighted incubating 26/7/19. Great wetland, large. Abundant emergent and fringing veg. Many waterbirds present, including breeding Black Swans. Water permanent or semi-permanent. One swan was observed during the aerial survey.
28387			Habitat	Seems permanently drained but not confirmed on-site.
28801	14		Yes	Currently water at a desirable depth for Brolga breeding. Some tussock grasses present. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28803			Habitat	Site currently supports sheep and has quite a few fences interspersed across the small property. Limited areas of standing water, though where water does occur, suitable tussocky veg also occurs. Level and extent of water currently observed is not suitable for breeding, but the site has some potential if conditions are to improve with more rainfall. Water levels down to 20% in December.

Wetland No.	Redefined wetland no.	Past breeding record	Breeding	Wetland description summary
28916	29460	2019, 2020 (Nature Advisory)	Yes	Brolga pair seen incubating in September 2019. The landowner says they have been around for the last 7 years. Water down to 40% in December. Two swan pairs and large nests observed. The wetland has tall sedgy vegetation covering it almost entirely and was fenced by GHCMA in July. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28966	29402	Landholder record from EHP report	Yes	Brolgas often forage here, according to landowner Rob. Most of this wetland site is not currently inundated, with much of the land closest to the road comprising thistles and heavily grazed currently supporting sheep. However, there is a section to the rear of the wetland which is currently holding water and in at least moderate condition for breeding. Multiple swan pairs at this location. Water levels were still high in December. Aerial surveys concluded this wetland to be subject to partial drainage. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
28986			Habitat	Permanent water in dam. Floodplain was moist but no water seen. Large tussocks and overall good wetland vegetation remain intact. Some cows in area.
29047	29404	1987 (VBA, landholder)	Yes	Fenced off and free of stock. Lined along edges with planted River Red Gum. The wetland itself appears full of water. The depth of wetland was unclear from the road. Grassy islets. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
29066			Habitat	Viewed from quite a distance from the roadside. Little to no emergent vegetation present, though appears to be at least semi-permanent. Black Swan present. Observation during aerial survey suggests it is drained.
30273			Habitat	West of the road: No water present, perhaps drained. Cattle present. East of the road: Currently holding suitable amounts of water, with good amounts of fringing vegetation and some emergent vegetation. Largely permanent. Black Swan breeding. Some raised island sections may hinder the preferred 360° view for Brolga breeding.
30276			Habitat	For the most part it is low quality and ephemeral. Water down to 60% in December, with cropping and draining evident. Nice patch of tussock vegetation that does become inundated to the far east of this wetland. Sheep present.

Wetland No.	Redefined wetland no.	Past breeding record	Breeding	Wetland description summary
30302			Habitat	Currently not inundated but does have great coverage of tussocks. Offline wetland to the waterway. Stock appears absent from site. If inundated, could become a high-quality site.
30307			Habitat	Dammed creek line, very shrubby with no open areas for nesting or surface water.
30312	106		No	A large, open water permanent farm dam with planted eucalypts lining the southern edge. The dam has steep banks and deep water. No floating, emergent or fringing vegetation. The dam supports a variety of waterbirds, and one Growling Grass Frog was heard in 2018.
30320	101		No	Farm dam with permanent water but no fringing or emergent vegetation. Access by cattle.
30330	20	2019 (landholder).	Yes	South side areas are suitable, with permanent water and fringing and emergent vegetation. Landowners see brolgas often and have seen them breeding, being followed by a small chick. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
30352			Habitat	Dammed, does hold water and likely to have emergent vegetation.
30366			Habitat	Open creek line with open woodland and tussocks. Black Swan nesting. Water levels still good in December.
30450			Habitat	Very good wetland with grassy cover and abundant waterbirds, down to 10% in December. Close to road and settlements.
	8		No	Very shallow, reaches up to 0.1 m deep. A deep drain was developed through this wetland in 2021. The wetland has not held water since. Permanently drained.
	12		Habitat	Semi-drained wetland that holds water on occasion.
	105		Habitat	Small dam with seasonal overflow in wet years. No emergent vegetation or littoral zone.
	109		No	Small farm dam with access by animals and no vegetation.
	110		No	The wetland fully drained, road crossing over.
	111		Habitat	Farm dam with high banks and pasture grass.
	112		No	Roadside farm dam. Brolgas were observed foraging here due to its proximity to suitable wetlands. Typical small farm dam with bare earth edges and no suitable Brolga breeding habitat.
	113		No	Farm dam lacking fringing and emerging vegetation.

Wetland No.	Redefined wetland no.	Past breeding record	Breeding	Wetland description summary
	114		No	Farm dam that overflows in wet years. Access of cattle keeps it vegetation-free.
	115		No	Semi-permanent farm dam. No fringing or emerging vegetation. The wetland did not meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
	116		No	Farm dam that may overflow in wet years. No emerging vegetation. Brolgas may forage due to proximity to suitable wetland.
	117		No	Small farm dam.
	118		No	Farm dam. Does not seem to overflow in wet years to allow Brolga to breed.
	119		No	Farm dam that overflows in wet years. Lack of vegetation and too close to main road.
	120		No	Farm dam. Does not seem to overflow enough in wet years to create a larger wetland.
	121		No	Farm dam surrounded by trees. No fringing vegetation.
	122		No	Farm dam with some fringing/emergent vegetation when overflows.
	123		No	Dam with gum plantation. Semi-permanent and showing fringing vegetation in wet years.
	124		Habitat	Permanent farm dam with fringing and some emergent vegetation. Wetland expands in wet years, creating suitable habitat. The wetland did meet the minimum breeding habitat suitability criteria in the hydrologist assessment.
	125		No	Drained. Only farm dam keeps water.
	126		Habitat	Semi-permanent farm dam. Minimal emerging vegetation. Island vegetation potentially suitable as habitat in wetter years.

Notes: green – confirmed breeding wetlands, blue – Brolga habitat, grey – not considered Brolga habitat (permanently drained or farm dams)

Appendix 4: Water Technology Wetland Analysis

Hexham Wind Farm – Wetland Analysis

Hexham Wind Farm Pty Ltd

21 August 2025

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

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Project Name	Hexham Wind Farm – Wetland Analysis
Client	Hexham Wind Farm Pty Ltd
Client Project Manager	Rory McManus
Water Technology Project Manager	Ben Hughes
Water Technology Project Director	Ben Tate
Authors	Ben Hughes, Charles Lee
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15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800
Fax (03) 9558 9365
ACN 093 377 283
ABN 60 093 377 283

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21 August 2025

Rory McManus
Development Manager
Hexham Wind Farm Pty Ltd
Suite 10 | 19-35 Gertrude St | Fitzroy | Victoria 3065
Via email rory.mcmanus@windprospect.com.au

Dear Rory

Hexham Wind Farm – Wetland Analysis

This report documents an assessment of the long-term inundation regime of depressions within and surrounding the Hexham Wind Farm. The inundation regime of these depressions has been used to identify their potential as brolga breeding habitat by specialist ecologists.

Yours sincerely

Ben Hughes
Senior Principal Engineer

Ben.hughes@watertech.com.au

WATER TECHNOLOGY PTY LTD

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1 INTRODUCTION

1.1 Overview

Hexham Wind Farm Pty Ltd are completing investigations into their proposed wind farm located between Hexham, Caramut and Ellerslie in south-west Victoria (Figure 1-1). Hydrologic and hydraulic modelling was completed to inform the assessment of potential impacts on brolga and their potential breeding and night roosting habitat. This modelling was then used as a basis for more detailed review and site assessment by specialist ecologists Nature Advisory.

It should be noted that this modelling and report has not been used to discount Brolga breeding wetlands which need to be considered in accordance with the Interim Brolga Guidelines

1.2 Purpose of the report

This report details the assessment methodology and the surface water modelling results dictating which areas were highlighted as potential brolga breeding habitat. The objectives of this assessment are summarised below:

- Determine which areas within and surrounding the Hexham Wind Farm have the potential to have water pooling.
- Assess the likelihood water will remain in these pools for a time sufficient to support successful brolga breeding and night roosting.

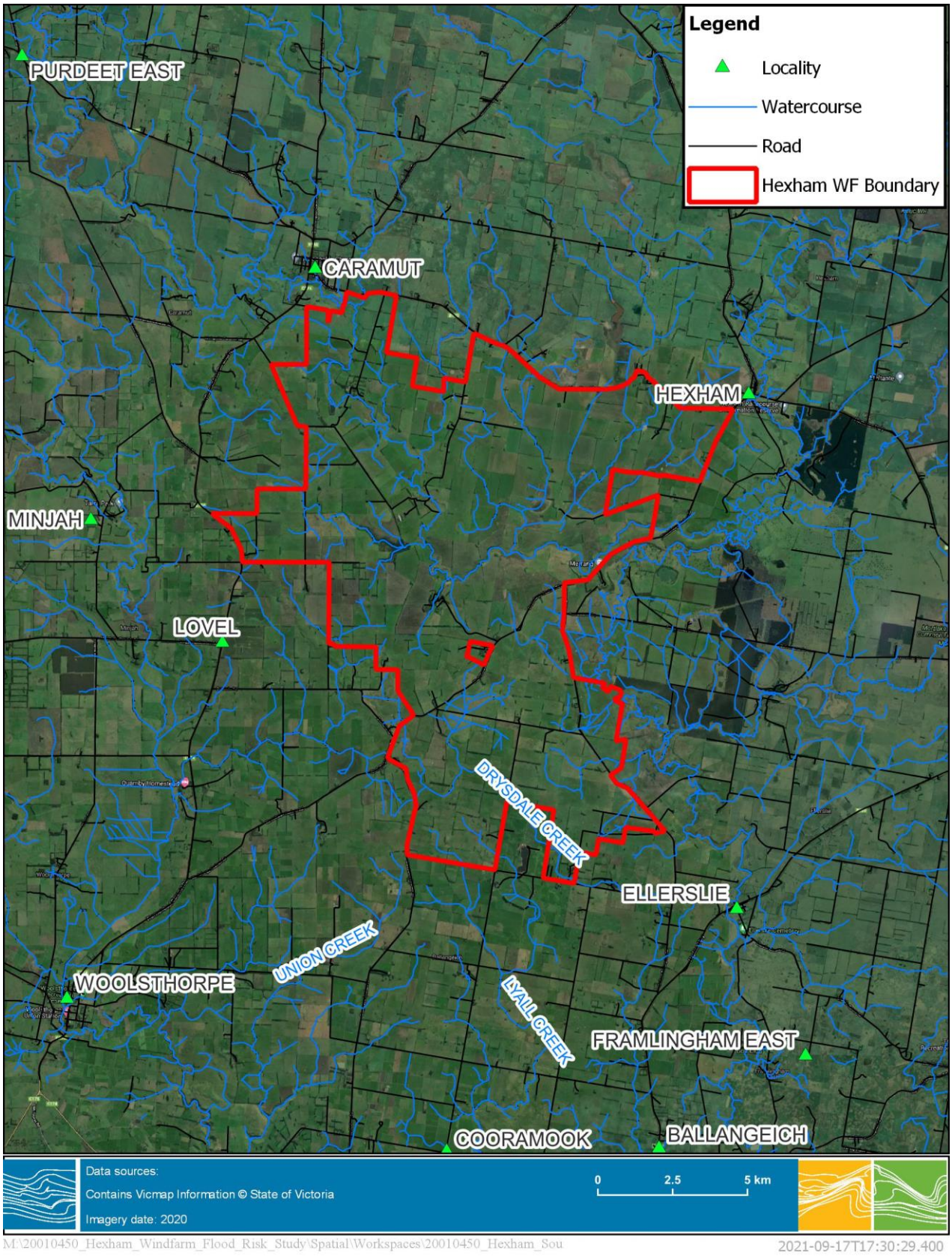


FIGURE 1-1 SITE LOCALITY

2 METHODOLOGY

2.1 Overview

The assessment methodology aimed to identify areas which held water for more than 120 consecutive days between July and December from the beginning of 2009 to the end of 2019 within and surrounding the proposed Hexham Wind Farm.

The inundation period of 120 days and the 10 year time period was advised by the Department of Environment, Land, Water and Planning (DELWP), now the Department of Environment, Energy and Climate Action (DEECA). Brolga nest in wetlands with emergent vegetation that holds water for at least 120 days, permitting nest building, egg laying and incubation, hatching and the growth of chicks to an age where they can walk to nearby wetlands should the original breeding wetland dry out (Nature Advisory, 2021).

Given the large and hydrologically complex nature of the windfarm area several steps and modelling tools were used to complete this assessment, an overview of these tasks is provided below with detail included in the sections that follow.

- A 'Rain on Grid' hydraulic model of the proposed windfarm and upstream catchment area was developed and modelling of the 1% Annual Exceedance Probability (AEP[1]), 72-hour event was undertaken to gain an understanding of overland flow paths, wetland interrelationships and wetland extents. The hydraulic model was run for seven days post rainfall ceasing allowing all water to flow to its terminal wetland/waterway
- All current DEECA mapped wetlands were modelled (hydraulic model results provided more accurate representation of the DEECA mapped wetland extents rather than relying on those digitised by DEECA relying on aerial imagery).
- All areas with a depth of greater than 2cm were filtered from the hydraulic model results and polygons of areas with depths greater than 2cm were created. It is standard practice in 'Rain on Grid' models to remove shallow depths which may be inaccurate due to minor incontinences in the model topography.
- All inundated areas less than 0.1 Ha (1,000 m^2) were removed. Nature Advisory advised that wetlands less than 0.1 Ha (1,000m^2) are not suitable for breeding habitat based on a review of brolga nesting habitat sites.
- Manual assessment of the remaining wetlands was completed, screening those from detailed analysis if they met the following criteria:
  - The wetland contained an excavated earthen channel connecting to a downstream drain, downstream waterway or downstream wetland that would prevent it from holding water for any significant period.
  - The wetland had a relatively small size (only slightly above 0.1 Ha), was shallow (less than 300mm - the Source model results showed wetlands generally need to have a maximum depth of at least 300mm to maintain water for more than 120 days) and had a small catchment area.
  - Incorrect topographic representation resulted in the water pooling – e.g. a road culvert was not represented.

[1] Annual Exceedance Probability (AEP) refers to the probability of a flood event occurring in any year. The probability is expressed as a percentage. For example, a large flood which may be calculated to have a 1% chance of occurring in any one year, would be described as 1% AEP flood event.

- An eWater Source hydrologic model was developed of the remaining wetlands to determine a daily water level series for each from 2000-2020 inclusive.
- The wetlands located adjacent to and potentially impacted by Mustons Creek are not suitable for hydrologic modelling using Source. These wetlands were assessed using a separate detailed hydraulic model with determined flow rate in the creek.
- All areas modelled in Source that held water for at least 120 days during the July to December period were mapped.

2.2 Hydraulic Modelling

Hydraulic modelling of the Hexham Wind Farm project area was completed using TUFLOW[2]. TUFLOW is one of the most widely used hydraulic modelling software packages in Australia and is the preferable modelling package for Glenelg Hopkins CMA (which the Hexham Wind Farm is within). The software is considered an appropriate modelling tool for modelling of the site. A Rain on Grid approach was used, allowing the simulation of runoff generated from local rainfall on a two-dimensional (2D) grid representative of the site topography (i.e. a 2D grid of cells with assigned topographic values). The TUFLOW model was used to identify how wetlands and other depressions are filled, their maximum expected extent and interconnections. The TUFLOW model had four key inputs, these included:

- A Digital Elevation Model (DEM) – The DEM was constructed by combining LiDAR data specifically flown for the Hexham Wind Farm (and provided by Hexham Wind Farm Pty Ltd at a 1m grid resolution) within the proposed windfarm and the VicMap20m DTM outside the proposed windfarm area. The combined DEMs were resampled to a 5x5 m grid resolution and were adopted in the model development to enable reasonable model run times.
- Hydraulic roughness – Roughness was modelled using a Manning's 'n'[3], determined using planning layers and verified using aerial imagery, the adopted values are highlighted in Table 2-1.
- Rainfall depths and temporal pattern - Bureau of Meteorology 2016[4] recommended Intensity Frequency Duration (IFD) rainfall data was adopted for modelling of the 1% AEP, 72-hour event. Temporal Pattern 08 was applied.
- Losses – No losses were used in the hydraulic modelling which determined the wetlands which required further assessment.

TABLE 2-1 MANNING ROUGHNESS COEFFICIENTS AND LOSSES

Land Use Type	Manning 'n'
Residential footprint – rural	0.04
Industrial/Commercial	0.03
Road	0.025
Farming zone	0.045

[2] https://www.tuflow.com/

[3] Manning's roughness coefficient is used in the Manning's formula to calculate flow in open channels - Chow, V.T. (1959) Open Channel Hydraulics. McGraw-Hill, New York.

[4] http://www.bom.gov.au/waterdata/

The hydraulic model was run for seven days post rainfall had ceased to allow water to drain to each depression. Results were also filtered to remove all depths less than 2cm ensuring very shallow areas were not erroneously indicating inundation.

The hydraulic model results at seven days post rainfall are shown in Figure 2-1.

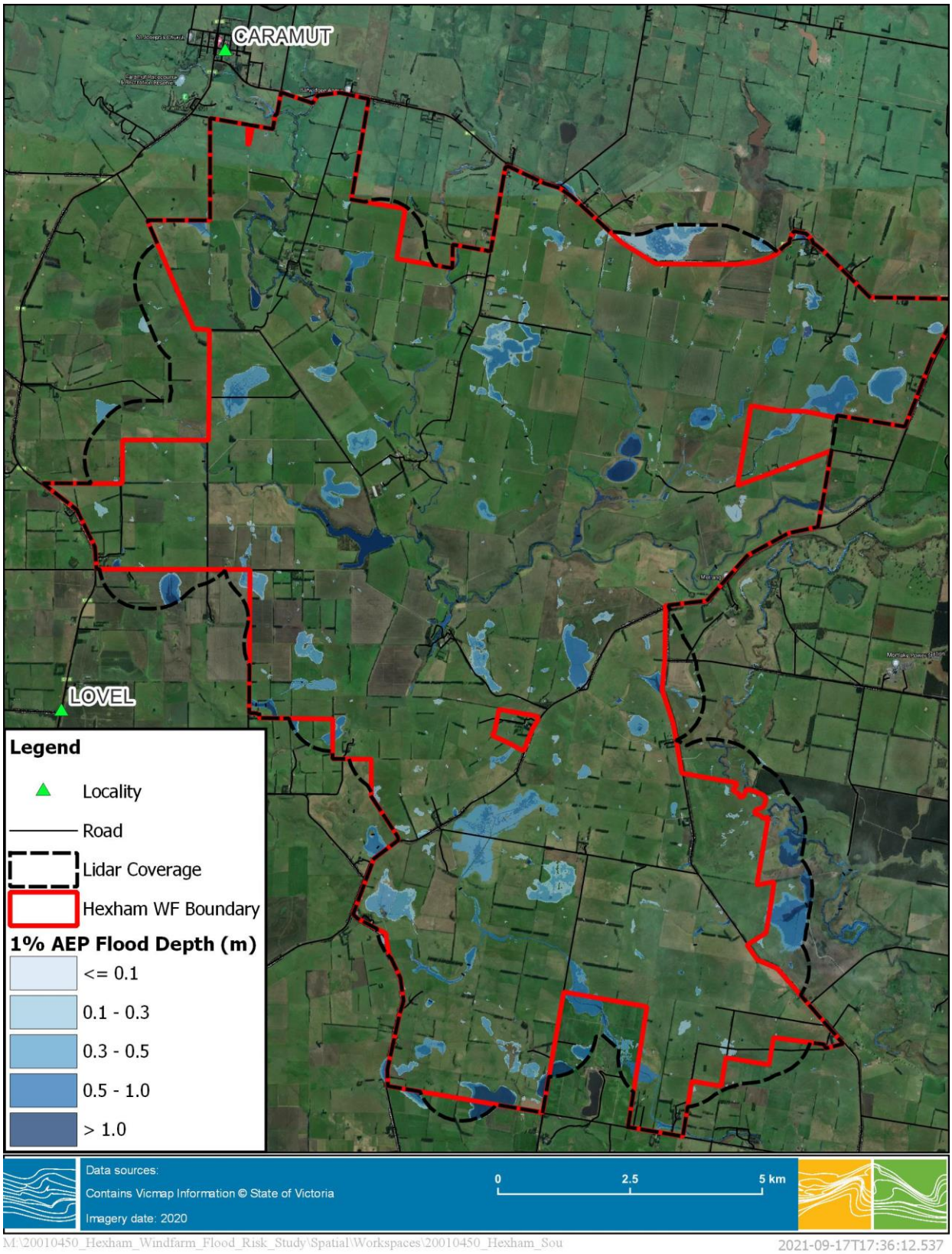


FIGURE 2-1 INUNDATION WITHIN THE PROPOSED HEXHAM WIND FARM – 1% AEP, 72 HOUR EVENT, 7 DAYS POST RAINFALL OCCURRING.

2.3 Wetland Selection

As discussed in Section 2.1, the hydraulic model results were used to delineate which wet areas would move to a more detailed hydrologic assessment. Inundated areas with an area of less than 0.1 Ha were removed, this left approximately 750 potential wetland sites across the windfarm area. These areas were assessed using a desktop assessment of LiDAR, hydraulic model results and aerial imagery to exclude those that did not require detailed modelling. There were three main reasons a wetland could be excluded from detailed modelling, these were as follows, with an example of each shown in Table 2-2.

- The wetland contained an excavated earthen channel connecting to a downstream drain, downstream waterway or downstream wetland that would prevent it from holding water for any significant period.
- The area had a relatively small size (only slightly above 0.1Ha), was shallow (less than 300mm – the Source model results showed wetlands generally need to have a maximum depth of at least 300mm to maintain water for more than 120 days) and had a small catchment area.
- Incorrect topographic representation resulted in the water pooling – e.g. a road culvert was not represented.

Farm dams were also excluded from the detailed assessment. Farm dams are constructed for the purpose of holding water for extended periods and no assessment was required to demonstrate their potential to hold water for more than 120 days.

TABLE 2-2 EXAMPLE EXCLUSIONS

Reason for exclusion	Explanation	Figure
Drained area	Drainage lines are observed on satellite imagery and topography. The drains are smaller than the hydraulic model resolution but have been constructed to prevent water from accumulating for long periods.	
Relatively small size (only slightly above 0.1Ha), was shallow (less than 300mm) and had a small catchment area	The wetland has an area of 1500 m^2, maximum depth of 0.18 m and there is no obvious upstream catchment that could contribute water or connectivity to nearby wetland areas.	

Reason for exclusion	Explanation	Figure
Incorrect topographic representation	The roads representation in the DEM prevents the area from draining, however a culvert under the road not modelled would enable water to move from one side to the other.	

2.4 Hydrologic Modelling

Wetlands which were selected for longer term hydrologic analysis were modelled in Source[6]. Source was used to conduct water balance modelling of each wetland individually or as a series of connected wetlands.

Source was used to estimate runoff volumes and wetland levels and included the following key components:

- Sources of inflow water to the water bodies (watercourses and wetlands) was rainfall and rainfall runoff.
- Outflows from the watercourses and wetlands modelled included evapotranspiration, evaporation (from the surface areas of wetlands and watercourses), interflow with soil layers and deep seepage to groundwater.

The interactions between these components over time produced a water level time series for each modelled wetland. An example of how one of the Source models was schematised is shown in Figure 2-2.

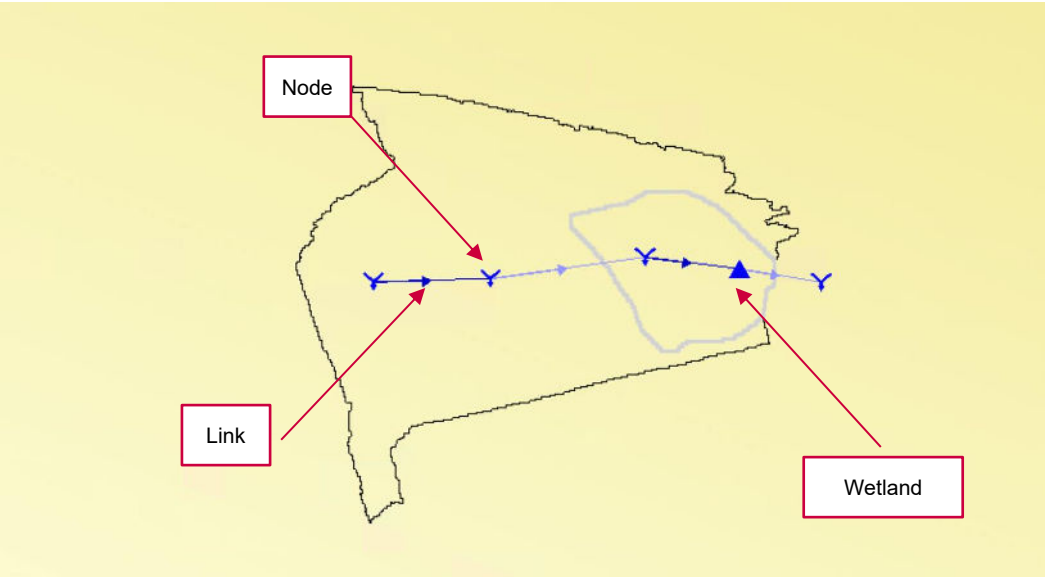


FIGURE 2-2 SOURCE MODEL

The rainfall runoff model adopted in Source was SIMHYD, estimating the flow generated from each sub-catchment based on the applied climatic data (rainfall and evapotranspiration). Climatic data was obtained from SILO Queensland Point Data and applied to the sub-catchments based on closest proximity. The model used the default parameter values outlined for the SIMHYD model in eWater Source documentation[2] as there was no gauge data available to calibrate the models. Catchments are represented by nodes, watercourses by links, and storage nodes for wetlands.

The model required daily rainfall and potential evapotranspiration data and had nine parameters as shown in Table 2-3, along with their recommended range.

TABLE 2-3 MODEL PARAMETERS

Parameter	Description	Units	Min	Max
Baseflow coeff.	Base flow Coefficient		0.0	1.0

[6] https://ewater.org.au/products/ewater-source/

Parameter	Description	Units	Min	Max
Impervious Threshold	Impervious Threshold	mm	0.0	5.0
Infiltration Coeff.	Infiltration Coefficient		0.0	400
Infiltration shape	Infiltration Shape		0.0	10.0
Interflow Coeff.	Interflow Coefficient		0.0	1.0
Perv. Fraction	Pervious Fraction		0.0	1.0
Recharge coefficient	Recharge Coefficient		0.0	1.0
RISC	Rainfall Interception Store Capacity	mm	0.0	5.0
SMSC	Soil Moisture Store Capacity	mm	1.0	500

Given the similarity of the landform, the rainfall runoff parameters were adopted using the values for Willatook Windfarm Wetland Analysis undertaken by Water Technology (2021). During the Willatook study, a single catchment was used as the basis for comparing model results to estimates made using the Australian Rainfall and Runoff (2019) Regional Flood Frequency Estimation (RFFE) model[7].

The comparison showed adopting the default Source parameters resulted in flow estimates higher than those recommended by the RFFE model, but within the estimated confidence limits. The default Source parameters were modified to achieve a closer match to the RFFE model estimates. A comparison of the RFFE model estimates and confidence limits was made against the modelled Source flows adopting both the default and modified model parameters, as highlighted in Table 2-4 and Figure 2-3.

TABLE 2-4 ADJUSTED PARAMETERS IN SOURCE

	SMSC	Infiltration Coefficient	Interflow Coefficient
Default parameters	320	200	0.1
Modified parameters	450	350	0.5

[7] https://rffe.arr-software.org/

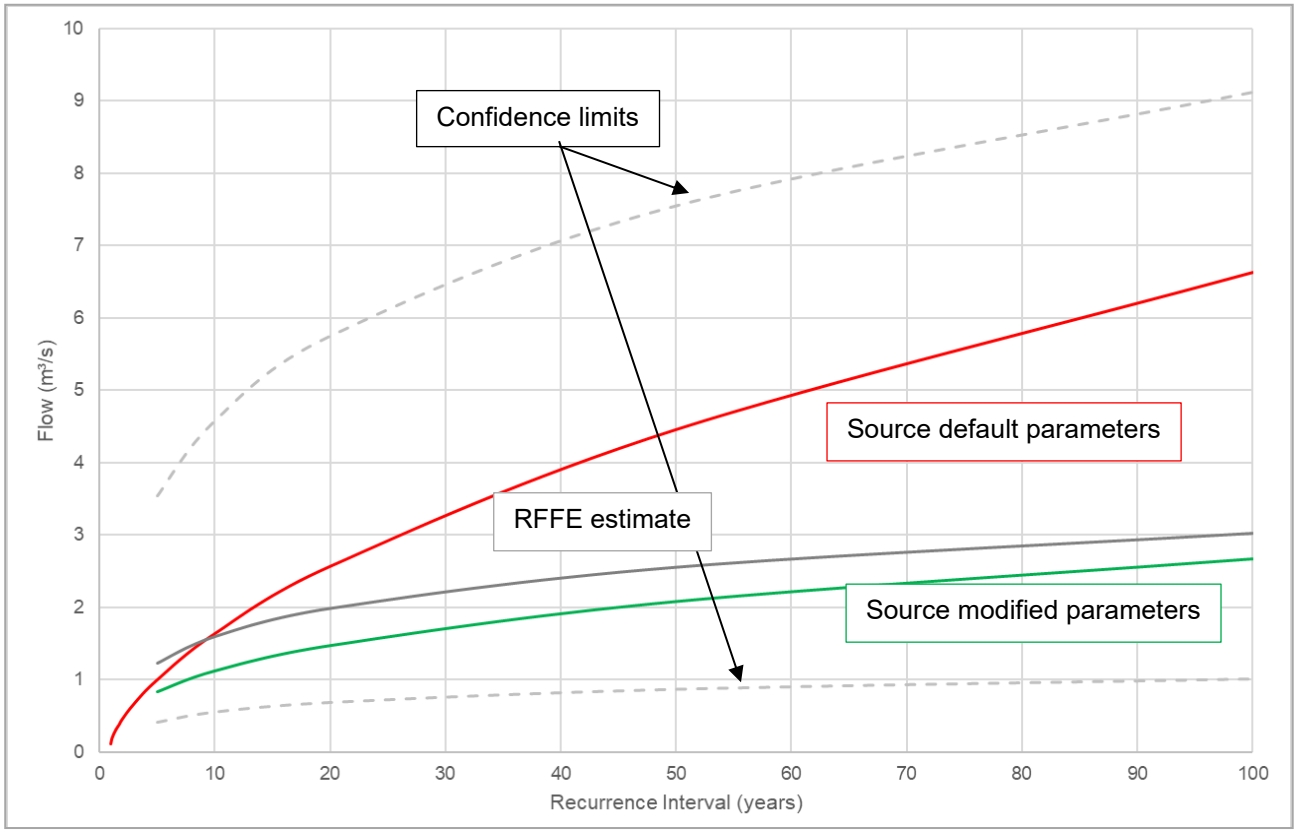


FIGURE 2-3 COMPARISON OF RFFE AND SOURCE DISCHARGES FOR DIFFERENT RECURRENCE INTERVALS

The wetlands were modelled as part of the catchment they were located within, with zero infiltration loss to rain applied to the wetland area. Each wetland was assigned rainfall and evapotranspiration data associated with its location, zero infiltration occurred within each wetland. Each wetland was also set to start with zero initial volume.

The water level between 01 Jan 2009 to the 01 Jan 2019 was determined for each wetland and those which met the 120-day continuous inundation criteria in any instance from July to December were highlighted as prospective brolga breeding and night roosting habitat for further assessment.

3 RESULTS

From the modelling undertaken the following was identified:

- The hydraulic modelled identified 748 areas which required further assessment. Of these:
  - 75 had incorrect topographic representation within the model.
  - 498 had constructed drainage from the invert of the depression.
  - 44 were excluded because of their limited size, depth and catchment area. This combination of low depth, the size being close to 0.1 Ha and the small catchment mean these areas would dry quickly.
  - 99 were farm dams.
  - 24 were deemed suitable and required further hydrologic assessment.
  - 6 wetlands were assessed using hydraulic model as they were potentially impacted by riverine inundation in addition to local runoff.
  - 2 wetlands were determined as suitable for brolga breeding and night roosting directly from the aerial image.
- The detailed hydrologic assessment determined 18 of the 24 wetlands assessed in detail met the inundation criteria required for the areas to be hydrologically suitable for brolga breeding and night roosting.
- The detailed hydraulic assessment determined all 3 assessed wetlands were inundated by flooding from Mustons Creek, hence suitable for brolga breeding and night roosting.

The areas modelled and those highlighted for further assessment are shown in Figure 3-1. The inundation of assessed wetlands from Mustons Creek are outlined in Figure 3-2. Those that met the inundation criteria, including farm dams are shown in Figure 3-3.

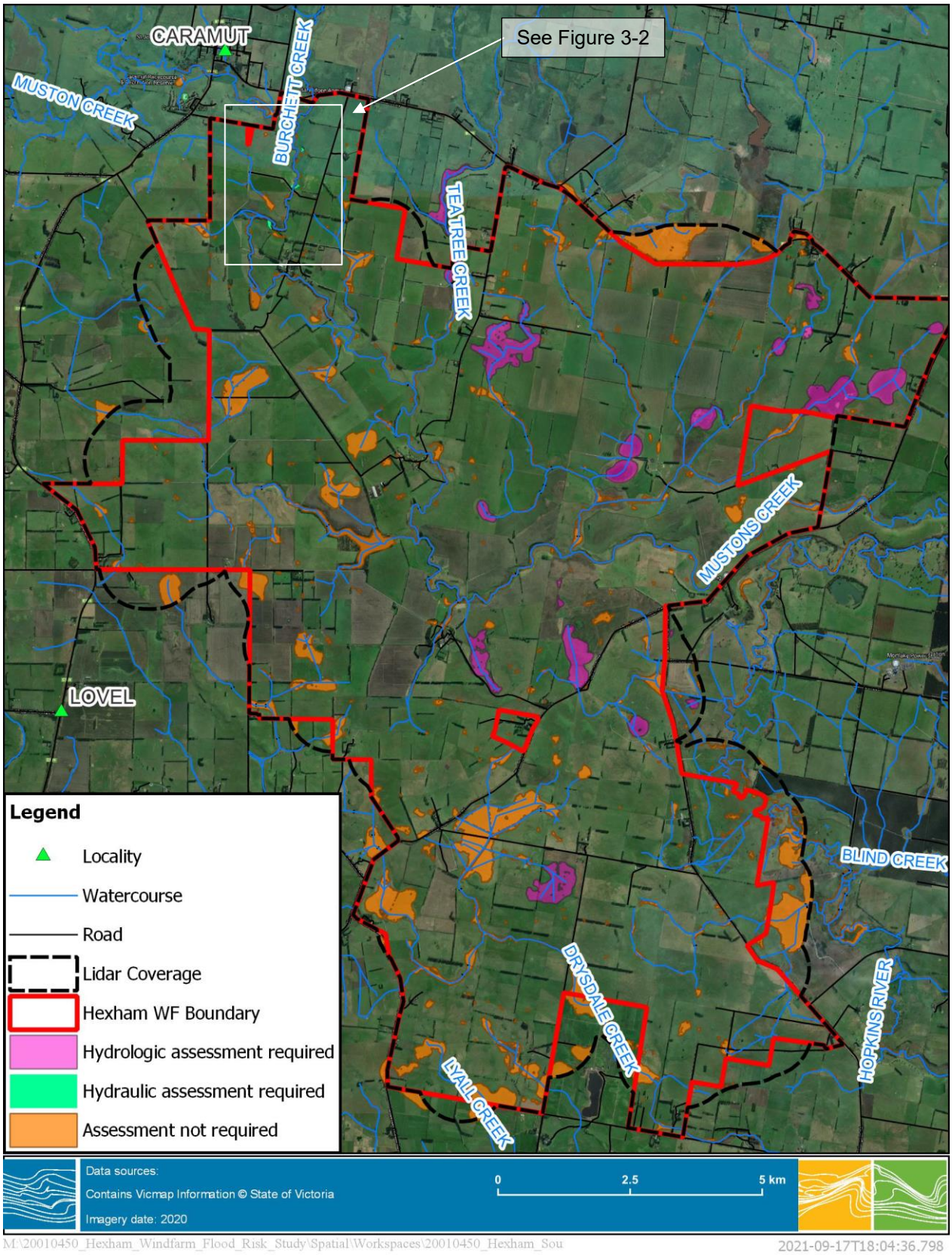


FIGURE 3-1 AREAS HIGHLIGHTED AS REQUIRING DETAILED HYDROLOGIC ASSESSMENT

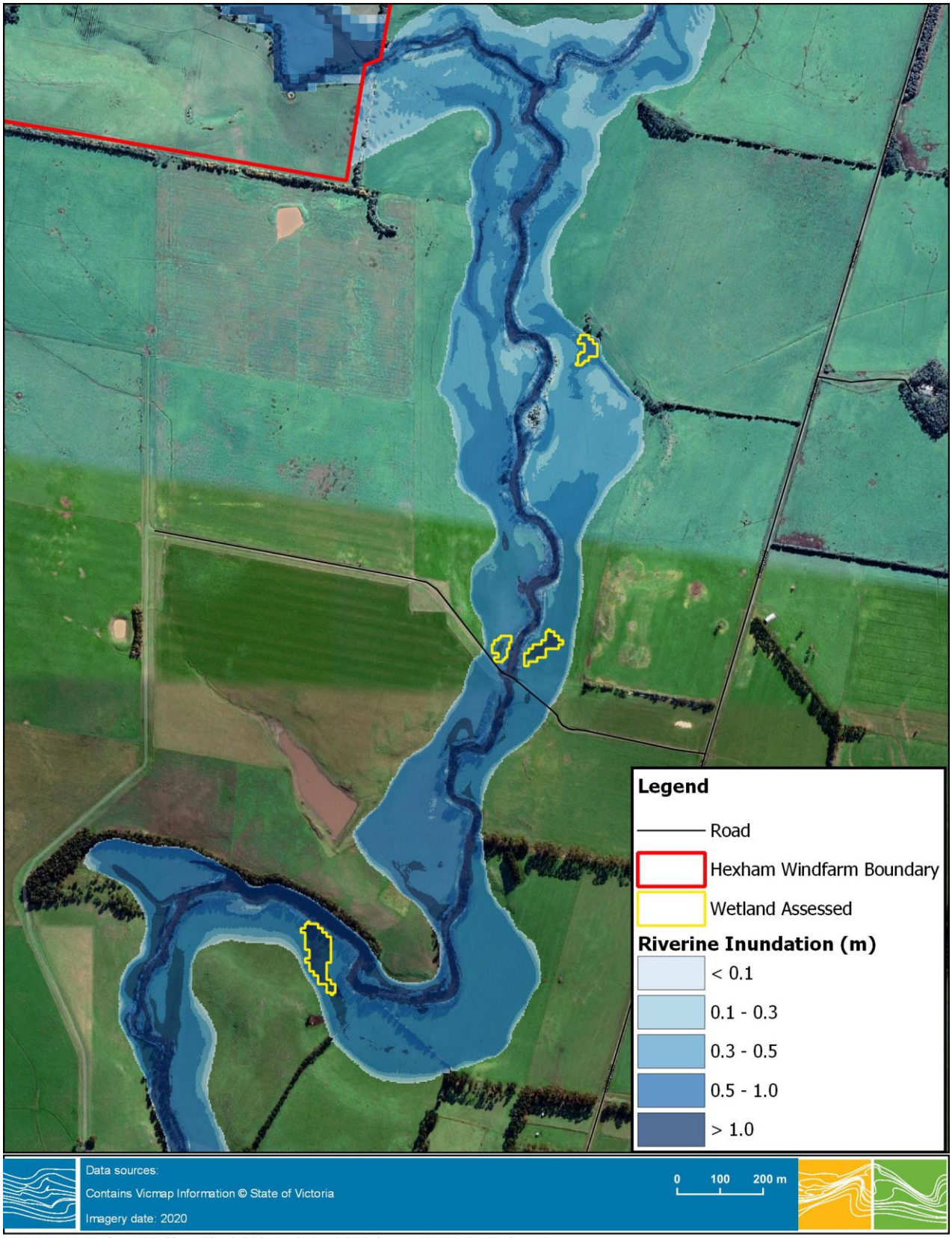


FIGURE 3-2 WETLANDS IMPACTED BY RIVERINE INUNDATION

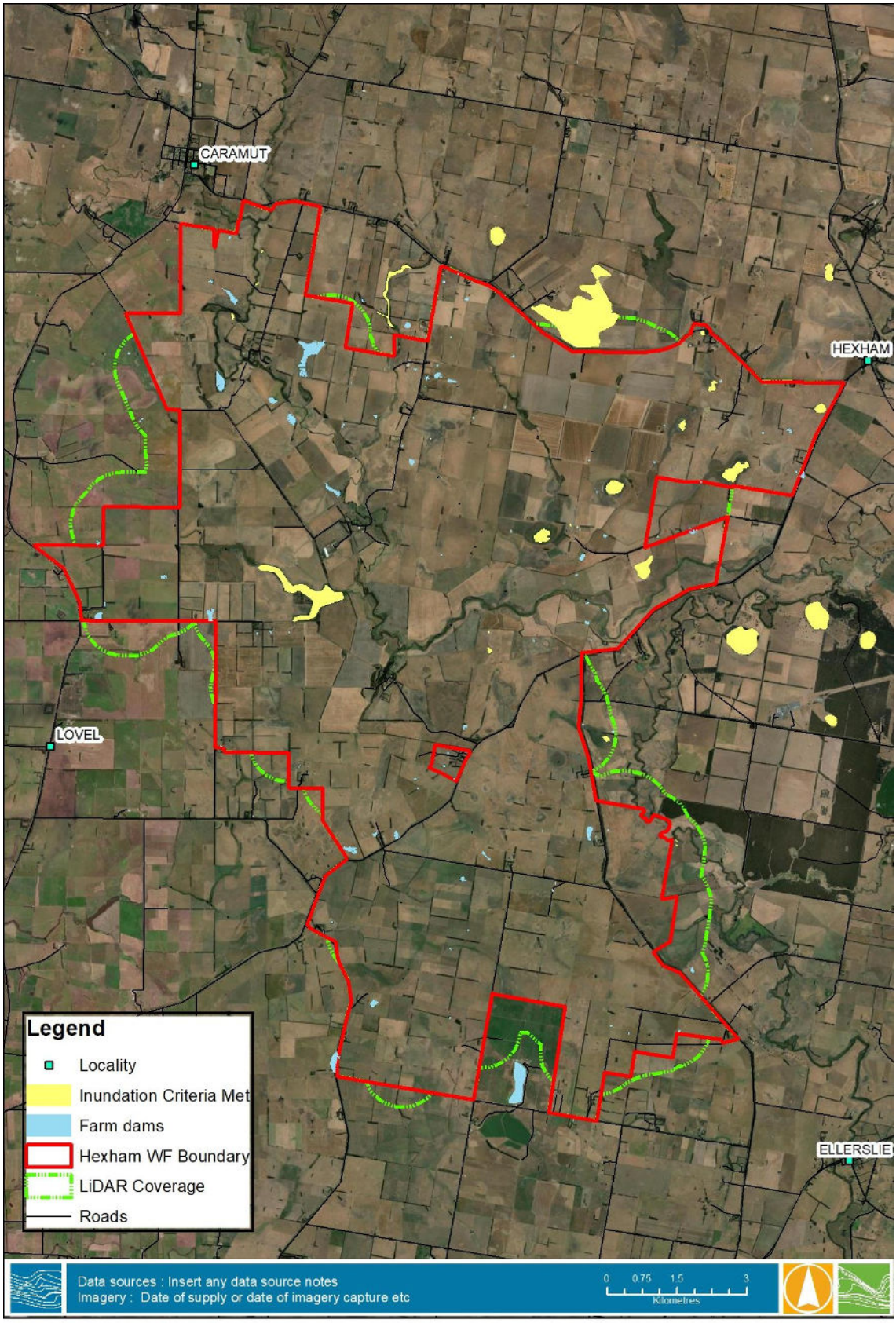


FIGURE 3-3 AREAS HIGHLIGHTED AS MEETING THE INUNDATION CRITERIA

Melbourne

15 Business Park Drive
Notting Hill VIC 3168
Telephone (03) 8526 0800
Fax (03) 9558 9365

Brisbane

Level 3, 43 Peel Street
South Brisbane QLD 4101
Telephone (07) 3105 1460
Fax (07) 3846 5144

Adelaide

1/198 Greenhill Road
Eastwood SA 5063
Telephone (08) 8378 8000
Fax (08) 8357 8988

Perth

Ground Floor
430 Roberts Road
Subiaco WA 6008
Telephone 0438 347 968

Geelong

PO Box 436
Geelong VIC 3220
Telephone 0458 015 664

Gippsland

154 Macleod Street
Bairnsdale VIC 3875
Telephone (03) 5152 5833

Wangaratta

First Floor, 40 Rowan Street
Wangaratta VIC 3677
Telephone (03) 5721 2650

Wimmera

PO Box 584
Stawell VIC 3380
Telephone 0438 510 240

www.watertech.com.au

info@watertech.com.au

Appendix 5: Water Technology – Assessment of Wetland 28238

MEMORANDUM

Date	21 August 2025
To	Rory McManus | Hexham Wind Farm
From	Ben Hughes | Water Technology
Subject	Wetland assessment – Wetland 28238
WT ref	23010166_M01V04_Wetland_28203_Assessment.docx

1 OVERVIEW AND PURPOSE

The proposed Hexham Wind Farm development area is located between Hexham, Caramut and Ellerslie in south-west Victoria. The area extends around 20km to the south from Caramut. The development area is spread across the several waterways, including Limestone Creek, Mustons Creek and Spring Creek, within the Glenelg Hopkins Catchment Management Authority (GHCMA) management area. Much of the site is low lying and has a poorly defined natural drainage systems with some constructed drainage. Land use within development area and upstream catchments is a mixture of private and public land that is largely used for agriculture, predominantly sheep and cattle grazing with some cereal and fodder crops.

As part of the development assessment, hydrologic and hydraulic modelling was completed to inform the assessment of potential impacts on brolga and their potential breeding and night roosting habitat. This modelling was then used as a basis for more detailed review and site assessment by specialist ecologists Nature Advisory.

The hydrologic assessment determined wetland 28238 (as mapped and numbered by the Department of Energy, Environment and Climate Action (DEECA)) was not hydrologically suitable for brolga breeding due to its lack of ability to sustain water within it for 120 consecutive days during the brolga breeding period of July and December. The assessment determined water would not pool in the wetland for extended periods due to constructed drains and the nature of its topography. Wetland 28238 is located around 7km south west of Hexham. Wetland 28238 is the first in a chain of three directly connected wetlands, consisting of wetlands 28238, 28237 and 28236. Limestone Creek runs through the wetlands, running on the eastern side of 28238 and the centre of 28237 and 28236.

Additional analysis was undertaken to confirm initial assessment findings, that the wetland was permanently drained. This assessment included review of the wetland's topography, review of aerial and satellite images and a site visit to assess the presence of drains and assess their efficiency.

The location of wetland 28238 and the surrounding wetlands are shown in Figure 1-1.

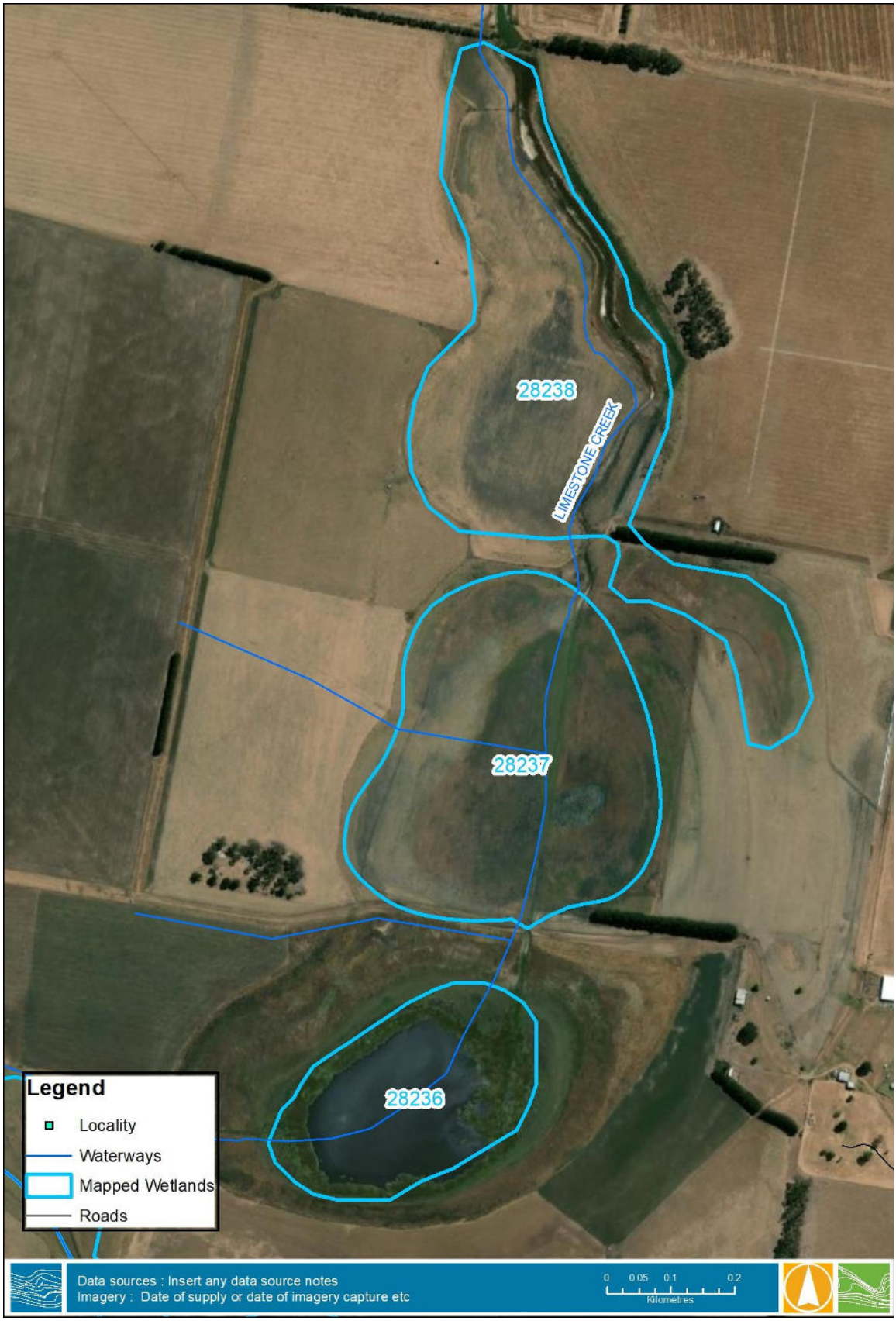


Figure 1-1 Wetland 28238 and downstream wetlands 28237 and 28236.

2 ASSESSMENT

2.1 Topographic review

The topography within and surrounding wetland 28238 is shown in Figure 2-2. The topography shows the wetland can freely drain to Limestone Creek and onto wetland 28237. There are several perimeter drains within the wetland, taking water from its outer edges to Limestone Creek. There are no areas lower than Limestone Creek or are disconnected from Limestone Creek within wetland 28237, allowing it to drain freely. The topography indicates water will not pool for extended periods, but the wetland may remain inundated by flooding of Limestone Creek for very short periods. The connection between wetland 28238 and wetland 28237 looks to be natural; however, some excavation may have been made to improve its drainage efficiency.

The drains shown in the topography are highlighted in Figure 2-2.

2.2 Aerial imagery review

A review of the available historic detailed aerial photography was undertaken for wetland 28238. Google Earth imagery was available for several dates. These dates and the observations made for each date are as follows:

- December 2006 – No water present in the wetland or Limestone Creek.
- December 2011 - No water present in the wetland, some water present in Limestone Creek.
- February 2013 - No water present in the wetland or Limestone Creek.
- January 2014 - No water present in the wetland or Limestone Creek.
- December 2016 - No water present in the wetland or Limestone Creek.
- October 2018 - No water present in the wetland or Limestone Creek.
- August 2019 – Some water in the wetland drains and Limestone Creek.
- May 2021 - No water present in the wetland or Limestone Creek.
- November 2021 - No water present in the wetland or Limestone Creek.
- October 2023 - No water present in the wetland, some water present in Limestone Creek.

Review of the available aerial imagery did not show any inundation in wetland 28238, aside from some water in the constructed drains. The available aerial imagery is shown in Appendix A.

2.3 Satellite image review

A review of the available satellite imagery was undertaken using data captured by Sentinel-2 L1C. Sentinel-2 is a European wide-swath, high-resolution, multi-spectral imaging mission. Its high-resolution optical images are often used for monitoring land use change and were extensively used to monitor flooding in Victoria during flooding on the Murray River in late 2022.

South west Victoria had an especially wet period during July-October 2016. The closest rainfall gauge to the Hexham Wind Farm is Mortlake Racecourse, Bureau of Meteorology (BoM) gauge 090176. The rainfall gauge has recorded daily totals from 1990 to present day. The mean monthly rainfall totals recorded at the gauge are compared to those recorded in 2016 are compared in Table 1. The totals recorded in May, July, September and October are considerably higher than the mean values, with the 2016 September rainfall more than double the mean monthly rainfall.

Table 1 Mortlake Racecourse – mean and 2016 monthly comparison

Month	Mean (mm)	2016 (mm)
May	56.3	102.4
June	54.0	62.8
July	62.3	103.0
August	64.2	51.4
September	57.9	119.8
October	56.2	95.4
November	49.2	38.0
December	40.2	32.6

The available Sentinel-2 data was reviewed through the late 2016 period (June to December) was used to identify any potential inundation or signs of history inundation in wetland 28238. Images were captured during several dates with cloud cover. The dates with clear imagery and a description of the imagery are as follows:

- 15 June 2016 - Water is present in Limestone Creek at around bankfull. Potentially some inundation within the drains of wetland 28238.
- 14 August 2016 – Water in Limestone Creek, no water shown in wetland 28238.
- 06 October 2016 – Water in Limestone Creek at around bankfull. Potentially some inundation has occurred in wetland 28238, as indicated by the dead vegetation. Dead vegetation is significantly larger in the downstream wetland 28237.
- 15 November 2016 – No water in Limestone Creek. Wetland 28238 is dry and may have been cut for hay or sprayed given it is completely brown.
- 12 December 2016 - water in Limestone Creek. Wetland 28238 is dry and may have been cut for hay or sprayed given it is completely brown. Wetland 28237 appears to have held some water given the black water damaged vegetation.

During the very wet period of late 2016, review of the available aerial imagery did not any inundation in wetland 28238 aside from some water in the constructed drains and within the Limestone Creek channel banks. If there was any water present in wetland 28238, it would have only been for a short period directly after the heavy rainfall, but nothing appears to have been present for an extended period. The downstream wetland 28237 shows more inundation than wetland 28238. The satellite imagery used is shown in Appendix B.

Sentinel-2 data is available from 2016 to current day, with imagery available in within most months across those years. Each available image in August, September, October and November in 2016 through to 2024 was reviewed. The largest amount of water shown in wetland 28238 occurred on the 12th of October 2022, as shown in Figure 2-1. The image shows water within Limestone Creek only, with no water shown in the wetland itself. No images showed water in the wetland with very few capturing any water at all.

Figure 2-1 Wetland 28238 on the 12th of October 2020.

2.4 Site visit

A site visit was undertaken on 11 September 2024 to gain an on-ground perspective of wetland 28238. The site inspection largely verified the desktop observations made via the topographic and aerial/satellite image review. The wetland inlet and outlet were viewed along with the drains within the wetland. There was no water within the wetland, although 2024 had been especially dry. There was water flowing in Limestone Creek and into the downstream wetland 28236.

Perimeter drains were evident, and the wetland is expected to function more as a pocket of floodplain rather than an area which would sustain water for any prolonged period of time. Flow through the wetland is constrained by its outlet where a natural/potential partially excavated area of rock limits the flow out of the wetland. This control is lower than the wetland itself allowing it to drain.

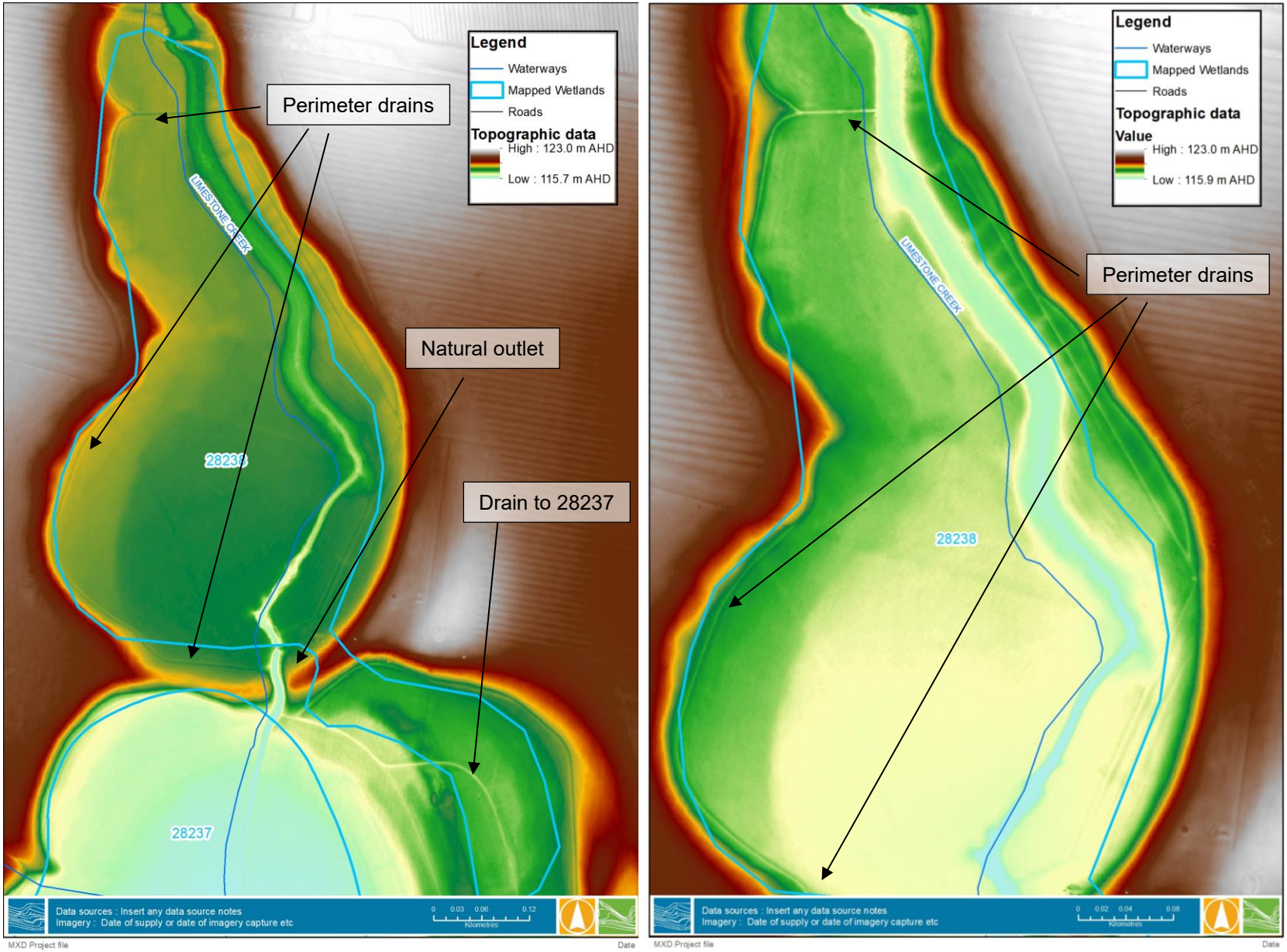


Figure 2-2 Wetland 28238 topography.

Figure 2-3 Edge of wetland 28238, showing perimeter drain

Figure 2-4 Limestone Creek between wetland 28238 and wetland 28237

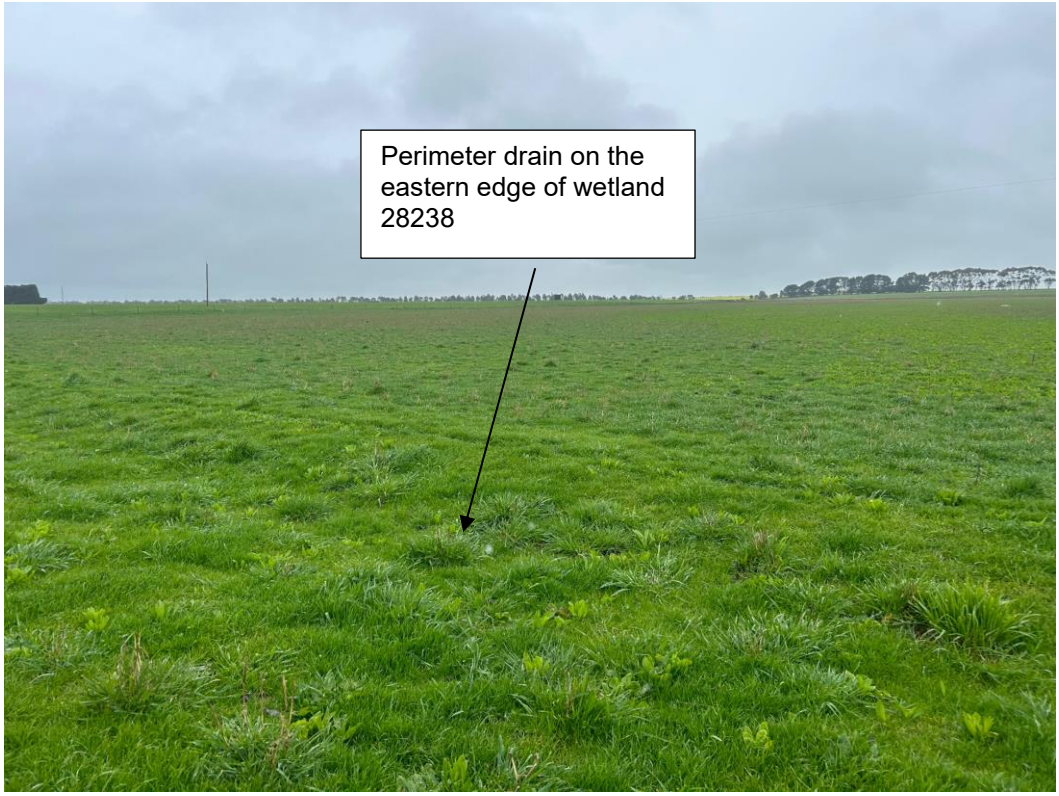


Figure 2-5 Edge of wetland 28238, showing perimeter drain

Figure 2-6 Limestone Creek upstream of wetland 28238

3 FINDINGS

The follow points describe wetland 28238's hydrologic characteristics based on the site inspection, aerial/satellite images and topography:

- It is permanently drained.
- Hydrologically, the wetland is more of a floodplain, conveying water and not an area which would hold static water for extended periods, only experiencing inundation immediately post rainfall or when there is flooding in Limestone Creek. It is expected flooding of Limestone Creek would last hours or potentially up to several days, at which point water would flow downstream and there would be no extended period of inundation with wetland 28238 outside a maximum of several weeks.
- The wetland and its drains were part of a grazed paddock.
- It is assumed the drains would be maintained if there was cause for maintenance (i.e. blockages) as no blockages were observed onsite.
- Both aerial and satellite imagery indicated no period of extensive inundation. This includes the very wet late 2016 period in south west Victoria, in which no evidence of prolonged inundation was observed.

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

APPENDIX A
AERIAL IMAGERY

December 2006
Limestone Creek

December 2011
Limestone Creek

February 2013
Limestone Creek
N

January 2014
Limestone Creek

December 2016
Limestone Creek

October 2018
Limestone Creek

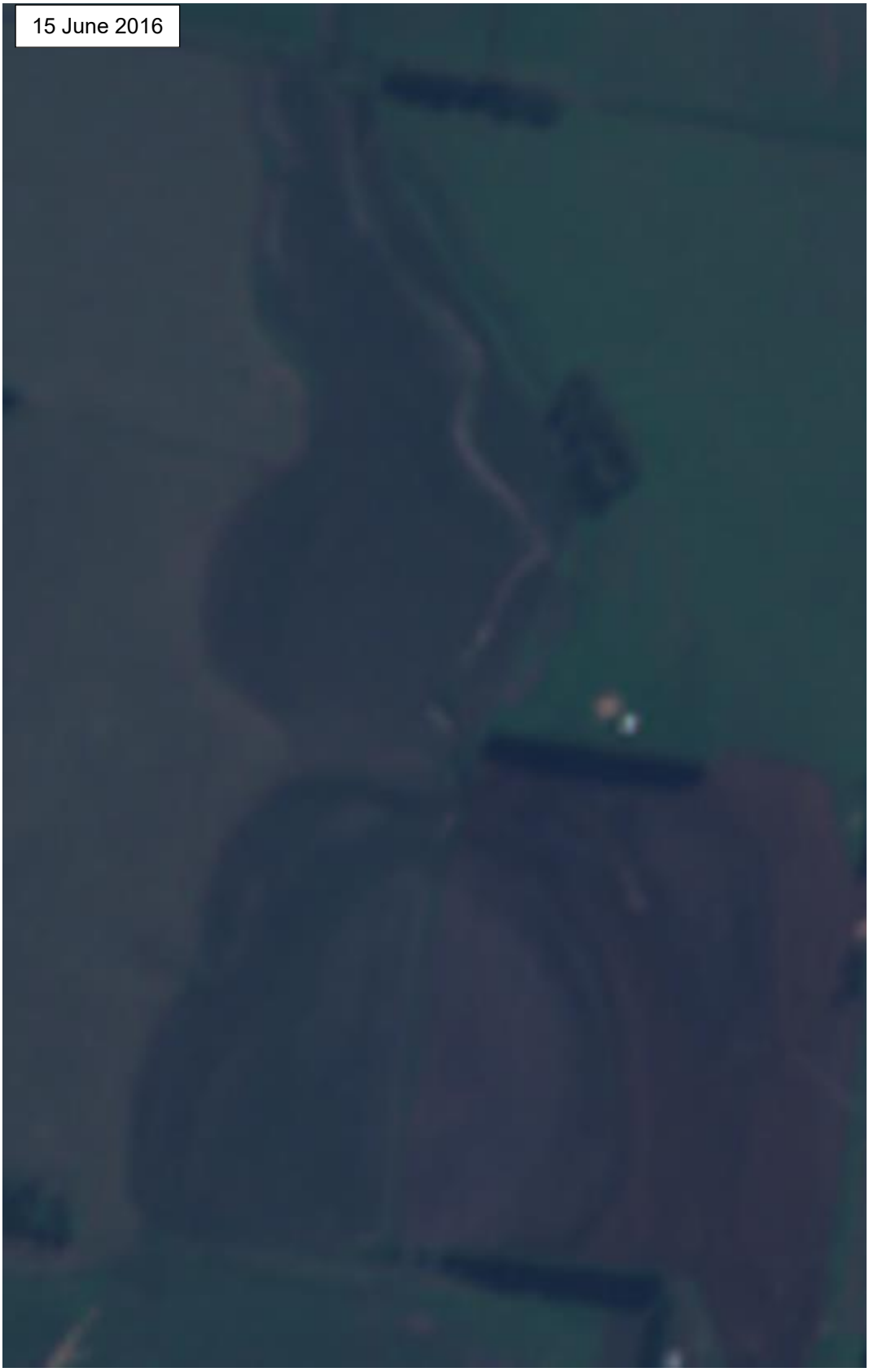
August 2019
Limestone Creek

May 2021
Limestone Creek

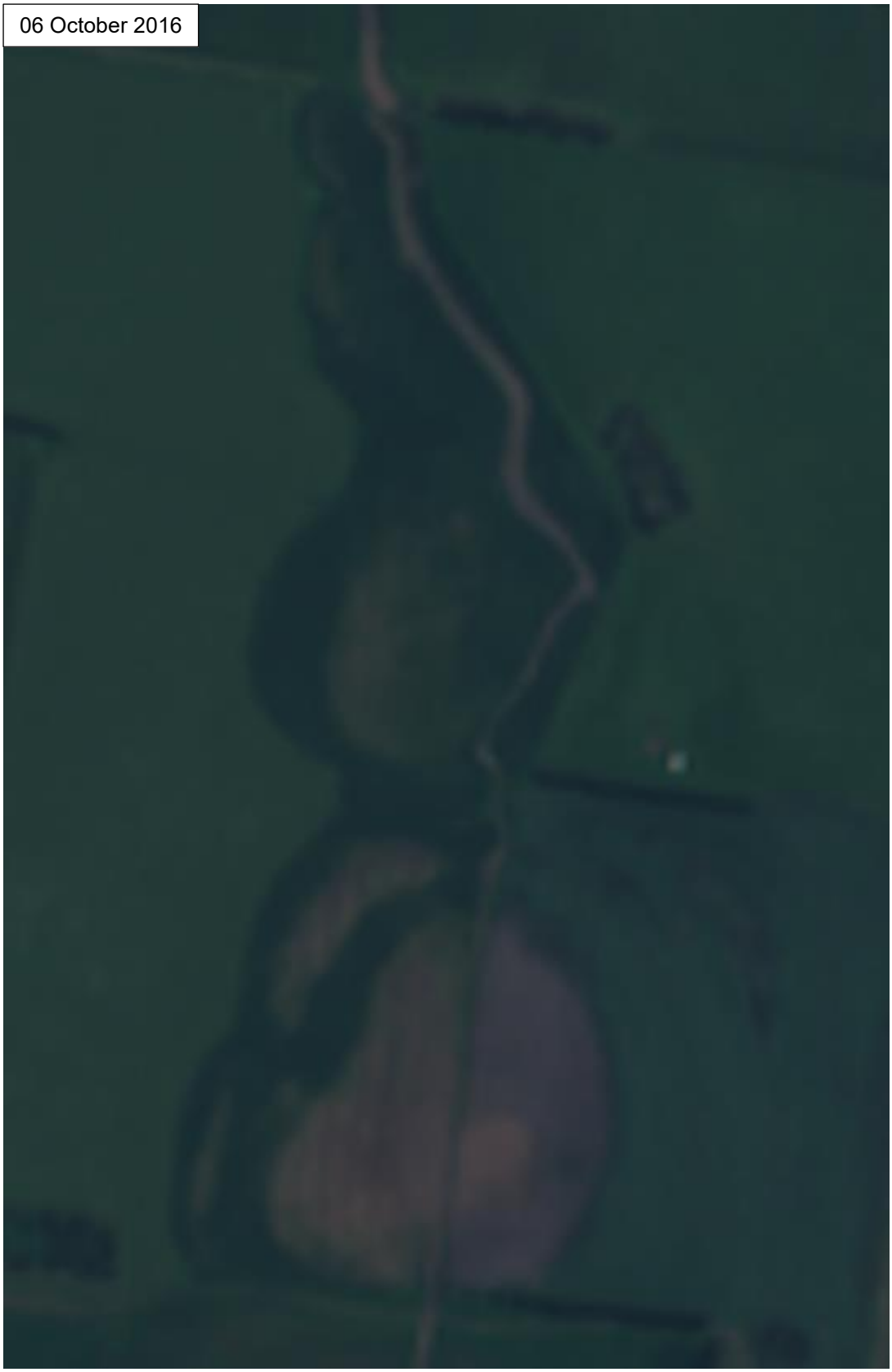
November 2021
Limestone Creek

October 2023
Limestone Creek

APPENDIX B
SATELLITE IMAGERY


15 June 2016

14 August 2016


06 October 2016

15 November 2016

12 December 2016

Appendix 6: Observations of the Brolga pair that regularly nest and forage at Macarthur Wind Farm

A pair of Brolga regularly breed at the Macarthur project site in two different wetlands surrounded by turbines. Monitoring activities have been undertaken in the past decade since the wind farm has become operational. Below are the results of the monitoring activities that have been undertaken.

Wetland 25650

This wetland is surrounded by three turbines, all within 290 m from the edge of the breeding wetland.

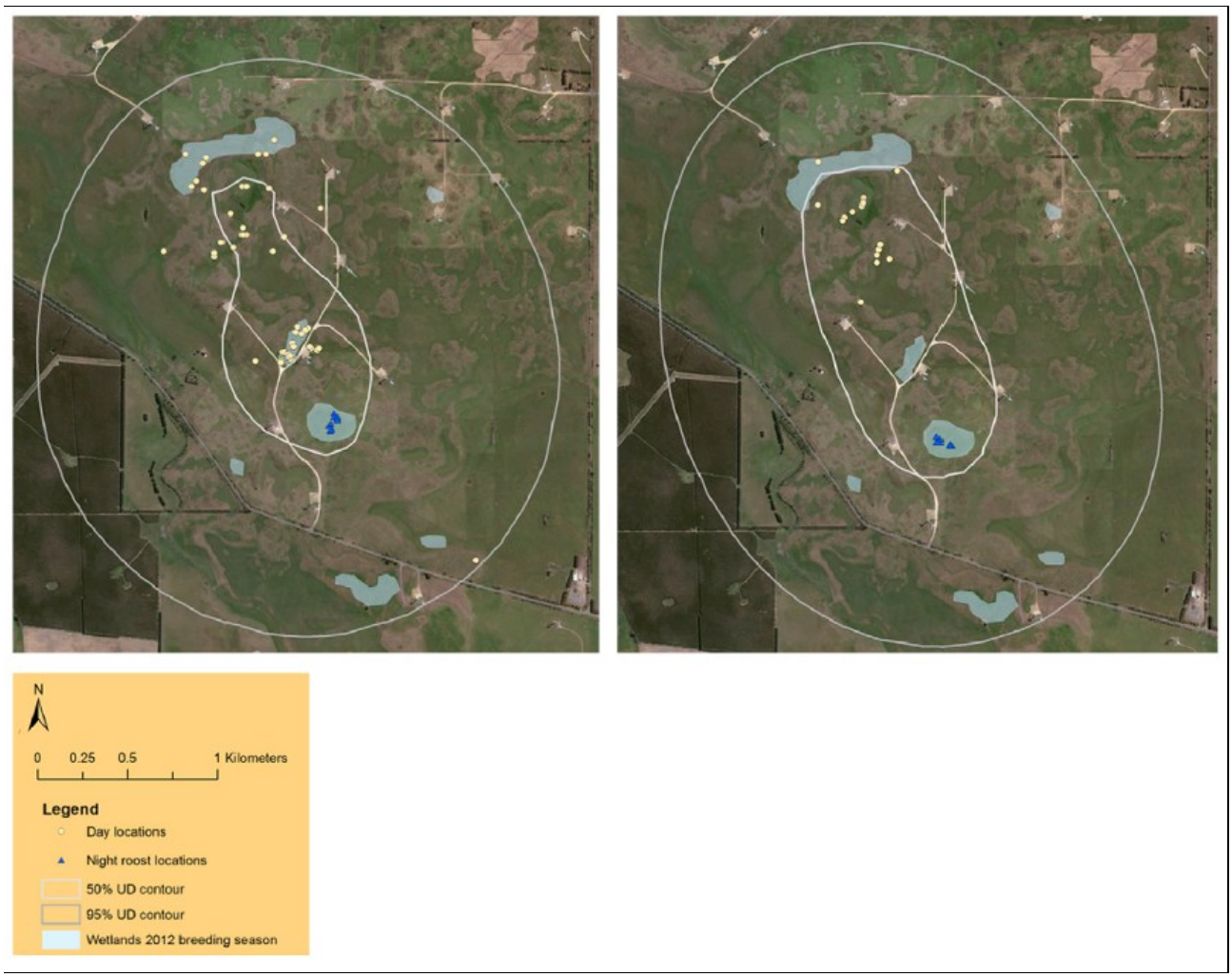


Figure 1: Monitoring undertaken during the 2012 breeding season (Source: Figure 3 in Veltheim *et al*. 2019)

Figure 1 above shows the results of the satellite tracking of pre-fledged Brolga chicks at the Macarthur Wind Farm. Brolga were recorded forging within 80 m of the base of one of the turbines.

Figure 2 below shows the results of a monitoring exercise undertaken by Nature Advisory during the 2018 breeding season. Points were recorded of adult birds every two hours while monitoring over 13 days from 5th September to 21st October 2021. Birds were observed foraging within 150 m from the base of a turbine. It is noteworthy that similar observations were made as Veltheim in that early in the breeding season the Brolga pair were confined to areas around the breeding wetland. Later in the breeding season, the birds moved further from the breeding wetland to the northwest.

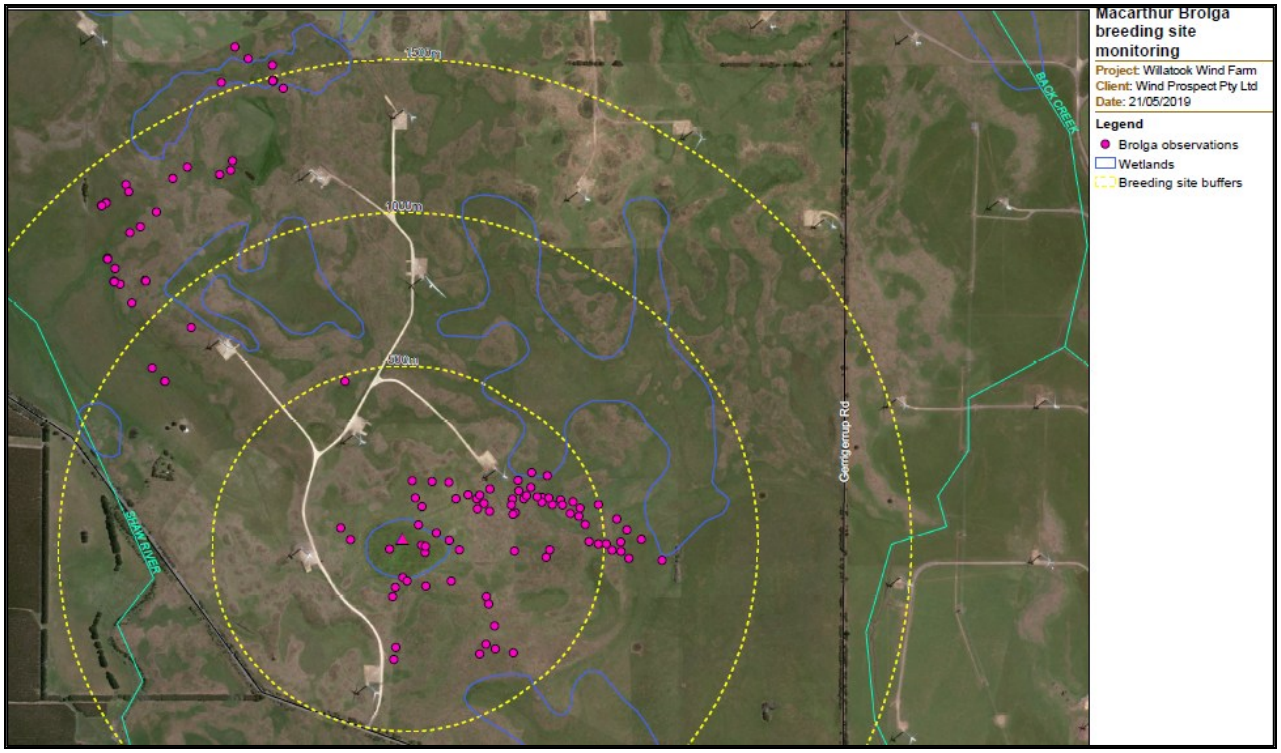


Figure 2: Monitoring undertaken by Nature Advisory during the 2018 breeding season

Wetland 25699

This wetland is surrounded by six turbines, all within 420 m from the edge of the breeding wetland.

Figure 3 below shows the results of the Brolga monitoring during the 2014 breeding season. It shows that Brolga were foraging on the hard stand under turbine 45 within 50 m of the base of the operating tower.

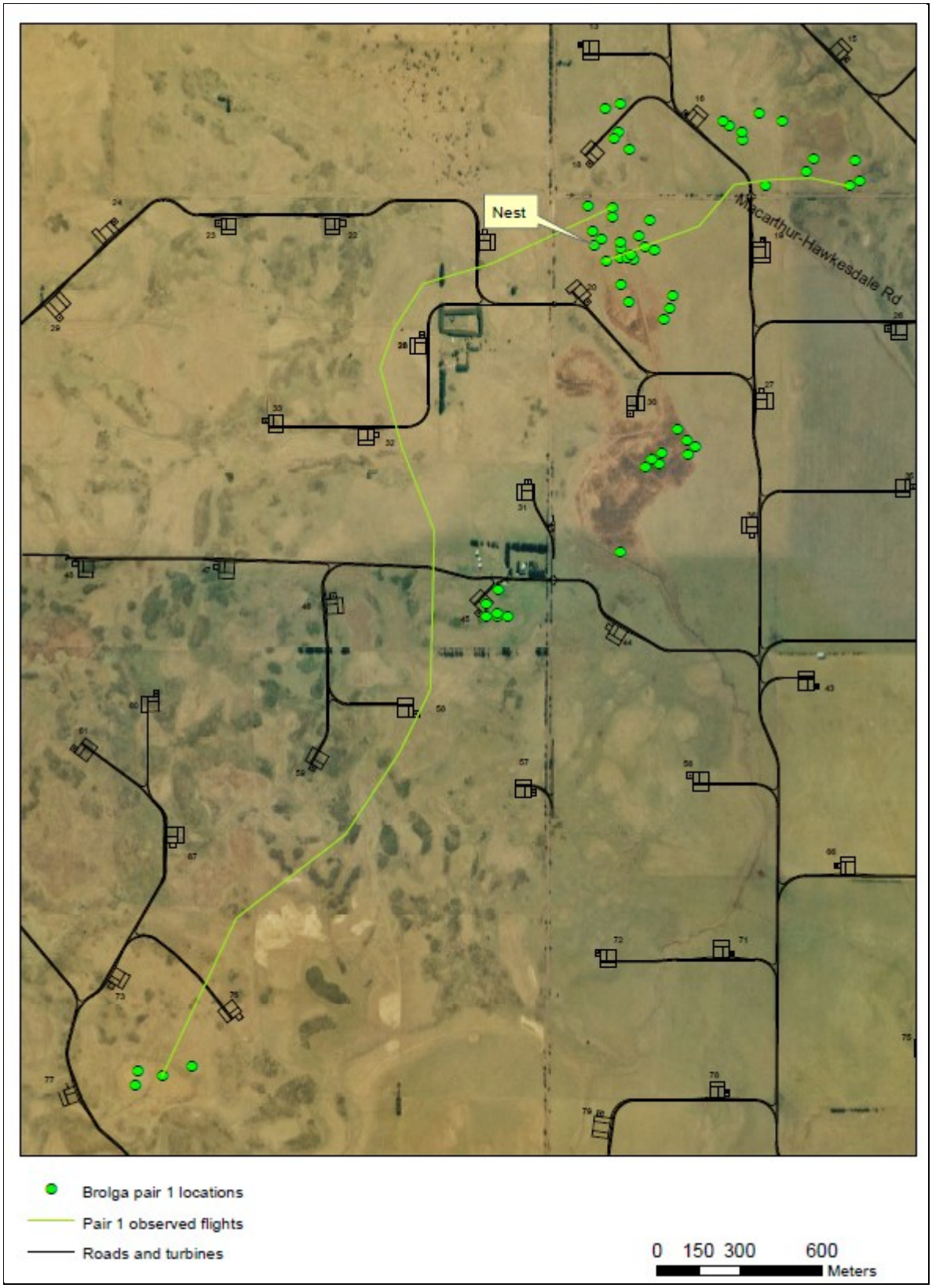


Figure 3: Monitoring undertaken during the 2014 breeding season (Source: Figure 4 in Wood 2014)

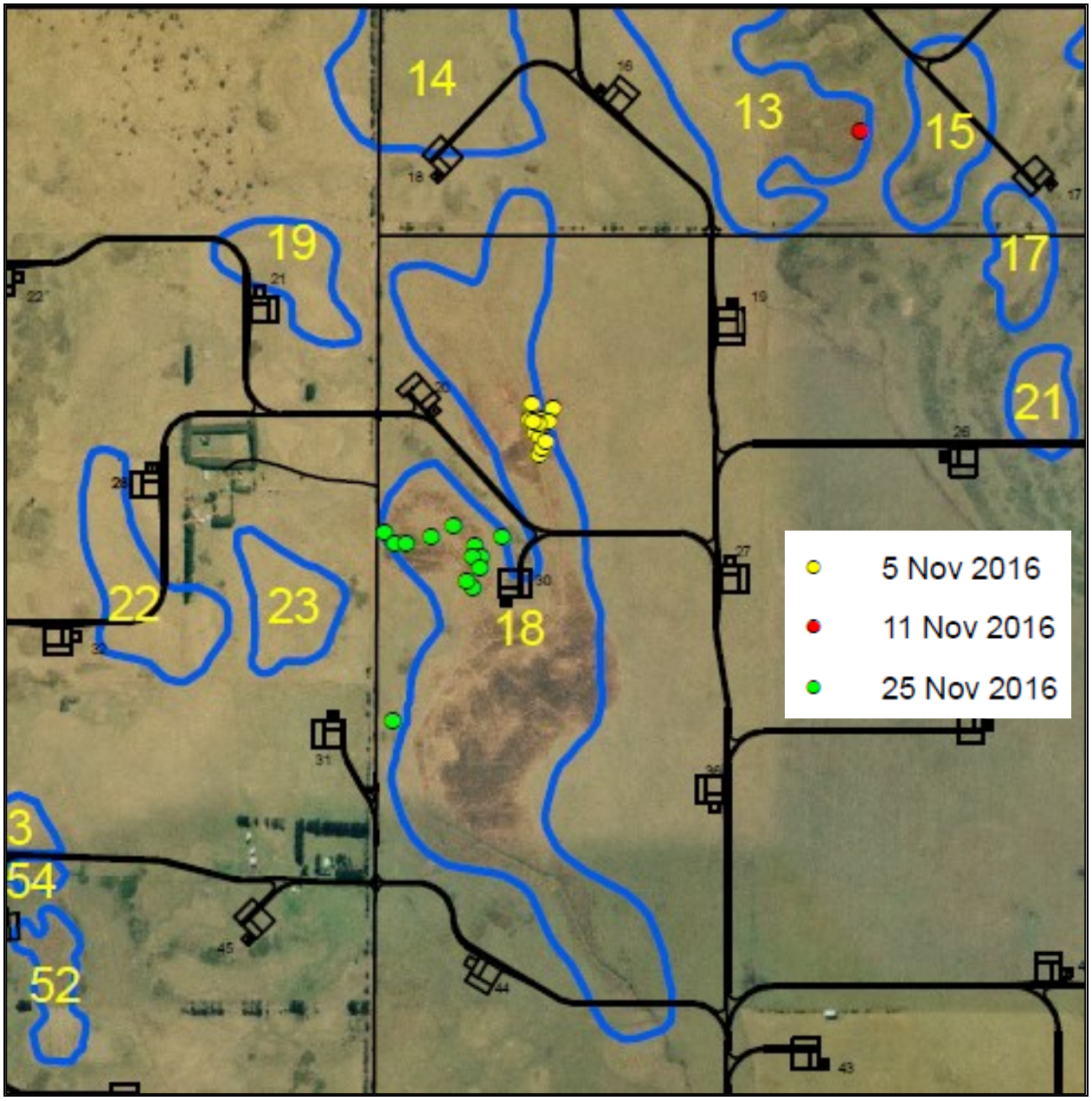


Figure 4: Monitoring undertaken during the 2016 breeding season (Source: Figure 10 in Wood 2017)

Wetland 18 in the above Figure 4 is wetland 25699 and is one of the wetlands where Brolga have nested in the past. Monitoring of the Brolga movements during the 2016 breeding season showed that Brolga were recorded foraging within approximately 90 m of an operating turbine.

Appendix 7: Collision Risk Model

Hexham Wind Farm - Brolga Collision Risk Modelling

Ver. 1.2

Submitted to Nature Advisory

symbolix

making your data work harder

Website: www.symbolix.com.au

Twitter: @SymbolixAU

3 Queensberry Pl

North Melbourne

VIC 3051

Acknowledgements

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Inga Kulik - Nature Advisory

Version Control

Version	Status	Date	Approved For Release	Issued To	Copies	Comments
0.1	Draft	2023-07-11	Internal	Internal	-	-
0.9	Draft	2023-07-17	E. Stark	To client	-	-
1.0	Final	2021-07-21	E. Stark	To client	-	-
1.1	Reissue	2025-03-11	E. Stark	To client	-	-
1.2	Update	2025-08-13	E. Stark	To client	-	-

Approved for release:

Elizabeth Stark 2023-08-13

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1 Executive summary

Hexham Wind Farm, in south western Victoria, includes up to 106 proposed wind turbines. Brolga (*Antigone rubicunda*) are known to breed in the region, and therefore modelling is required to determine the risk that wind farm infrastructure poses to breeding pairs that might utilise nearby wetlands. This document summarises the estimated annual collision rate of Brolga at the proposed Hexham Wind Farm. This information satisfies the requirements of step two of the Level Three assessment under the 'Interim guidelines for the assessment, avoidance, mitigation and offsetting of potential wind farm impacts on the Victorian Brolga population, 2011'.

Turbine collision risk was estimated using an avian collision risk model, based directly on Band, Madders, and Whitfield (2007) and Band (2012). This collision risk modelling report presents the results of the Nature Advisory (NA) Bird Collision Risk Model, developed for Nature Advisory Pty Ltd by Symbolix Pty Ltd. The NA application (NA-BAND) updates the model to accept spatial data inputs. This modification extends Band, Madders, and Whitfield (2007) and Band (2012) to more correctly calculate the probability that a flight will interact with a turbine (if a flight occurs on-site) for each sites. The probability of collision after interaction is a geometric calculation using Band, Madders, and Whitfield (2007) and Band (2012). The NA-BAND model has previously been applied and peer reviewed as part of the approvals process for a number of Australian Wind Farms, for example Golden Plains Wind Farm (Victoria). For full details see Section 2.

A total of 24 wetlands were identified as potential Brolga breeding sites by NA during the Level 1 and Level 2 Brolga Assessment (i.e. desktop assessment, targeted Brolga surveys and habitat assessments). These assessments indicate that up to eight pairs of Brolga utilise these wetlands for breeding. Based on the Level 1 Assessment the number of breeding pairs and frequency of breeding in each of these wetlands was estimated. As per NA advice, we assumed flat utilisation across the site (i.e. an equal chance of any of breeding wetlands being used for breeding by the eight Brolga pairs).

An important note is that the NA-BAND model estimates the number of flights that are at risk of collision under the assumption that any breeding resident Brolga is immediately replaced. Therefore our estimate of flight collisions can be higher than the actual individual collision rate.

This document presents an overview of the model methodology, the inputs used, and scenario results.

1.1 Summary of turbine collision risk

Table 1 summarises the output of the turbine collision risk model for turbine layouts provided by NA. We present here a 'flat' utilisation scenario, with avoidance rates of 90%, 92% and 95%.

Table 1: Turbine collision risk modelling results.

Avoidance	Collisions/yr	Expected coll. (30 yrs)	30 yr 95% pred. interval
0.90	0.1764	5.3	[1, 10]
0.92	0.1411	4.2	[1, 9]
0.95	0.0882	2.6	[0, 6]

Using these parameters, the most conservative annual collision rate (assuming 90% avoidance and equal use of wetlands) is 0.176 collisions per year. This could manifest as between one and 10 Brolgas struck in the life of the wind farm (30 years). This assumes an estimate of eight breeding pairs utilising the area each year. The numbers in the final column of Table 1, and in the above paragraph, represent 95% prediction bounds.

2 Methods

2.1 Collision risk model

Collision risk modelling (CRM) requires a step-wise risk model (Reason (1997)), where the total risk is the probabilistic combination of the risk of each step in the process. The process can be summarised by the equation:

$$N_{\text{collision}} = F \times P(I|F) \times P(C|I) \times (1 - \text{AR}) \tag{1}$$

where:

- $N_{\text{collision}}$ is the estimated number of flights ending in collision over some time period
- F is the estimated activity rate of flights in the area over some time period
- $P(I|F)$ is the probability of a flight interacting with a infrastructure, given a flight in the study region
- $P(C|I)$ is the probability of collision, given an interaction occurs
- AR is the avoidance rate

The probability of collision given interaction (the fourth dot point above) is generated using the exact model published in Band, Madders, and Whitfield (2007) and Band (2012)).

The probability of interaction component in Band, Madders, and Whitfield (2007) and Band (2012) (the third dot point above) includes an unreasonable assumption that every flight interacts with every turbine. The NA-BAND model uses spatial statistics to estimate the probability of interaction for each turbine, removing the reliance on the Band, Madders, and Whitfield (2007) and Band (2012) assumption. This use of Band (2012) with spatial input parameters has been peer reviewed in Australia as part of the approvals process for sites such as Dundonnell and Golden Plains Wind Farms.

2.2 Probability of interaction of a flight with windfarm infrastructure

In the Brolga breeding season we assumed that flights are centred on wetlands and can radiate from there in any direction. The **probability of interaction** $P(I|F)$ is given by:

$$P(I|F) = P(\text{wetland occupied}) \times P(\text{direction}) \times P(\text{distance}) \times P(\text{height}|\text{distance}) \tag{2}$$

where:

- $P(\text{wetland occupied})$ is the probability that a given wetland will be occupied in a given year.
- $P(\text{direction})$ is the proportion of flights which travel in the right direction to interact with a turbine. This is a geometric calculation of the ratio between the angle subtended by the infrastructure and the 360 degree circle around the wetland (assuming that Brolga might

fly in any direction).

- $P(\text{distance})$ is the probability that a flight will travel far enough to reach the turbines from any wetland.
- $P(\text{height}|\text{distance})$ is the probability that the flight will be at a height in which they can collide with a turbine, given that it travelled the requisite distance.

For modelling of Brolga flight characteristics (height and distance of flights), the distribution of flight distance is taken from combined NA breeding data from a range of sites through south-west Victoria (Brett Lane & Associates 2018). The distribution of flight height at a given distance is taken from combined breeding and flocking season data (obtained by NA) from sites in south-west Victoria (Brett Lane & Associates 2018).

Breeding and flocking season was not a significant factor in the relationship between flight height and distance so the data sets were combined to increase the size of the dataset.

2.3 Probability of wetland occupancy

A Level 1 and Level 2 Brolga Assessment (i.e. desktop assessment, targeted Brolga surveys and habitat assessments) have been undertaken by NA. The desktop assessment included collation of Brolga breeding records from the Victorian Biodiversity Atlas (VBA), Birdlife Australia, Sheldons Brolga Flocking Database and opportunistic sightings by local landowners. Additionally, NA undertook habitat assessments and roaming surveys across the site. From these surveys, 24 wetlands were identified as potential breeding location for Brolga. NA Level 1 and 2 assessments indicated that all wetlands had equal probability of utilisation for breeding with eight pairs of Brolgas estimated to be utilising the site. As such, we used a flat breeding scenario, whereby in a given year, a breeding pair is equally likely to utilise any of the wetlands. This reflects NA's observations, but is also the most conservative scenario when estimating collision risk.

See Figure 1 for their locations.

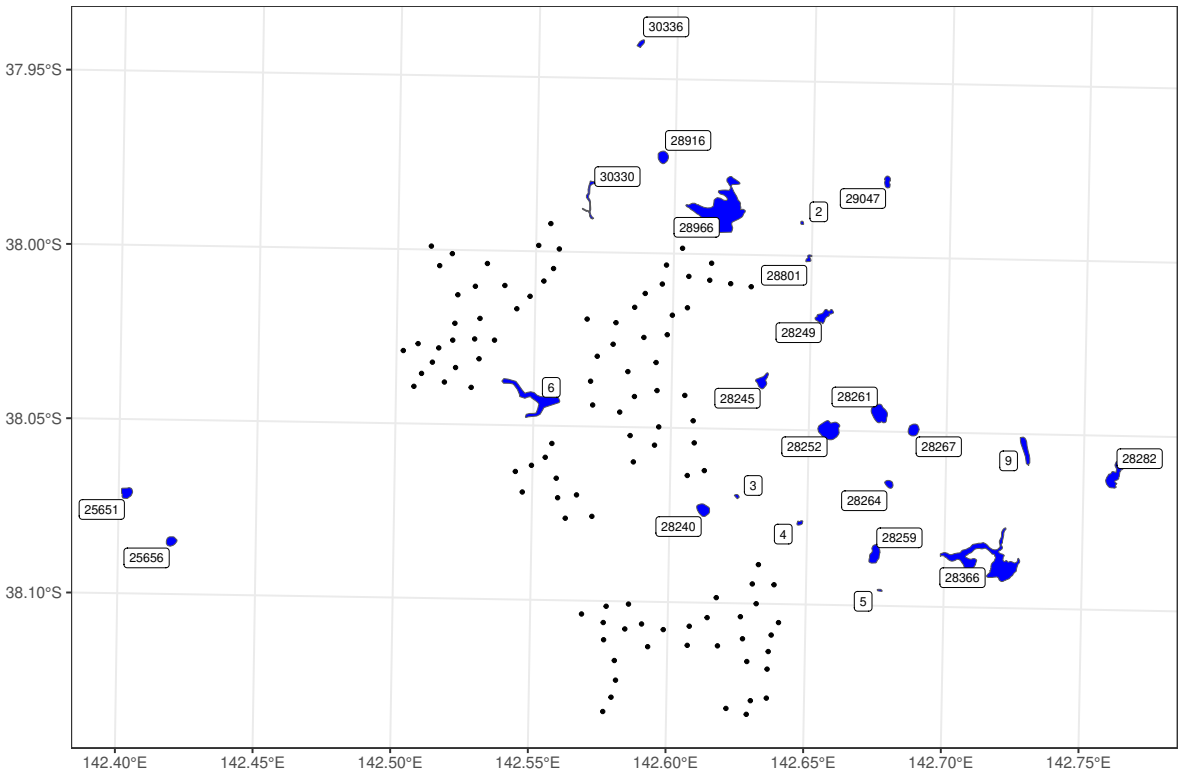

Figure 1: Breeding wetlands identified across the site, with turbine locations (black dots) for reference.

2.4 Probability of a flight reaching the windfarm infrastrucutre

The distribution of flight distance is taken from combined NA breeding data from a range of sites through south-west Victoria (Brett Lane & Associates 2018). The dataset was small (163 records) but demonstrates a clear preference for shorter flights (up to one kilometre).

We fit a gamma distribution to the data, which allowed us to infer the probability that a flight would travel a given distance (i.e. the $P(\text{distance})$ component), even if no observations were recorded at that distance. A histogram of observed distances is given in Figure 2.

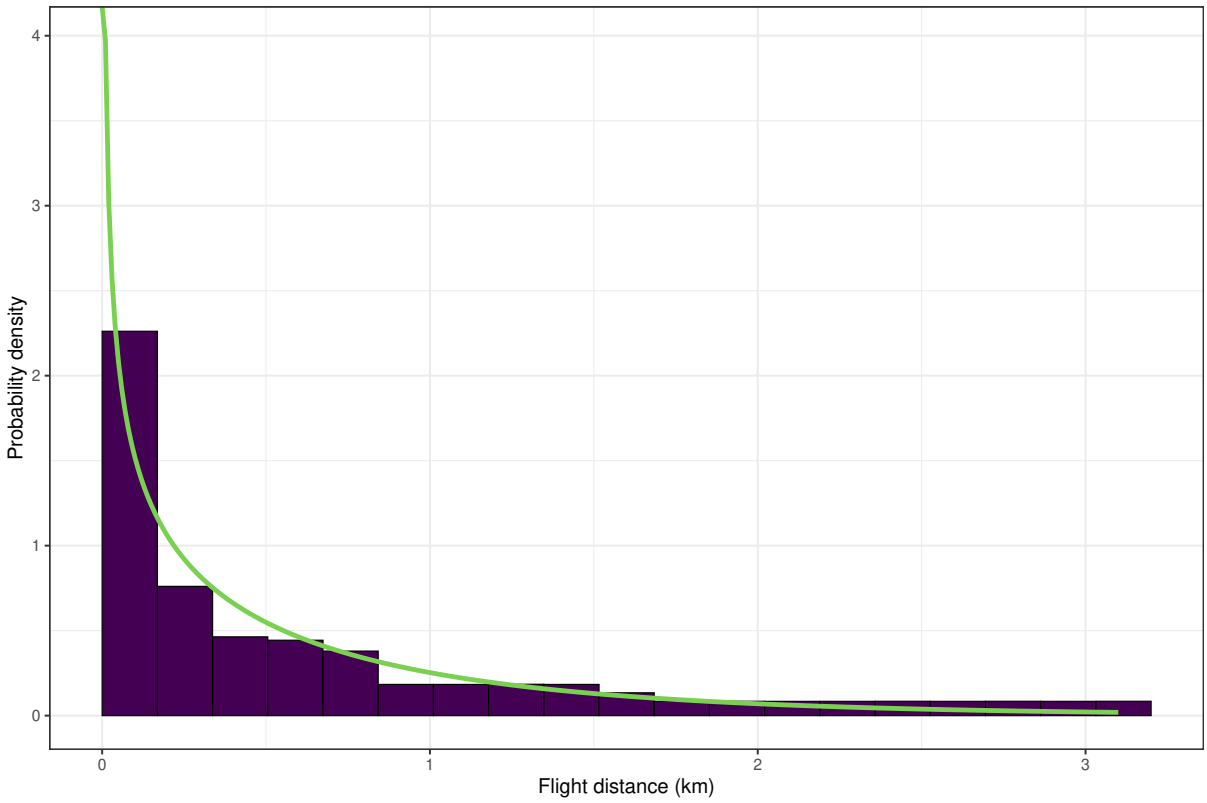

Figure 2: Empiricial flight distance distribution (histogram) and fitted gamma probability density function (curve).

2.5 Probability of flying at rotor height

The dataset of breeding season observations used in the previous section also contains flight height data. The dataset used for the distance distribution included 67 records for which height data was also recorded. To supplement this data, we included matched flight and height data from 547 flocking season flights at Dundonnell Wind Farm, also provided by NA. As seen in Figure 3 there is a clear linear relationship between flight height and distance (if we pre-transform both variables using the natural log function). We fit linear models to quantify this relationship. Testing breeding/non-breeding as a factor showed no significant difference

between the two seasons (thereby justifying our combining of the data).

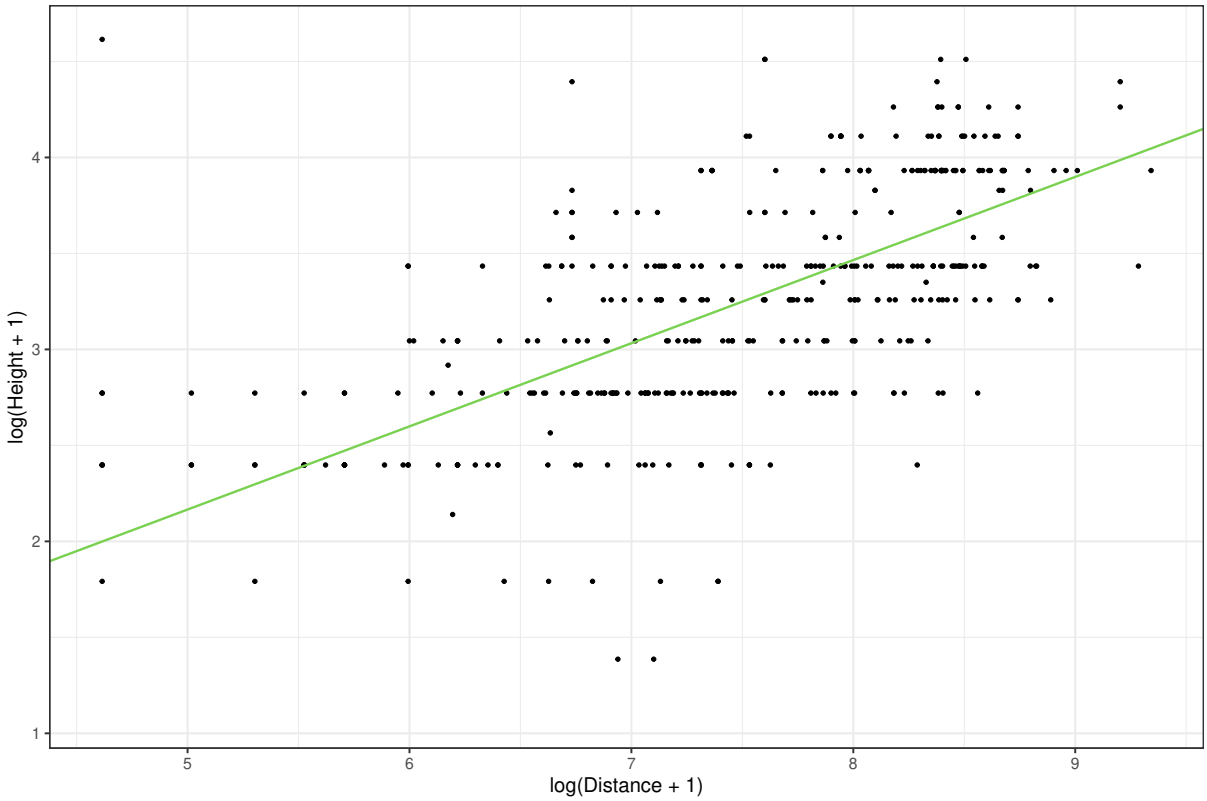

Figure 3: Relationship between flight height and distance. The pre-transformed units of height are metres, and distance is in kilometres.

The linear model allowed us to predict the expected height at a given flight distance, but to estimate the probability that a flight will occur in the rotor swept height we also need to consider the variability of the data around this expected value (i.e. we want to know the distribution of model residuals).

At any given distance, the probability of seeing a given flight height is described by the percentiles of the distribution of the residuals around the modelled value. $P(\text{height}|\text{distance})$ is the proportion of this distribution that falls in the height range (see Table 2) of the infrastructure being modelled.

2.6 Calculation of the probability of interaction

From the above methods we now have:

- The probability that a wetland is occupied is taken from our breeding scenario model.
- The probability of direction (at any point on the site) is taken by assuming that a turbine is placed there, and then using geometry to calculate the angle.
- The probability of travelling the requisite distance is taken from the gamma distribution fit to empirical data.
- The probability of being at the rotor swept height, given distance, is taken from the log-log linear model fit to empirical data.

We therefore have all the components to calculate $P(I|F)$ at any point in the landscape. The probability of interaction at any point in the landscape is the sum of $P(I|F)$ over all wetlands.

2.7 Probability of collision given turbine interaction

Turbine collision risk was estimated using an avian collision risk model, based directly on Band, Madders, and Whitfield (2007) and Band (2012). The NA application (NA-BAND) updates the model to accept spatial data inputs. This modification extends Band, Madders, and Whitfield (2007) to more correctly calculate the probably that a flight will interact with a turbine (if a flight occurs on-site) for general sites. The probability of collision after interaction is a geometric calculation using Band, Madders, and Whitfield (2007) and Band (2012). The NA-BAND model has previously been applied to assess collision risk for Moorabool Wind Farm, Dundonnell Wind Farm, and Golden Plains Wind Farm (Victoria).

An important note is that the NA-BAND model has no assumption about the likelihood that an individual bird would be replaced in the local area if it is struck. The model estimates the number of flights that are at risk of collision under the assumption that any breeding resident bird is immediately replaced. Therefore, our estimate of flight collisions is likely to be higher than the actual individual collision rate.

The NA-BAND model requires a number of turbine-related and bird-related inputs, which are summarised in Table 2 and 3 respectively.

Table 2: Turbine parameter inputs for the NA-BAND model.

Turbine parameters	value
Model	Theoretical
Rotor diameter (m)	220
Hub Height (m)	150
Rotation period (s)	4.96
Maximum chord (m)	5.5
Pitch (degrees)	Averaged at 6
Number of Blades	3
Blade Height Maximum (m)	260
Blade Height Minimum (m)	40

Table 3: Bird parameter inputs for the NA-BAND model.

Bird parameter	value
Length (m)	1.65
Wingspan (m)	2
Flight speed (m/s)	16.7
Flapping (0 = flapping, 1 = gliding)	0
Breeding season length (days)	130
Breeding pairs	8
Brolga per breeding pair	2.1
Breeding flights per day	2

3 Data preparation

Datasets were provided by NA, including:

- Turbine physical parameters
- Brolga physical parameters
- Distance data
- Height given distance data
- Turbine layout data
- Wetland location data
- Brolga breeding information

3.1 Pre-processing

The following data pre-processing steps were performed:

- Wetland spatial data was filtered to the breeding wetlands.
- For the height modelling, the response variable was taken to be the mean of the minimum and maximum height of each observation.
- For the distance modelling, flights with unspecified end points were set to be right-censored.
- The probability of utilisation given flat utilisation of 24 wetlands by eight Brolga pairs.

3.2 Dataset summary

Table 4 summarises the parameters, data sources, and model input values for the collision risk model.

Table 4: Collision risk model data inputs.

Variable	Input data	Data source	Model input value
Number of flights	Scenario for Brolga breeding flights, based on estimate of 8 breeding pairs in the region, making an average of two flights daily. Breeding attempts were assumed to last an average of 130 days. We have assumed Brolgas are on-site during breeding season, and there are no flocking flights.	Regional population and activity estimates provided by NA based on historical records, landowner liaison and habitat surveys at Hexham Wind Farm. The number of birds per breeding pair uses the juvenile to adult ratio of 0.05 (Herring (2001), in McCarthy (2008)).	4368 flights in a year.
P(wetland occupied)	Twenty-four wetlands were identified as potential breeding sites, each with an equal probability of utilisation.	Spatial layer provided by NA and observational records provided by NA	For modelling each wetland had an 4.17% chance of utilisation.
P(distance)	A gamma distribution was fit to breeding season flight distance data to estimate the probability that a flight from a wetland will travel (at least) the distance to a given turbine.	Breeding season survey data provided by NA.	A probability was generated for each suitable wetland and each turbine location. The total probability is the sum of these values.

$P(\text{height}\|\text{distance})$	We fit a linear (log-log) model to predict the expected height for a given flight distance. The proportion of flights within rotor swept height was then calculated by the proportion of the residuals within this range at the given distance.	NA provided regional breeding and flocking season flight data with both heights and distances rom other Victorian sites. The rotor swept height was assumed to be 40 to 260 metres, as provided by NA	A value was calculated for each turbine/wetland combination.
AR (avoidance rate)			Turbine collision models used avoidance rates of 0.90, 0.92 and 0.95.

4 Results

Figure 4 shows the risk of Brolga flight interaction with turbines, under the current turbine layout. Comparatively higher risk areas are shown in yellow and green, while lower risk areas are in blue and purple. We can see that areas were there is a higher density of breeding wetlands (e.g. between wetland 28261 and 28366), have a higher probability of Brolgas interacting with the turbines.

Table 5 shows the collision risk modelling results. Under the 90% avoidance scenario, we expect on average 0.176 collisions per year, over the 30 year lifetime of the farm (assuming a flat utilisation and eight breeding pairs a year).

The plausible range of cumulative mortalities over a 30 year period (assuming 90% avoidance) is shown in Figure 5. These counts represent the potential yearly manifestation of the long-term rate. There is a 95% chance that the expectation would manifest as between one and 10 collisions across the life time of the wind farm. Alternatively, there is a 0.5% chance of zero turbine collisions in the life of the wind farm.

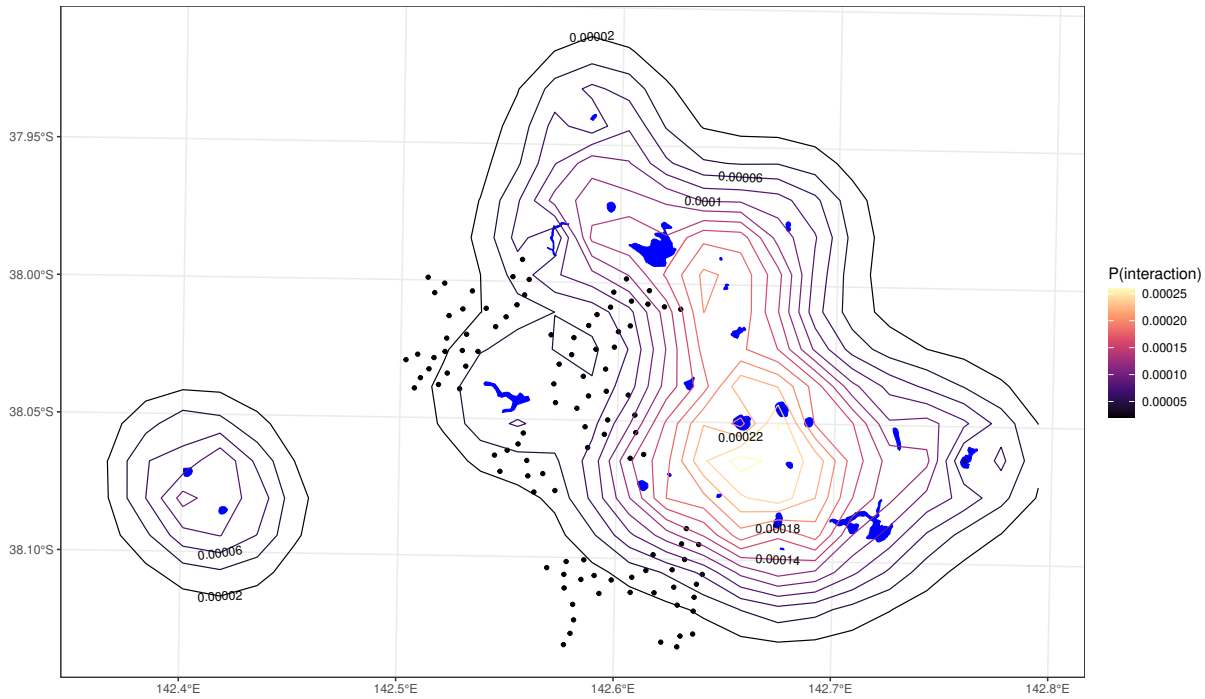

Figure 4: Contour plot of the probability of interaction with the proposed turbines. Turbine locations are shown with black dots. Contour lines (or isolines) provide a visualisation of the two-dimensional probability functons.

Table 5: Turbine collision risk modelling results.

Avoidance	Collisions/yr	Expected coll. (30 yrs)	30 yr 95% pred. interval
0.90	0.176	5.3	[1, 10]
0.92	0.141	4.2	[1, 9]
0.95	0.088	2.6	[0, 6]

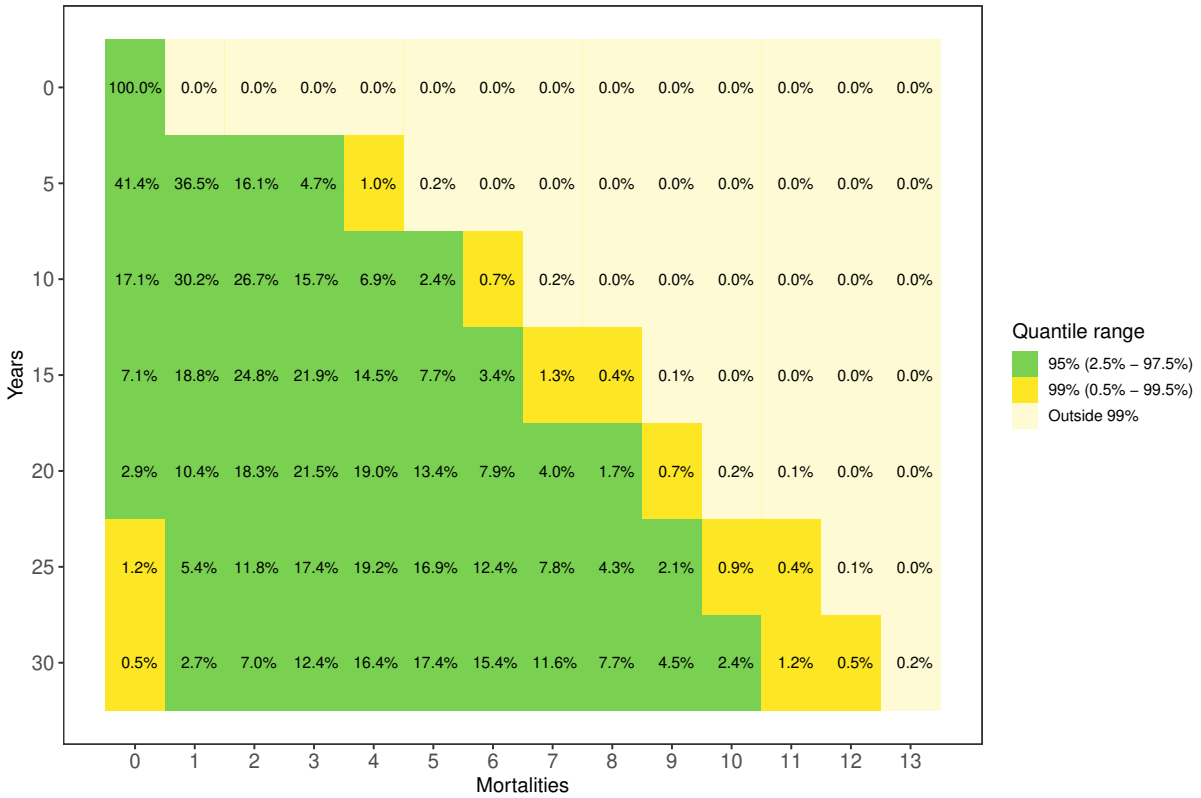

Figure 5: Plausible range of cumulative turbine mortalities, assuming 90% avoidance, flat utilisation and up to eight breeding pairs utilising the identified breeding wetlands.

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Appendix 8: Population Viability Analysis

Results for Brolga PVA for the Hexham Windfarm

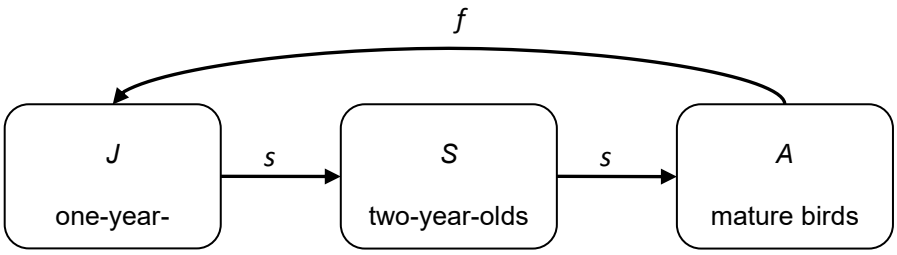
Michael McCarthy

School of Agriculture, Food and Ecosystem Sciences, The University of Melbourne

1 September 2025

This report documents a population viability analysis (PVA) of brolga to predict the impacts of the proposed Hexham wind farm. The report uses projections of the number of annual collisions with turbines and powerlines. The predictions of impacts on the brolga population in south-western Victoria are based on three different avoidance rates (90%, 92%, 95%) as reported in the Hexham Wind Farm Collision Risk Modelling by Symbolix (ver. 1.2). These correspond to 0.1764, 0.1411, and 0.0882 collisions per year for the variable scenario. These annual rates were converted to a per-capita annual rate by assuming the population size of brolga is 625 birds. The dynamics of the brolga population were simulated for a period of 30 years. The same scenarios were also run assuming the initial population size was 907 birds (DSE report of simultaneous flock counts in April 2013). The expected minimum population size (EMP) was calculated for each of these scenarios, and compared to the EMP in the absence of windfarm collisions.

The population viability analysis was based on an age-structured model, with individuals classified as being one year old birds (juveniles), two year-old birds (sub-adults) and mature birds (adults). Let *J*, *S* and *A* be the abundances in each of these age classes. The per capita fecundity rate (*f*) and survival rate (*s*) define the transitions among these age classes, which can be represented diagrammatically:



The fecundity rate *f* is the product of the probability that an adult breeds, the average number of chicks produced, and the survival of any chicks to one year of age. The transitions between age classes can be defined by a matrix (**M**):

$$\mathbf{M} = \begin{bmatrix} 0 & 0 & f \\ s & 0 & 0 \\ 0 & s & s \end{bmatrix}$$

Estimation of the parameters s and f is problematic for brolga because mark-resighting data are not available. However, estimates can be derived from the observed ratio of immature (one-year-old and two-year-old birds) to mature birds and assumptions about the population trend with particular assumptions. If the population is stable (abundances of each of the age classes are the same from year to year):

$J = f A$,
$S = s J$, and
$A = s (S + A)$.

Solving these equations leads to:

$f = (1 - s) / s^2$, and
$s = \sqrt{(R + 1)} / (R + 1)$,

where R equals the ratio of immature to mature birds ($(J + S) / A$). Therefore, if $R = 0.05$, which is approximately the case for contemporary populations in southeastern Australia (Herring 2001), $s = 0.976$ and $f = 0.025$, which are used as the standard set of parameter values. The estimate of s can be compared to predictions from an allometric model (McCarthy et al. 2008, but with additional data on cranes: Bennett and Bennett 1990, Link et al. 2003, Masatomi et al. 2007) that predicts the annual survival rate of adult birds from body mass. Based on a body mass of 6 kg, the predicted annual survival rate of cranes is 0.91 with a 95% credible interval of [0.77, 0.96]. Therefore, the estimate based on age structure is higher than might be expected for a crane of this size but not inconceivably so. Nevertheless, a survival rate less than 0.976 may be possible, and in fact may be likely.

The population growth rate based on the matrix model can be obtained by eigenanalysis of the transition matrix **M**, and is the (real) solution to the cubic equation:

$\lambda^3 - s \lambda^2 - f s^2 = 0$.

A closed form solution can be obtained, but it is unhelpfully complicated (result not shown). However, the solution can be approximated using a first-order Taylor series expansion around the point $f = 0$, leading to $\lambda \approx s + f$. The next term in the expansion is $-f^2/s$, which is small when f is small and s is large. Therefore, $\lambda \approx s + f$ is a good approximation if $f \approx 0$ and $s \approx 1$, which is the case for the brolga. This means that reductions in the population growth rate due to decreased survival of brolgas can be approximately compensated by an increase in fecundity of the same magnitude.

Initial abundances in the simulation were set at 79 1-year-olds, 75 2-year olds, and 753 adults, reflecting the 2013 simultaneous flock counts, or 54 1-year-olds, 52 2-year olds, and 519 adults when assuming an initial population size of 625 birds. The numerous younger birds (17% of the population) suggests that the annual recruitment rate in the last two years has been approximately 10% in the last couple of years following high rainfall. Assuming annual survival of 0.976, and a reproduction rate of 2.5% on average to obtain a stable population size, this suggests large variation in reproduction – a value of 100% for the CV seems plausible. This value was chosen for the CV for fecundity, and 50% was chosen for the CV of mortality (which translates to small variation in survival).

Simulations were based on 1,000,000 stochastic iterations for each set of parameters with analyses done within the statistical programming language R.

Results

In the absence of losses to wind turbines and powerlines, the expected minimum population size over the next 30 years was 548.2 brolgas when the initial population size was 625 brolgas, and was 796.8 when the initial population size was 907 brolgas. Impacts of the turbines and powerlines can be compared to these values (Tables 1).

Table 1. Expected minimum population (EMP) size of the south-west Victorian brolga population for each of the three different turbine avoidance rates when the initial population size was 625 brolgas or 907 brolgas. Results are shown for the "flat" wetland ustilisation pattern reported by Symbolix. The reduction in the EMP compared to the absence of turbines is given in brackets.

	Expected minimum population (EMP) size over 30 years, and the reduction in EMP due to collisions (in brackets).		
Initial brolga population size and scenario	90% avoidance rate	92% avoidance rate	95% avoidance rate
625 birds (flat)	545.7 (2.5)	546.2 (2.0)	546.9 (1.3)
907 birds (flat)	794.2 (2.5)	794.7 (2.0)	795.5 (1.3)

The expected minimum population size (EMP) is a useful metric of the risk of decline. It is calculated from stochastic simulations of the model. The smallest population size in each of the simulations is recorded. The EMP is the average of these, representing the average number of birds by which a quasi-extinction risk curve is from extinction (McCarthy 1996; McCarthy and Thompson 2001).

The linear approximation of the population growth rate ($\lambda = f + s$) indicates the number of births that would be required to offset mortality events from collisions. Because fecundity and survival have approximately additive effects on growth rate, each mortality event would need to be mitigated by an extra bird being raised to adulthood. This might be achieved by improvement to breeding habitats or reduced collision with other infrastructure such as existing powerlines or fences (Beaulaurier 1981; Alonso et al. 1994; Brown & Drewien 1995). For example, with a 95% avoidance rate, the expected number of extra deaths is a little more than 1 bird over the 30-year period. If survival of juveniles to

adulthood is *j*, then the required number of extra juveniles can be calculated as 1/*j*, which is on the order of one or two birds.

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Glossary of acronyms

CV	coefficient of variation, equal to the standard deviation divided by the mean.
EMP	expected minimum population size; a measure of risk of decline of a population.
PVA	population viability analysis; a model-based analysis of the risk of decline of populations.