Appendix 21

Blade Throw Risk Assessment

middleton Group

Client: Umwelt (Australia) Pty Ltd

Project: Junction Rivers Wind Project

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Revision history

Table 1: Revision history

Revision	Date	Description	Prepared by	Reviewed by	Approved by
A	19/06/2023	Initial Draft for Review	E. Bendtsen	J. Rowcroft	T. Cervenjak
B	08/01/2024	Second Draft for Review	E. Bendtsen	J. Rowcroft	T. Cervenjak
C	15/02/2024	Addition of BESS risk assessment	E. Bendtsen	J. Rowcroft	T. Cervenjak
0	22/03/2024	First Issue	E. Apps	E.Bendtsen	T.Cervenjak
1	16/05/2024	Second Issue – Amended non-associated dwellings	E. Apps	Eric Bendtsen	Alex Low

Disclaimer

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1 Executive summary

In the Secretary's Environmental Assessment Requirements (SEARs) issued for the Junction Rivers Wind Project (the Project) under Section 4.12(8) of the Environmental Planning and Assessment Act 1979 and Part 8, Division 2 of the Environmental Planning and Assessment Regulation 2021, an Environmental Impact Statement (EIS) must be prepared, assessing, amongst other requirements, blade throw risks. Specifically, the SEARs state "Blade Throw – assess blade throw risks, including consideration of associated dwellings, non-associated dwellings and of battery energy storage facilities."

The assessment of both the likelihood of fatality and BESS impact is based on the characterisation of the following:

- The likelihood of a blade failure, based on existing Australian wind turbines and reported blade failure events in Australia
- The impact of such a blade failure
- The likelihood that the impact extent of such a blade failure would be occupied
- The likelihood that the blade failure impacts on an occupier/BESS facility within the impact extent.

For residential land use, the boundary between "broadly acceptable" and "tolerable" risks is generally taken as a 1 in one million years fatality. The boundary between "tolerable" and "unacceptable" is generally taken for the public at large as a 1 in 10,000 years fatality [1]. For industrial land use, a 1 in 10,000 years fatality is considered as the acceptable individual fatality risk probability [2].

By way of conclusion, the likelihood of a fatal blade throw event at the Project is estimated to be once in 19.46 million years, which is comfortably within the bounds of what is considered to be broadly acceptable for residential land use [2].

The likelihood of the BESS at the Project Area impacted by a blade throw event is estimated to be once in 32,900 years, which is comfortably within the bounds of what is considered to be broadly acceptable for industrial land use [2].

The low likelihood of adverse outcome is in due to the low incidence of failure and low rates of occupation in the vicinity of the WTGs.

2 Abbreviations and definitions

Table 2: Abbreviations and definitions

Abbreviation / definition	Explanation
DPHI	Department of Planning, Housing and Infrastructure
HIPAP4	Hazardous Industry Planning Advisory Paper No 4
km	Kilometre
km/h	Kilometres per hour
m	metre
MGE	Middleton Group Engineering
MW	Megawatt
MWh	Megawatt hour
NSW	New South Wales
P(…)	Probability
QLD	Queensland
the Project	Junction Rivers Wind Project
SEARs	Secretary's Environmental Assessment Requirements
VIC	Victoria
WTG	Wind Turbine Generator

3 Introduction

3.1 Background

Windlab Developments Pty Ltd (Windlab) proposes to develop the Junction Rivers Wind Project (the Project) to provide a reliable and affordable source of energy for the people of New South Wales (NSW) and contribute to reducing greenhouse gas (GHG) emissions associated with energy generation. The Project is located approximately 15 kilometres (km) south of Balranald, 10 km north of Kyalite, 24 km north of Tooleybuc, and 20 km northeast of the NSW and Victorian border within the southern section of the Murray-Darling Basin. The Project is within the Murray River Council Local Government Area (LGA) and immediately east of Balranald Shire LGA. The Project is located within the South-West Renewable Energy Zone (SW REZ), which the NSW Government has identified as a target area for renewable energy development in its Transmission Infrastructure Strategy (EnergyCo 2023) and Electricity Infrastructure Roadmap (NSW Government 2020).

The Project is State Significant Development (SSD) as defined under *State Environmental Planning Policy (Planning Systems) 2021* (Planning Systems SEPP) and will require development consent under Part 4 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

The Project will have a generating capacity of approximately 750 megawatts (MW) and would connect to the existing 220 kilovolt transmission line that traverses the site and/or the proposed Project EnergyConnect transmission line. The key components of the Project include:

- up to 96 (3 blade) Wind Turbine Generators (WTG)s with a maximum blade tip height of up to 300 m.
- electrical connections between the proposed WTGs and substations/switching stations (underground or a combination of underground and overhead powerlines).
- substations/switching stations and transmission connections to connect to the existing 220 kV transmission line and/or the proposed Project EnergyConnect transmission line.
- up to four battery energy storage system (BESS) facilities (to a total of 200 megawatts (MW) with a 4 hour delivery capacity), or up to four static synchronous compensator (STATcom) facilities.
- Permanent Power Performance Masts.
- other associated infrastructure including access roads and tracks, operation and maintenance buildings, construction facilities.
- temporary on-site concrete batching plants, rock crushing facilities, calibration meteorological masts during the construction phases.
- targeted road network upgrades to facilitate delivery of WTG components to the site as required.

The Project may be constructed in two stages. Stage 1 may see the construction of up to 30 WTGs and required ancillary infrastructure and Stage 2 may see the construction of the remaining balance of WTGs and required ancillary infrastructure. The construction period would be approximately four years across the two stages.

For environmental assessment purposes, a Project ‘Development Corridor’ has been established consisting of an area around the infrastructure layout for the Project. The Development Corridor represents a worst-case assessment scenario and allows for refinement of Project infrastructure, such as micro-siting of WTGs, during the detailed design phase. Middleton Group Engineering (MGE) has been engaged by Umwelt (Australia) Pty Ltd (Umwelt) on behalf of Windlab to undertake an assessment of the risk associated with blade throw for inclusion within an Environmental Impact Statement (EIS).

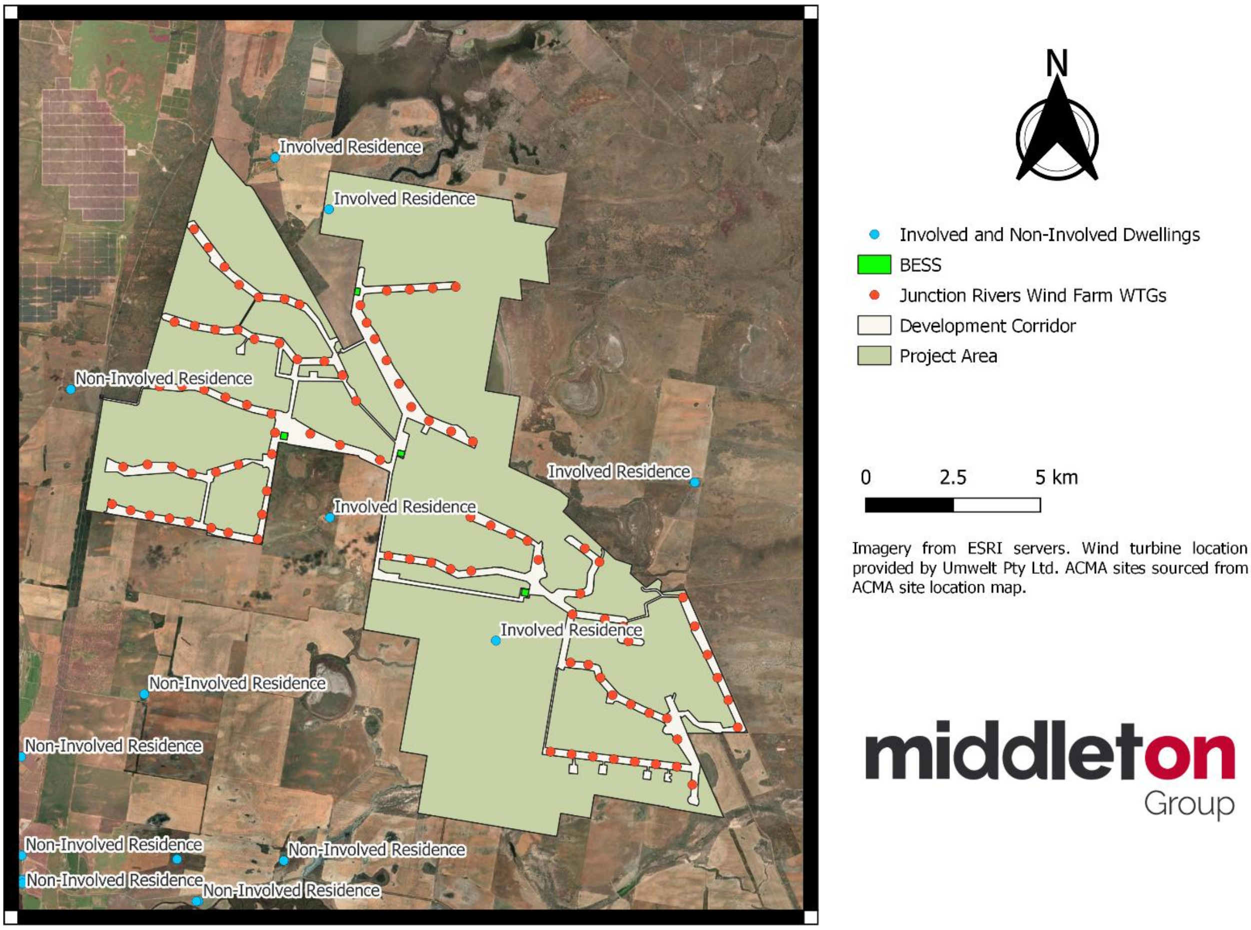

Figure 1: Junction Rivers Wind Project site overview

Note that “involved / non-involved” dwellings is used interchangeably with “associated / non-associated” dwellings.

3.2 Purpose and Scope

In the Secretary of the Department of Planning and Environment’s (DPE’s) Environmental Assessment Requirements (SEARs) issued for the Project under Section 4.12(8) of the Environmental Planning and Assessment Act 1979 and Part 8, Division 2 of the Environmental Planning and Assessment Regulation 2021, an EIS must be prepared, assessing, amongst other requirements, blade throw risks. Specifically, the SEARs state “Blade Throw – assess blade throw risks, including consideration of associated dwellings, non-associated dwellings and of battery energy storage facilities.”

Thus, the purpose of this study is to estimate risk to human life associated with a blade failure event, based on likelihood of a human occupying space within the potential impact zone and likelihood of blade failure.

4 Methodology

The high-level methodology applied is:

1. Find the probability of fatality due to blade failure for a *representative* wind turbine installed in the Junction Rivers Wind Project. This considers Project layout specifics such as number and location of dwellings, farm buildings and public roads.
2. Find the overall probability of fatality due to blade failure by multiplication of the probability for a representative wind turbine in the Junction Rivers Wind Project by the total number of wind turbines in the Project.
3. Assess probability of fatality/BESS impact against HIPAP4 risk criteria.

4.1 Probability of Fatality Methodology

Various approaches have been employed to assess the risk associated with WTG blade throw around the world, based on a mix of empirical and kinematic models (e.g. [3, 4, 5, 6, 7]). The methodology used here has been developed using data from these various models.

The methodology to identify the inputs to the *P(fatality)* equation for a *representative* wind turbine considers the following four factors:

- Likelihood of blade failure
- Area of impact in the case of blade failure
- Likelihood of the impact area being occupied
- Likelihood of person within the impact area to be hit by blade fragment.

Likelihood of Blade Failure is developed by the following steps:

- Identify the number of operating years of WTGs in Australia.
- Identify and classify the number of blade failures in Australia.
  - Classification is based on whether blade drop is observed or whether there is fragmentation.

Impact Area is found by identifying the radii of impact for blade fragmentation and blade drop based on the kinematic and empirical models.

Likelihood that the Impact Area is Occupied is developed through conservative estimates of farming practices, traffic data, dwelling and shed occupancy rates, and wind farm maintenance practice.

Likelihood that a person within the Impact Area is hit is found by combination of:

- For an area within 300 m of the WTG (based on Rogers et al.'s kinematic model [7]) this is taken as the likelihood of blade drop plus the likelihood of blade fragmentation.
- For an area within 800 m of the WTG (based on Rogers et al.'s kinematic model [7]), this is taken as the likelihood of blade fragmentation.

4.2 Probability of Fatality Equation

The probability of a fatality *P(fatality)* is described in the following equation:

$$
\begin{aligned}
P(fatality) = {} & P(Blade\ Drop) \times P(Blade\ Drop\ on\ Particular\ Location) \\
& \times P(Blade\ Drop\ Area\ Inhabited) \\
& + P(Fragmentation) \\
& \times P(Fragmentation\ reaching\ Particular\ Location) \\
& \times P(Fragmentation\ Area\ Inhabited)
\end{aligned}
$$

Blade Drop is the case where a wind turbine blade, or part of the blade, drops vertically.

Blade Fragmentation is the case where a part, or fragment, of the blade detaches from the wind turbine and is launched through the air.

Based on the above, it is possible to assess whether likelihood of injury/fatality falls below accepted community standards.

4.3 BESS Impact Methodology

This methodology section refers specifically to the likelihood of the BESS being impacted by blade failure. The likelihood of a person impacted by blade failure while conducting routine operations & maintenance on the BESS is included within the representative wind turbine method (specifically within 'Likelihood that the Impact Area is Occupied'.

The method to calculate the likelihood of BESS impacted by blade failure deviates from the likelihood of a person impacted by blade failure with the following:

- The specific WTGs which impact the BESS are considered, a representative WTG is not considered.
- The area of the BESS within WTG impact areas is calculated for each BESS

4.4 Risk Assessment Criterion

Risk is assessed as a combination of likelihood and consequence. Where a hazard has fatal consequences, such as WTG blade throw, the likelihood must be extremely low for the residual risk to be considered acceptable.

The British Health & Safety Executive identify that the boundary between “broadly acceptable” and “tolerable” risks is generally taken as a 1 in one million years fatality. The boundary between “tolerable” and “unacceptable” is generally taken for the public at large as a 1 in 10,000 years fatality [1], on the proviso that there is a broader benefit to society in accepting this higher risk. Similarly, the NSW Department of Planning, in their Hazardous Industry Planning Advisory Paper No 4 (HIPAP4), set similar return periods for fatalities: a 2-million-year return period for hospitals, schools, child-care facilities, old age housing. Residential premises and places of continuous occupancy should have return periods greater than 1 million years, see Table 3. For industrial facilities, the return period should be greater than 20,000 years. These values assist in providing appropriate benchmarking.

For the purposes of this assessment, the relevant risk criterion which Junction Rivers Wind Project will need to pass is the 1-million-year return period for the fatality assessment and the 10-thousand-year return period for the BESS Impact Assessment.

Table 3: NSW HIPAP4 Fatality Risk Criterion

Land Use	Suggested Criteria (risk in a million per year)
Hospitals, schools, child-care facilities, and old age housing	0.5
Residential, hotels, motels, and tourist resorts	1
Commercial developments including retail centres, offices, and entertainment centres	5
Sporting complexes and active open space	10
Industrial	50

5 Study Inputs

The aim of this study is to identify the probability of a person being struck by a blade fragment or a blade from a WTG.

The probability of a blade throw event is estimated by the number of WTG years of operation in Australia and the number of relevant failure events, identified in Sections 5.1 and 5.2. The probability of a blade dropping on a particular location is based on the potential impact radius, which is described in Section 5.3. The probability that the impact radius is inhabited is assessed in Section 5.4. Finally, Section 5.5 assesses the probability that a person present within the impact radius is impacted.

5.1 Wind turbine years of operation

As tabulated in Appendix A, 3,840 WTGs have accumulated in excess of 34,000 years of operation in Australia since 1993 to 2023. These numbers are increasing rapidly as new wind farms are built.

5.2 Identifying Blade Throw events

Blade failures are generally not publicised by wind farm owners and WTG manufacturers; however, catastrophic failures such as Blade Throw events are generally reported in the media, as WTGs tend to be prominently placed in the landscape.

In their analysis, Branner and Gharidian [8] identify four levels of blade damage:

0. Observation, no harm.
1. Damage to be repaired at an opportunity.
2. Damage must be repaired as soon as possible.
3. Serious damage, the turbine is stopped.

It is noted that blade defects, examples of which are described by Branner & Ghadirian [8] – whether by manufacturing defect or by wear and tear – are not included in this assessment, except if they result in catastrophic failure of a blade – that is, where they form a subset of damage level 3.

Blade defect and/or degradation events are relatively commonplace in wind farms around the world, with Branner and Ghadirian [8] identifying a mean outage per WTG due to blade or rotor issues between 9 and 62 hours per year, and a mean outage time per failure of between 0.9 hours and 17.2 days, with the majority of these events being dealt with in the course of the WTG's maintenance programme, and posing no risk to human life. Even where serious damage occurs, WTG control systems will typically detect the failure and shutdown the WTG preventing a catastrophic failure, i.e., a Blade Throw event [9].

Research by Brouwer et al. [10] demonstrates that blade failure events have tended to reduce with time, owing to "improvements in wind turbine safety over time", as shown in Figure 3.

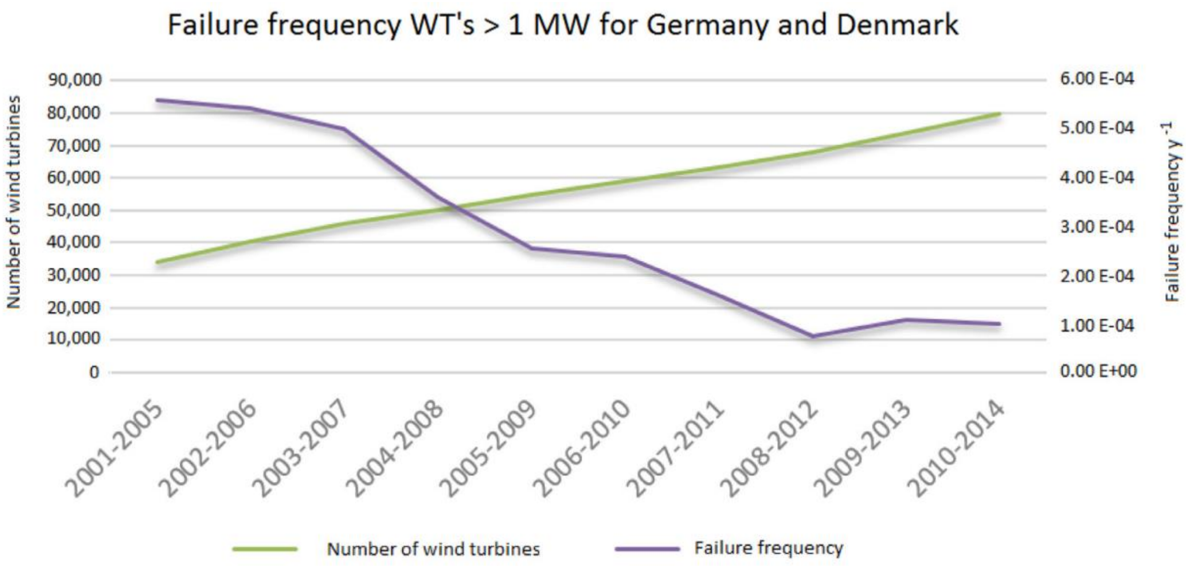

Figure 3: Estimated failure frequencies of wind turbines of 1MW and above based on Germany and Denmark statistics. [10]

Five catastrophic blade failures have been identified in Australia and are assumed to represent Blade Throw events. These are described and classified in Table 4. It is noted that there is very little detail on the incidents in the public domain. Thus, details such as root cause analyses, projectile/debris scatter zones, and failure modes are not available. However, there are some broad data to suggest that manufacturing defects and lightning are two key causes of failure. There have been no injuries or fatalities associated with these events.

Table 4: Blade failures in Australia.

Event	Date	Description	Classification	Source
Windy Hill WF (QLD)	July 2005	Blade “sheared off” from wind turbine.	General Failure: Unsure – Assume fragmentation.	Herald Sun, 29 July 2005.
Wonthaggi WF (VIC)	March 2012	Blade cracked. Fibreglass delaminated. Blade fill strewn around vicinity of WTG.	General Failure: Fragmentation.	Wonthaggi Wind Farm – Wikipedia Various media reports.
Lal Lal WF (VIC)	September 2019	Blade broke and fell to the ground. Prior to incident, there was severe weather including lightning.	Lightning Failure: Blade drop.	Lal Lal Wind Farms Press Release: 23 September 2019
Bald Hills WF (VIC)	June 2020	No reliable details on cause.	General Failure: Assume fragmentation.	Turbine Trouble For Bald Hills Wind Farm – South Gippsland Sentinel-Times (sgst.com.au)
Dundonnell WF (VIC)	October 2020	A single blade separated from the hub of a turbine and fell to the ground, soon after mechanical completion.	General Failure: Blade drop.	Tilt Press Release: 6 October 2020 Dundonnell wind farm stops production after blade falls off turbine |

Event	Date	Description	Classification	Source
				RenewEconomy (wpengine.com)

Of the failure events identified in Table 4, two failures are described as “blade drop”, while the remaining three events are classified as “fragmentation”.

In addition to these Blade Throw events, MGE are aware of several other catastrophic WTG failures, however, these failures did not constitute Blade Throw, and are beyond the scope of the current study.

For the purposes of this study, it is assumed that each of the events had the potential to be a life-threatening event. It is noted that in the case of the Wonthaggi Wind Farm blade failure event, reports describe debris, in the form of foam packing, being strewn across fields in the vicinity of the affected WTG. While details are scant, at face value the impact potential (that is, the potential to cause death or serious injury) for foam packing appears to be less than for fragments of a blade shell.

Based on the three fragmentation events across approximately 34,000 years of WTG operation, the return period for a catastrophic failure event resulting in fragmentation is 11,000 years of operation, or 0.000,088 year^{-1}. For application in the probability of fatality equation in section 4.2, the probability of blade fragmentation or P (Fragmentation) is 1 in 11,000 years.

Similarly, based on the two blade drop events, the return period for a catastrophic failure event resulting in blade drop is 17,000 years of operation, or 0.000,059 year^{-1}. For application in the probability of fatality equation in section 4.2, the probability of drop or P (Blade Drop) is 1 in 17,000 years.

5.3 Determination and characterisation of impact radius

Two impact radii are considered – a 300 m radius to account for blade drop events and an 800 m radius to account for fragmentation.

The values are based on Rogers et al’s [7] simplified point-mass blade fragment model for maximum throwing distance that assumes a flat surface. The maximum blade throwing distance D is a function of tip velocity v_T, the sine and cosine of the launch angle θ_T, denoted as $s_{\theta T}$ and $c_{\theta T}$, gravitational acceleration, g, the hub height, h, and the rotor radius, R.

Thus, the maximum blade throwing distance is given as:

$$D = \frac{v_T^2 s_{\theta_T} c_{\theta_T} \pm v_T^2 \sqrt{s_{\theta_T}^2 c_{\theta_T}^2 + 2\frac{g}{v_T^2}\left(h - Rc_{\theta_T}\right) c_{\theta_T}^2}}{g}$$

The frame of reference is provided in Figure 4 and results are plotted in Figure 5.

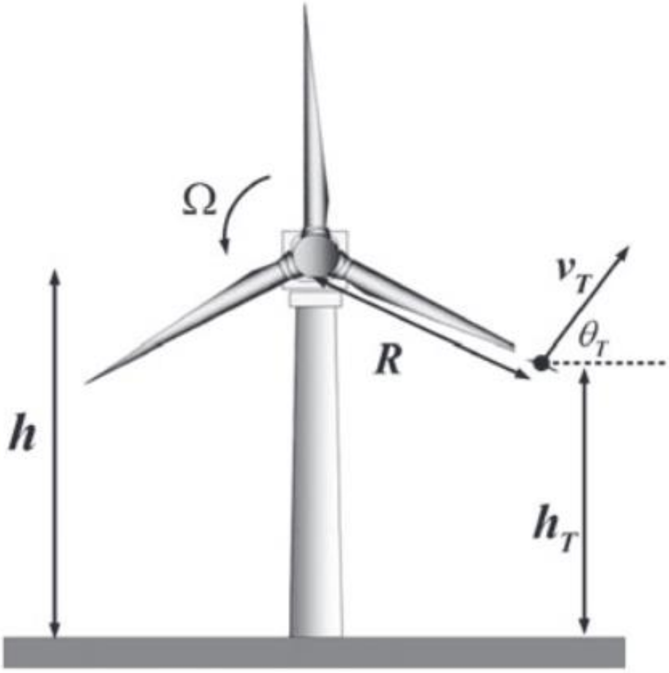

Figure 4: Frame of reference. Diagram from Rogers et al. [7].

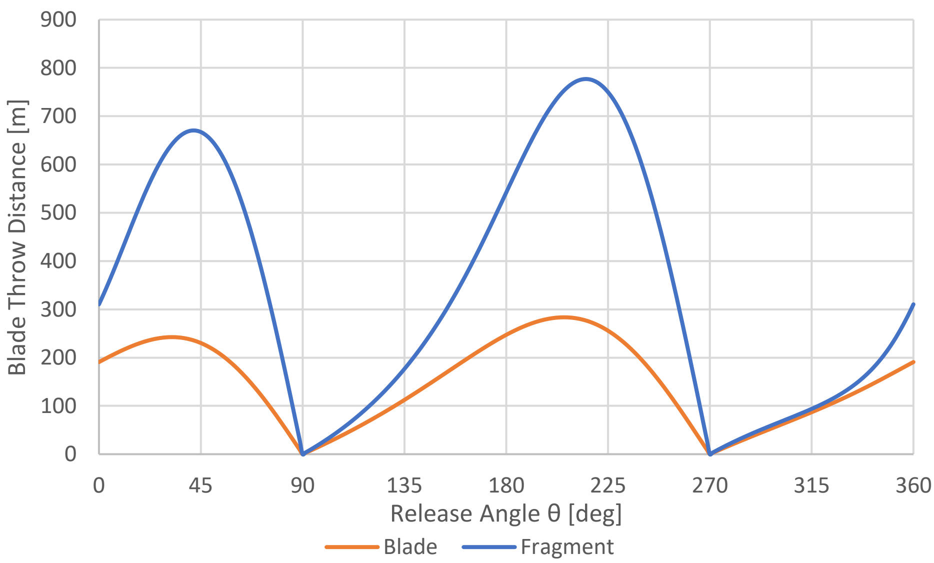

Figure 5: Maximum blade throw distance based on Rogers et al.'s kinematic model assuming a 75 m/s release velocity for the fragment, a 170 m hub height and a 172 m rotor. The blade scenario is based on a 37.5 m/s release velocity and the effective radius being halfway along the blade.

Various sources provide a wide range of impact radii. For example, Braam & Rademakers [11] provide a commentary on the Dutch "Handbook Risk Assessment of Wind Turbines", which assessed 200 severe incidents that occurred over 43,000 WTG years in Germany, Denmark and Holland until 2002 with WTGs having nameplate capacities ranging between 500 kW and 2 MW. Of those 200 incidents, 62 were relevant to the assessment of safety of nearby objects. Based on these data, the handbook identified "maximum throwing distances of a blade during overspeed" varying between 300 m and 400 m. Interestingly, the kinematic model developed by Rogers et al. [7] highlights that "maximum throwing distance" is most dependent on the tip speed, rather than on the size of the WTG, suggesting that older studies such as Braam & Rademakers' [11] empirical assessment may have some level of applicability for much larger WTGs.

Alternatively, Persimia conducted Monte Carlo simulations using a WTG with rotor diameter of 158 m. The maximum simulated blade fragment throw distance was less than 475 m [5].

While the empirical data is useful for sanity-checking the empirical models, there is simply insufficient empirical blade throw data on which to base a blade throw assessment. As such it would seem prudent to base modelling on Monte Carlo simulations.

Further, there is some conjecture regarding whether it is more or less conservative to model a larger area. In assuming a larger potential area of impact, the likelihood of impacting a person within that area of impact is reduced, assuming a homogenous distribution. However, by assuming a larger potentially impacted area, a greater number of people may be impacted. As such the conservatism is entirely dependent on the specific scenario modelled.

5.3.1 Blade Fragmentation

The characterisation of the likelihood of a blade fragment landing in a particular location is assessed based on a Monte Carlo simulation. Persimia [5], in their blade throw assessment for the Grove Park Wind Farm, used a Monte Carlo simulation to derive a probability density function, with the likelihood of a blade landing in a specific location generally decreasing as that location is farther from the WTG [5]. GE's Cypress platform with a 158 m rotor diameter was used as the candidate WTG; the result is shown in Figure 6. This study provides a helpful reference point as it is a recent-model utility-scale WTG. Figure 6, using 12.5 m distance bins, shows that within 50 m of a WTG, the likelihood of impact is approximately 75% higher for the 50 m to 200 m range. Beyond 200 m there is a steady decline in likelihood of impact.

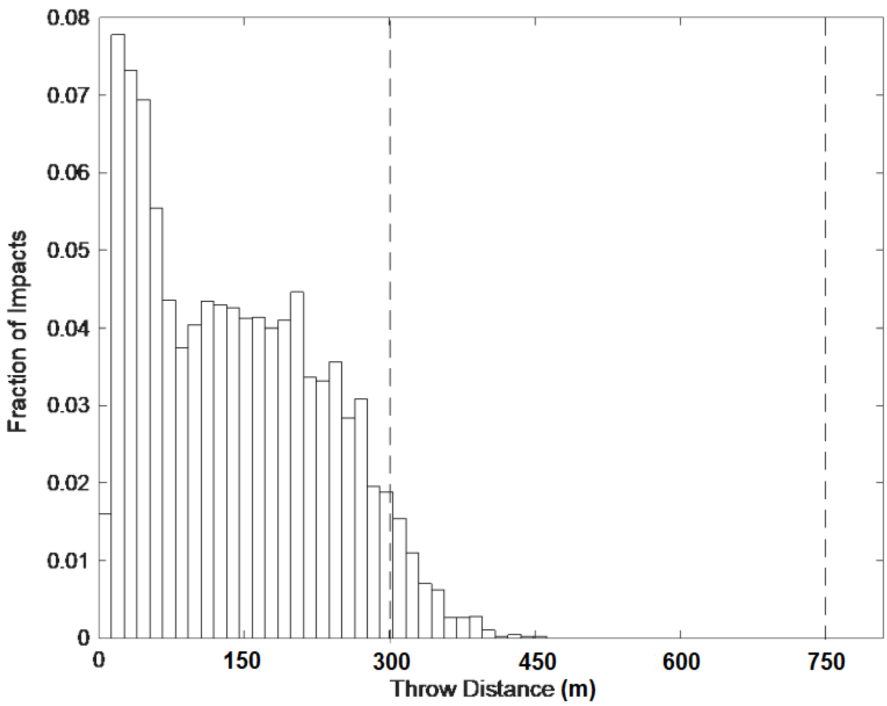

Figure 6: Histogram of blade fragment throw distance based on Monte Carlo simulations [5]. Throw distances converted from feet to metres.

Based on Figure 6, the impact area is broken up into four concentric circles and the respective likelihood of occurrence, as described in Table 5 for the blade fragment analysis, and Table 6 for the blade drop analysis, to give distance weightings. Examples of the concentric circles are shown in . Table 5 is derived from the work of Persimia [5], with some minor modification to capture the full extent of the impact zone (800 m in this study).

Table 5: Characterisation of fragmentation impact area.

Area	Radius Limits [m]	Distance weighting: Probability of Fragment within Area	Area [m^2]
1	0 - 50	25%	7,854
2	50 - 275	65%	229,729
3	275 - 400	9.9%	265,072
4	400 - 800	0.1%	1,507,964

5.3.2 Blade Drop

For the blade drop analysis, the impact area around WTGs are divided into two regions – a 50 m radius, and an outer area with radius of 300 m. It is assumed that while the level of human activity within these two areas differs, the likelihood of a blade dropping in a particular location within that 300 m radius is homogenous across the area.

Table 6: Characterisation of blade drop impact area.

Area	Radius [m]	Distribution	Area [m^2]
1	50	2.8%	7,854
2	300	97.2%	274,890

5.4 Likelihood of person within impact radius

The likelihood of a person being within the impact radius of a wind turbine blade drop or blade fragmentation is estimated by assessing the usage of land in the Project Area.

The area around WTGs is divided into various categories of how the land is used. A significant portion of the land is used for farming, while smaller portions are used for buildings, roads and vegetation.

The occupancy rate for each land use category is estimated in section 5.4.1.

The area of each land use category within the impact radius of WTG is estimated for a representative WTG in section 5.4.2 and section 6.4.3.

The occupancy rate for each land use category is combined with the land area to find the hours spent in each land area over the course of a year, for a representative wind turbine.

5.4.1 Land Area Use Categories and Occupation Rates

The land in the impact area of a wind turbine blade at Junction Rivers Wind Project is divided up into land usage categories. A significant portion of the land is used for farming, while smaller portions are used for buildings, roads and vegetation.

The land use categories at the Junction Rivers Wind Project are tabulated in Table 7. This table also shows the assumed occupancy rate for any given location within that land area category.

Table 7: Land use categories and occupancy rate assumptions

Category	Occupancy Rate Assumption
Farmland – cropping and grazing	Ploughing/seeding/spraying/harvesting: assume coverage of area six times per year, at a rate of 20 km/h, at a width of 5 m. By default, all land is assumed to be farmland unless otherwise assigned.
Farm Buildings	4 hours per day for 2 people.
Road – public	100 cars per day driving at 60 km/h.
Road – internal	4 cars per day driving at 40 km/h.
Native Vegetation, creeks, rivers and dams.	Minimal human interaction
Wind farm maintenance	8 hours per day for 2 working weeks (10 days) for 4 people.
Associated and Non-Associated Dwellings	16 hours per day for 3 people.

5.4.2 Land Area Use for Representative Wind Turbine

The land use at the representative WTG of the Junction Rivers wind project is tabulated in Table 10. The total area of each sector is derived from Table 5.

It is not practical, for the purpose of this study, to exactly measure the area of land use for each category for each wind turbine. Conservative assumptions for land use are applied for a representative wind turbine and then scaled to the entire wind farm, as presented in the results section.

<u>Dwellings</u> assume negligible land area use. They are separately assessed in the next section.

<u>Internal road</u> describes access roads within the wind farm which connect wind turbines and may be used by farm personnel to traverse their land. Each WTG has an internal road. Reference to internal road also refers to unnamed roads within 1 km of WTGs. Internal roads are assumed to be of 5 m width. Internal road length within each impact area sector is shown in Table 8.

Table 8: Length of internal road in Impact Areas for representative WTG

Impact area sector	Internal road length [m]	Calculation Method
800 m	1,500	800 m of access road plus 700 m of internal farm roads
400 m	270	250 m of access road plus 20 m of internal farm roads
275 m	470	450 m of access road plus 20 m of internal farm roads
50 m	100	100 m of access road

Three public roads are in the vicinity of the Project; Yanga Way, Balranald Rd and Arundel Rd. Yanga Way is further than 800 m from any WTG. Public roads are assumed to be of 20 m width. The input summary is provided in Table 9 and a Project overview of blade throw radii and public roads is provided in Figure 7.

Table 9: Length of public road in Impact Areas for representative WTG

Impact area	Public road length [m]	Calculation Method
800 m	167	20 of 96 WTGs have 1 x 800 m of public road length
400 m	34	13 of 96 WTGs have 1 x 250 m of public road length
275 m	0	No public roads within 275 m of any WTGs
50 m	0	No public roads within 50 m of any WTGs

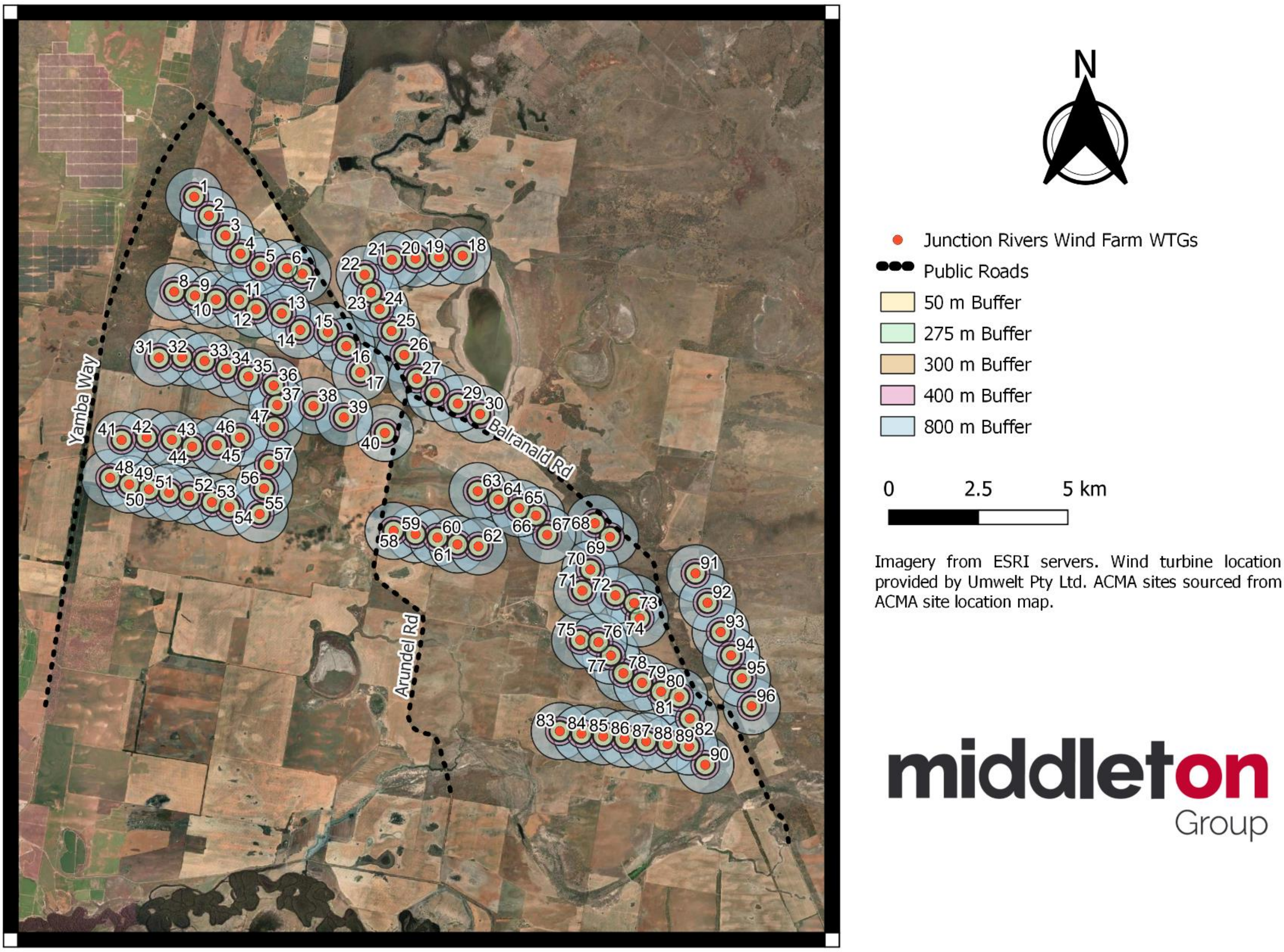

Figure 7: Public Roads and WTGs with blade throw radii

Native vegetation, creeks, dams take roughly 7% of the impact area outside of 50 m from the WTG.

Farming is the land use allocated to the remaining land not used by roads or vegetation.

Table 10: Representative WTG surrounding land use area.

Impact area sector	Area of sector [m²]	Internal road [m]	Public road [m]	Native vegetation, creeks, dams [m²]	Farming [m²]
800 m	1,507,964	1,500	162	105,000	1,391,264
400 m	265,072	270	33	18,500	241,222
275 m	229,729	470	0	16,000	209,379
50 m	7,854	100	0	0	7,354

5.4.3 Dwellings and Farm Buildings

As shown in Figure 8, no involved (associated) or non-involved (non-associated) dwellings are located within the maximum blade fragmentation radius, 800 m, of any WTG. The closest involved dwelling is 1.9 km from the nearest WTG (56). The closest non-involved dwelling is 2.3 km from the nearest WTG (31). As such, there is **no risk** of blade throw to any associated or non-associated dwellings.

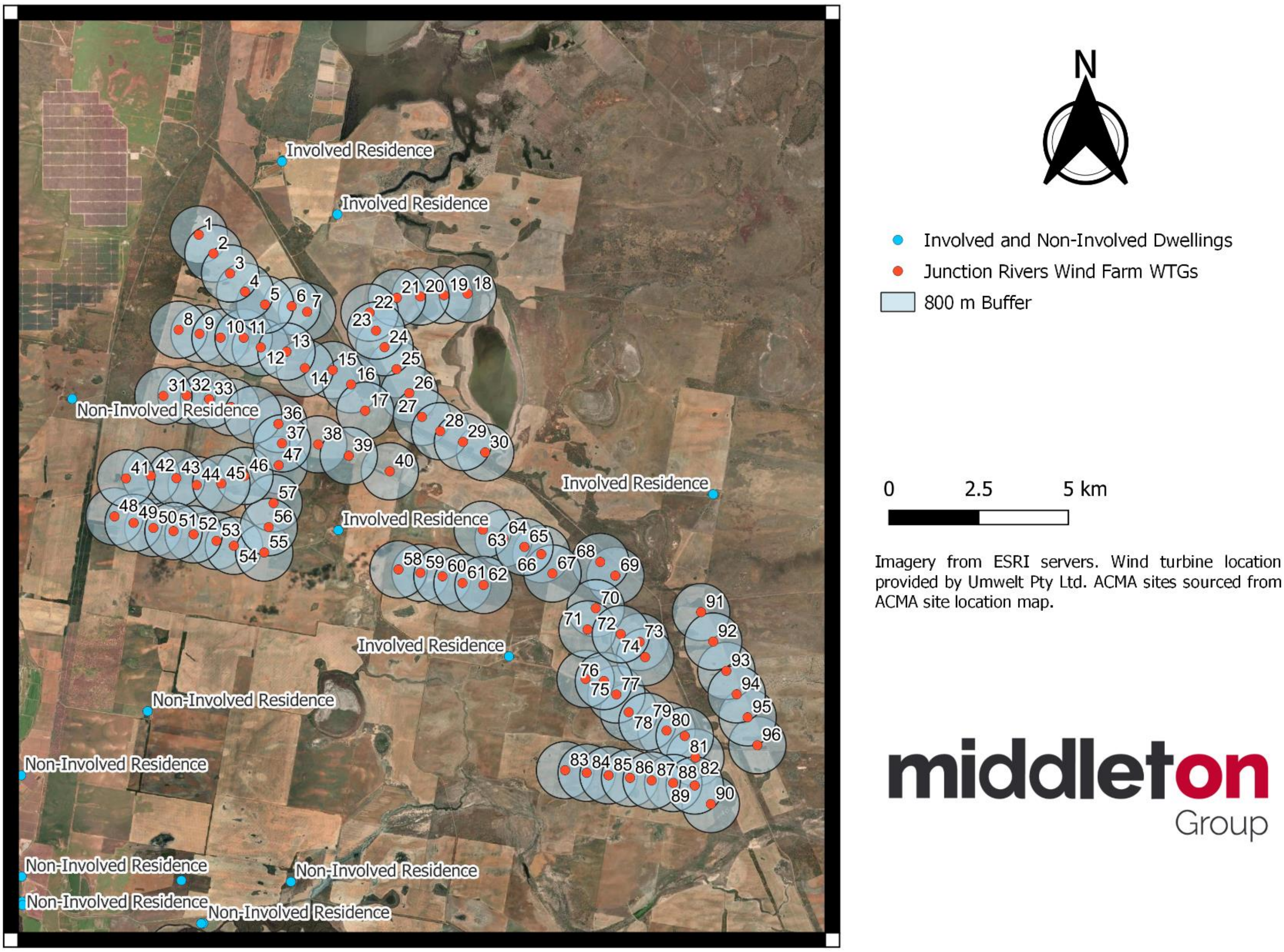

Figure 8: WTG Blade Throw Radii and nearby involved and non-involved dwellings

One farm building is located within 800 m of WTGs 46, 47 and 57, as seen in Figure 9. A second farm building is located within 800 m of WTG 18, as displayed in Figure 10. No farm buildings are located within the blade drop radius, 300 m, of WTGs.

Farm buildings were identified via review of satellite imagery. The farm buildings belong to landowners associated with the Project.

Table 11: Dwellings and farm buildings in vicinity of WTGs.

Impact area sector	WTGs with associated/non-associated dwellings in sector	WTGs with associated landowner's farm buildings in sector
800 m	0	4
400 m	0	0
275 m	0	0
50 m	0	0

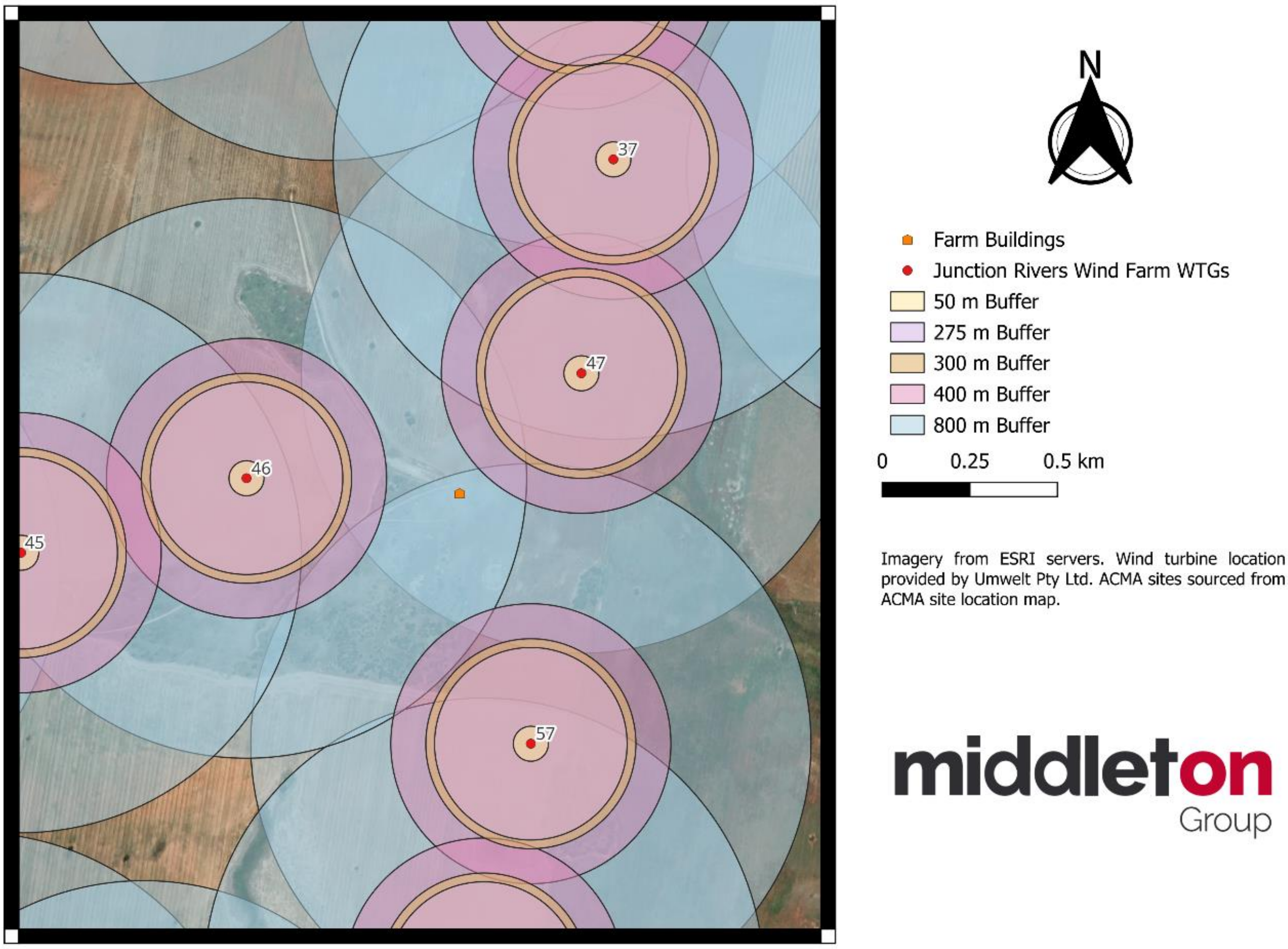

Figure 9: Farm Building within Blade Throw Radii of WTG 46, 47 and 57.

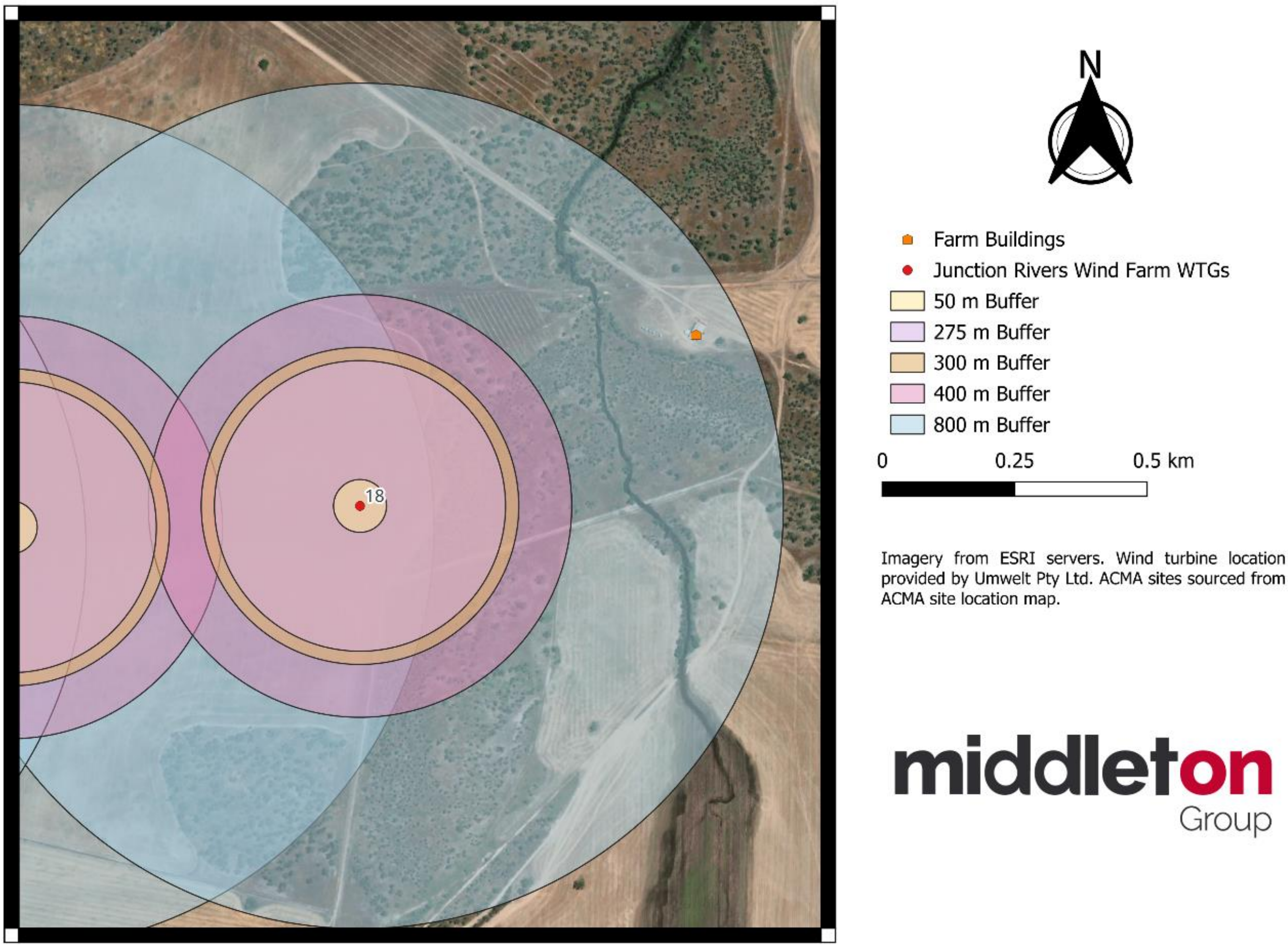

Figure 10: Farm building within blade throw radii of WTG 18.

5.4.4 Battery Energy Storage System

Four locations are being considered for onsite battery energy storage, or up to four static synchronous compensator (STATcom) facilities, as shown in Figure 11. For this study, the BESS / STATcom units are referred to by their location: North BESS, West BESS, Central BESS and South BESS. The position of each BESS with respect to nearby WTG blade throw radii is shown in subsequent figures. The quantity of WTGs with a BESS within its impact sectors is summarised in Table 12.

Table 12: WTGs with BESS in impact sectors

Impact area sector	WTGs with BESS in sector (total)
800 m	9
400 m	0
275 m	1
50 m	2

Figure 11: The Project BESS Layout

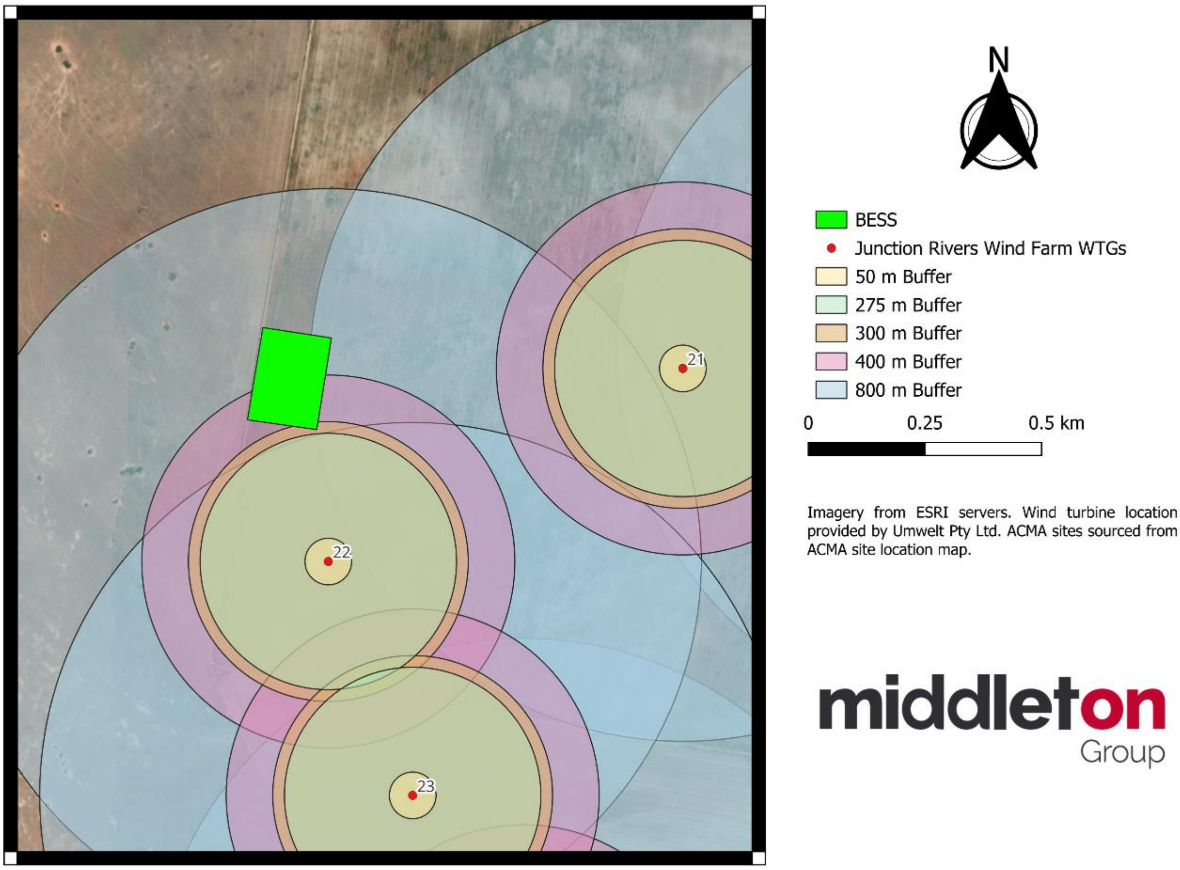

Figure 12: North BESS and blade throw radii

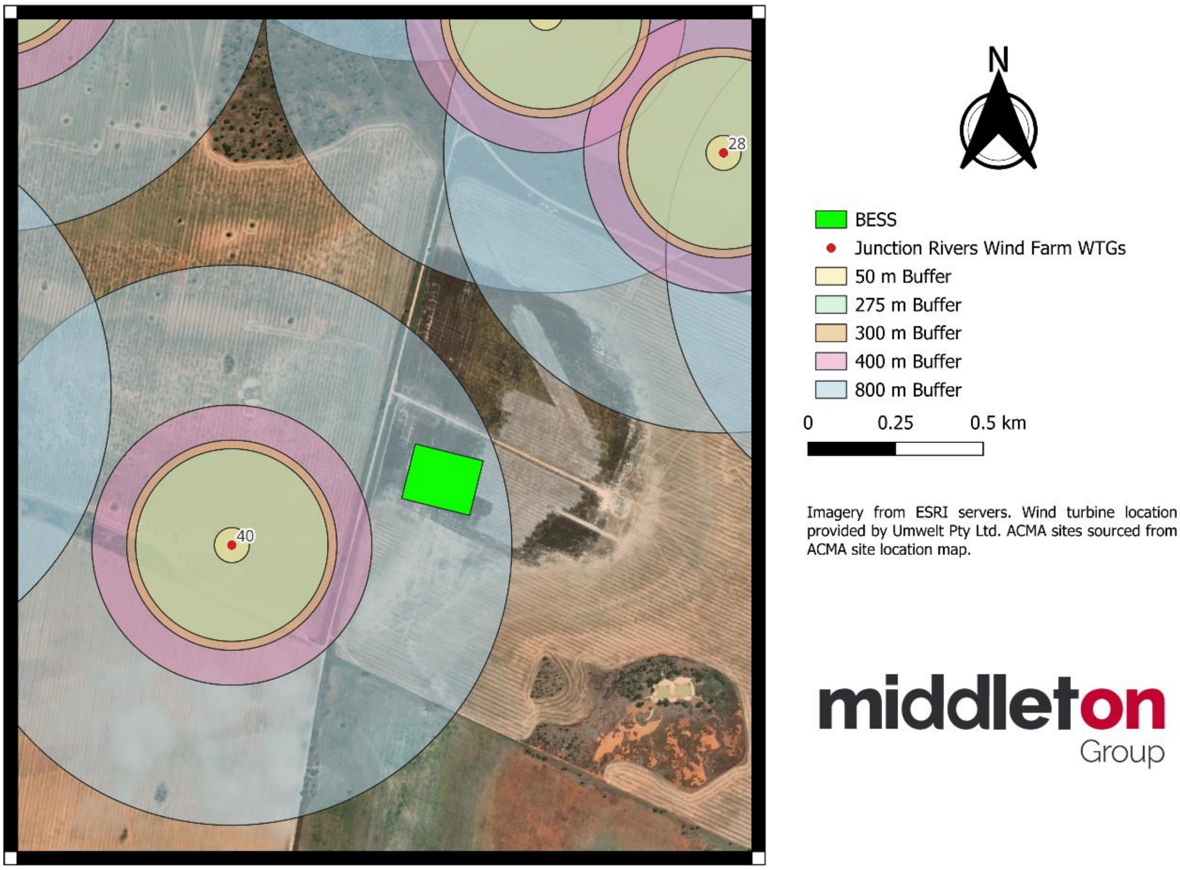

Figure 13: Central BESS and blade throw radii

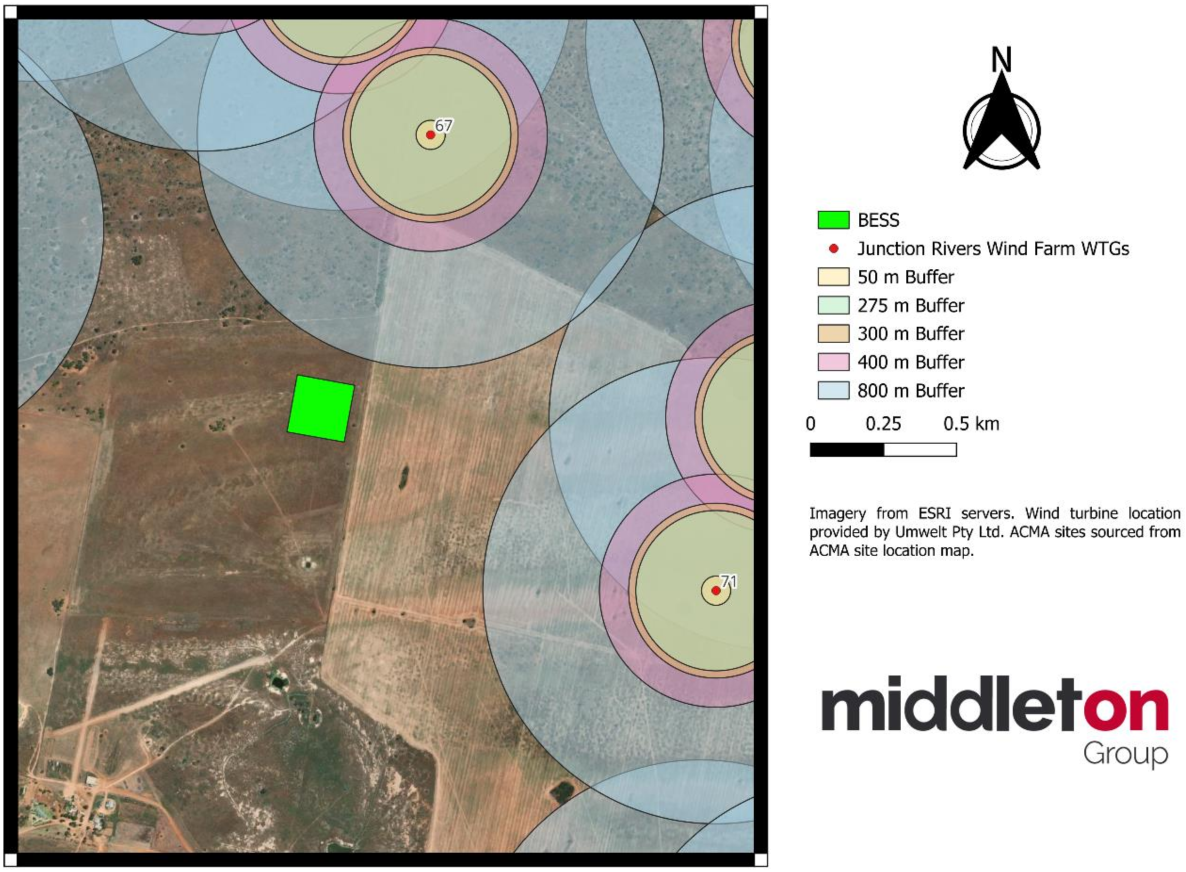

Figure 14: South BESS and blade throw radii

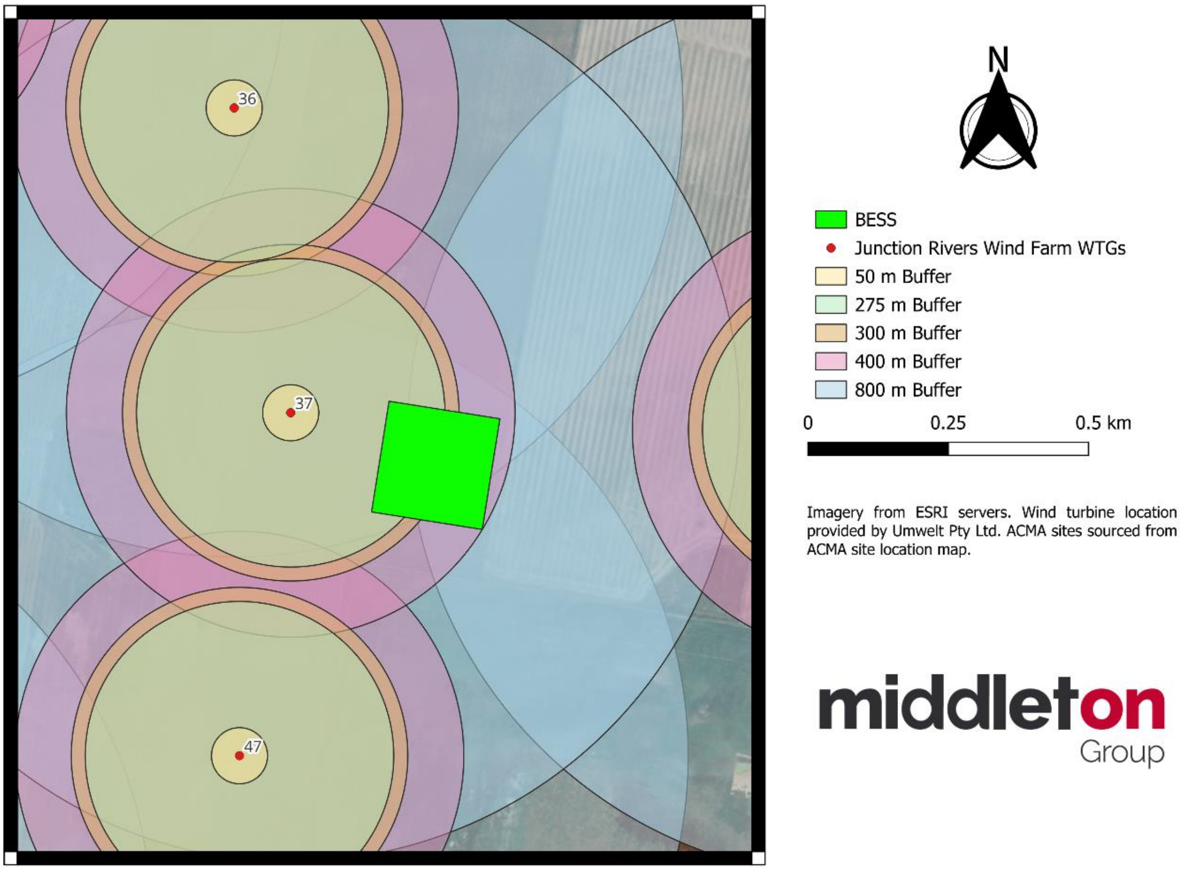

Figure 15: West BESS and blade throw radii

5.4.5 Land Use Occupation Hours for Representative Wind Turbine

The assumed occupancy around the representative WTG is tabulated in Table 13 for the blade fragmentation case, with the equivalent analysis for the blade drop case shown in Table 14.

Table 13: Land use categories and assumed occupation rates for a representative WTG – for analysis of blade fragmentation.

Category	Occupancy details	Hours of occupation per year			
		800 m	**400 m**	**275 m**	**50 m**
Farmland – cropping and grazing	Ploughing/seeding/spraying/harvesting: assume coverage of area six times per year, at a rate of 20 km/h, at a width of 5 m.	83.8 h	15.0 h	12.3 h	0.4 h
Farm Buildings	4 hours per day for 2 people.	122 h	0 h	0 h	0 h
Road – public	100 cars per day driving at 60 km/h.	101.6 h	20.7 h	0 h	0 h
Road – internal	4 cars per day driving at 40 km/h.	54.8 h	9.9 h	17.2 h	3.7 h
Native Vegetation, creeks, rivers and dams.	Minimal human interaction	0 h	0 h	0 h	0 h
Wind farm maintenance	8 hours per day for 2 working weeks (10 days) for 4 people.	0 h	0 h	0 h	320 h
Associated Dwellings	16 hours per day for 3 people.	0 h	0 h	0 h	0 h
BESS maintenance	8 hours per day for 2 working weeks (10 days) for 4 people.	30 h	0 h	3.3 h	6.7 h
TOTAL		361.5 h	75.6 h	29.8 h	324.1 h

Table 14: Land use categories and assumed occupation rates for a representative WTG – for analysis of blade drop.

Category	Occupancy details	Hours of occupation per year	
		300 m	**50 m**
Farmland – cropping and grazing	Ploughing/seeding/spraying/harvesting: assume coverage of area six times per year, at a rate of 20 km/h, at a width of 5 m. By default, all land is assumed to be farmland unless otherwise assigned.	16.3 h	0.4 h
Farm Buildings	4 hours per day for 2 people.	0 h	0 h
Road – public	100 cars per day driving at 60 km/h.	0 h	0 h
Road – internal	4 cars per day driving at 40 km/h.	18.7 h	3.7 h
Native Vegetation, creeks, rivers and dams.	Minimal human interaction	0 h	0 h
Wind farm maintenance	8 hours per day for 2 working weeks (10 days) for 4 people.	0 h	320 h
Associated Dwellings	16 hours per day for 3 people.	0 h	0 h
BESS maintenance	8 hours per day for 2 working weeks (10 days) for 4 people.	3.3 h	6.7 h
TOTAL		35.0 h	324.1 h

5.5 Area footprint of person impacted by blade failure

The area footprint of a person within the impact radius is assumed to be reflective of both the size of the person, and the potential landing area of debris should it pass through a person.

This area varies as a function of both the size and location of the person, the size of the blade or blade fragment, and the trajectory of the projectile. As a conservative measure, it is assumed that a person inhabiting the impact radius is 1 m wide, and that, due to the projectile's trajectory, a potential landing area of 3 m in length would impact on the occupant, as illustrated in Figure 16. Thus, an impact area of 3 m^2 is assumed.

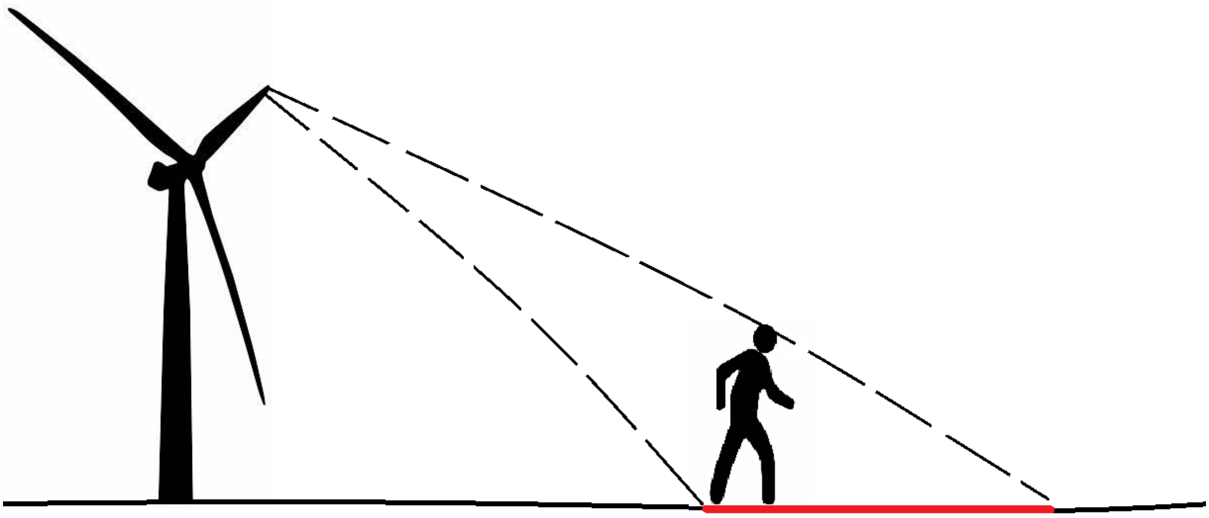

Figure 16: Illustration of potential landing area. The landing area is assumed to be longer than the occupant is tall.

5.6 Area footprint of BESS impacted by blade failure

For the purposes of the BESS risk assessment, the cumulative area taken up by a BESS under each impact sector for a representative WTG was measured from the figures shown in section 5.4.4.

Table 15: BESS area calculation

WTG Impact Sector	Cumulative BESS Area (m^2)
800 m	214,260
400 m	4,400
275 m	33,340
50 m	2,160

6 Results

Probability of blade failure is presented in Table 16.

Land use in the vicinity of the representative WTG is presented in Table 10, which is based on aerial imagery of the site, conservative estimates of traffic volumes and speed. The number of WTGs with associated and non-associated dwellings and buildings located within impact areas is shown in Table 11.

The data is aggregated in Table 17 to represent blade fragmentation scenarios and in Table 18 to represent blade drop scenarios. The probability of these two scenarios is then summed to provide a final estimate of the probability of a fatal blade throw incident, and the corresponding return period. The analysis highlights the very low risk of impact on human life due to blade throw, with a calculated return period of 19.846 million years. This return period fits comfortably with the levels of risk described as acceptable in HIPAP4.

Table 16: Blade failure probability.

	Fragmentation	Blade Drop
Probability [years^{-1}]	8.80E-05	5.87E-05
Return Period [years]	11,364	17,045

6.1 Likelihood of person impacted by blade failure

Table 17: Occupancy by sector and calculation of return period for fragmentation events.

Impact Area Sector	Hours of occupancy	% Time occupied	Occupier footprint/ Sector Area (m^2)	Distance weighting	P(Location)	P(fatality) = % Time occupied × P(Location) × P(Blade Fragmentation)
800 m	391.5	4.5%	1.99E-06	0.10%	1.99E-09	7.82E-15
400 m	75.6	0.9%	1.13E-05	9.90%	1.12E-06	8.51E-13
275 m	33.1	0.4%	1.31E-05	65%	8.49E-06	2.83E-12
50 m	330.8	3.8%	3.82E-04	25%	9.55E-05	3.17E-10
			P(fatality, fragmentation, single WTG) [$years^{-1}$]			3.21E-10
			P(fatality, fragmentation, Project) [$years^{-1}$]			3.08E-08
			Return Period Junction Rivers Wind Project [years]			32,449,804

Table 18: Occupancy by sector and calculation of return period for blade drop events.

Impact Area Sector	Hours of occupancy	% Time occupied	Occupier footprint/ Sector Area (m^2)	Distance weighting	P(Location)	P(fatality) = % Time occupied × P(Location) × P(Blade Fragmentation)
300 m	35.0	0.4%	1.09E-04	97%	1.06E-05	2.72E-12
50 m	324.1	3.%	3.82E-04	3%	9.55E-05	2.12E-10
			P(fatality, blade drop, single WTG) [$years^{-1}$]			2.14E-10
			P(fatality, blade drop, Project) [$years^{-1}$]			2.06E-08
			Return Period Junction Rivers Wind Project [years]			48,613,622

Table 19: Probability of fatality due to blade failure

	Fragmentation	Blade Drop	Combined
P(fatality, single WTG) [$years^{-1}$]	3.21E-10	2.14E-10	5.35E-10
P(fatality, Project) [$years^{-1}$]	3.08E-08	2.06E-08	5.14E-08
Return Period Junction Rivers Wind Project [years]	32,449,804	48,613,622	**19,460,101**

6.2 Likelihood of BESS impacted by blade failure

Table 20: BESS footprint by sector and calculation of return period for fragmentation events

Impact Area Sector	Sector Area (m^2)	BESS Footprint (m^2)	BESS Proportion of Area	Distance Weighting	P(Location)	P(Hit)
800 m	1,507,964	214260	0.142085575	0.10%	1.42E-04	1.25E-08
400 m	265,072	4400	0.016599271	9.90%	1.64E-03	1.45E-07
275 m	229,729	33340	0.145127543	65%	9.43E-02	8.30E-06
50 m	7,854	2160	0.275019742	25%	6.88E-02	6.05E-06
			P(impact, blade fragmentation, BESS) [$years^{-1}$]			1.45E-05
			Return Period Junction Rivers Wind Project [years]			68,923.65

Table 21: BESS footprint by sector and calculation of return period for blade drop events

Impact Area Sector	Sector Area (m^2)	BESS Footprint (m^2)	BESS Proportion of Area	Distance Weighting	P(Location)	P(Hit)
300 m	274,889	33340	0.121285161	3%	3.37E-03	1.98E-07
50 m	7,854	2160	0.275019742	97%	2.67E-01	1.57E-05
			P(impact, blade drop, BESS) [$years^{-1}$]			1.59E-05
			Return Period Junction Rivers Wind Project [years]			62,956.76

Table 22: Probability of BESS impact due to blade failure

	Fragmentation	Blade Drop	Combined
P(*impact, Project*) [years-1]	1.45E-05	1.59E-05	3.04E-05
Return Period Junction Rivers Wind Project [years]	68,923.65	62,956.76	**32,903**

7 Assumptions

This report relies upon several assumptions:

- Blade throw return period
  - The study assumes that the hours of operation to date of WTGs in Australia and the number of blade throw events reported is representative of Junction Rivers Wind Project and that a return period can be extrapolated from these data.
  - It is assumed that blade throw events that have been reported are representative of all such events.
- Statistical independence
  - It is assumed that the site usage can be approximated as a simple occupancy likelihood while the likelihood of blade failure can also be described through a failure return period, and that the two events are statistically independent.
  - Blade failure is likely to occur during severe weather events, while occupancy within the vicinity of the WTG is likely to be reduced during severe weather.
  - The assumption of statistical independence is a source of conservatism in the model.
- Australian data
  - Analysis is confined to Australian data and Australian events.
- Representative WTG
  - Analysis for the likelihood of fatality is based on a representative WTG that is representative of an average WTG at the Junction Rivers Wind Project, with representative road distances, dwellings and buildings located within the impact zones.
- Traffic volumes and site occupation
  - Traffic volumes and site occupation specifications have been assumed based on consultation with Umwelt and Windlab.

8 Conclusion

This study provides an estimate of the risk to human life associated with a blade failure event, based on likelihood of a human occupying space within the potential impact zone at the time of blade failure.

It is noted that the distance between both the nearest non-associated dwelling and associated dwelling to a proposed WTG location is beyond 1 km as shown in Figure 8. The various models and empirical data examined demonstrate that the risk associated with blade throw for these dwellings is negligible as they are beyond the potential impact area.

Based on the available data, it is estimated that there is a 19.46 million year return period for a blade failure causing a fatality at Junction Rivers Wind Project. Thus, the likelihood of such an event occurring is very low and the level of risk is well within the bounds of being considered broadly acceptable. NSW Planning's HIPAP4 document [2] provides suitable thresholds of acceptability; these thresholds are shown in Table 23.

There is a 32,900 year return period for a blade failure impacting the BESS at the Junction Rivers Wind Project. This risk calculation exclusively considers the impact on the BESS hardware, while the risk of fatality is addressed in Table 23. Thus, the likelihood of such an event occurring is greater than and the acceptable return period, 1 in 10,000 years, for Industrial land use.

The low likelihood of adverse outcome is due to the low incidence of blade failure and low rates of occupation in the vicinity of any of the WTGs.

Table 23: HIPAP4 risk thresholds [2] alongside the calculated return period for the Project for a fatality due to blade throw.

Land Use or Activity	Acceptable Risk/Return Period
Junction Rivers Wind Project blade failure event causing fatality	19.46-million-year return period
Hospitals, schools, child-care facilities, old age housing	2 million years
Residential, hotels, motels, tourist resorts	1 million years
Commercial developments including retail centres, offices and entertainment centres	200,000 years
Sporting complexes and active open space	100,000 years
Junction Rivers Wind Project blade failure event impacting BESS	32,900 years
Industrial	20,000 years

9 References

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[4] ERM, “Blade Throw Risk Assessment: Hills of Gold Wind Farm,” Newcastle, 2020.

[5] Persimia, “P122020-3-002: Panther Grove Wind Project Ice Shed and Blade Throw Risk Assessment,” Tri Global Energy, Atlanta, 2020.

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[11] H. Braam and L. Rademakers, “Guidelines on the Environmental Risk of Wind Turbines in the Netherlands,” *Proceedings of the Global Wind Energy Conference, Paris, 2002,* p. 4, 2004.

Appendix A Wind Turbine Years of Operation

Wind Farm	State	No of WTGs	Year of Commencement	Years of Operation	WTG Years
Bango WF	NSW	46	2022	1	46
Crudine Ridge	NSW	37	2022	1	37
Mortlake South	VIC	35	2022	1	35
Port Augusta	SA	50	2021	2	100
Murra Warra II Wind Farm	VIC	38	2021	2	76
Ferguson	VIC	3	2021	2	6
Biala Wind Farm	NSW	31	2021	2	62
Cherry Tree WF	VIC	16	2020	3	48
Coopers Gap Wind Farm	QLD	123	2020	3	369
Moorabool Wind Farm (North & South)	VIC	104	2020	3	312
Stockyard Hill Wind Farm	VIC	149	2020	3	447
Diapur	VIC	2	2020	3	6
Warradarge	WA	51	2020	3	153
Yandin WF	WA	51	2020	3	153
Agnew	WA	5	2020	3	15
Bodangora Wind Farm	NSW	33	2019	4	132
Silverton Wind Farm	NSW	58	2019	4	232
Willogoleche Wind Farm	SA	32	2019	4	128
Lal Lal Wind Farm	VIC	60	2019	4	240
Murra Warra Wind Farm	VIC	61	2019	4	244
Cattle Hill Wind Farm	TAS	48	2019	4	192
Badgingarra	WA	37	2019	4	148
Beros Rd	WA	19	2019	4	76
Port Gregory	WA	5	2019	4	20
Bulgana	VIC	56	2019	4	224
Kennedy	QLD	12	2019	4	48
Crowlands Wind Farm	VIC	39	2018	5	195
Granville Harbour Wind Farm	TAS	31	2018	5	155
Hornsdale 3	SA	35	2018	5	175
Lincoln Gap Wind Farm	SA	59	2018	5	295
Mount Emerald Wind Farm	QLD	53	2018	5	265
Mount Gellibrand Wind Farm	VIC	44	2018	5	220
Sapphire Wind Farm	NSW	75	2018	5	375
Kiata	VIC	9	2018	5	45
Crookwell 2	NSW	46	2018	5	230
Salt Creek WF	VIC	15	2018	5	75
Timboon West	VIC	2	2018	5	10
Maroona	VIC	2	2018	5	10
Yaloak South	VIC	14	2018	5	70
Ararat Wind Farm	VIC	75	2017	6	450

Wind Farm	State	No of WTGs	Year of Commencement	Years of Operation	WTG Years
Hornsdale 1	SA	32	2017	6	192
Hornsdale 2	SA	32	2017	6	192
Waterloo 2	SA	6	2017	6	36
White Rock Wind Farm (Stage I)	NSW	70	2017	6	420
Flinders Island	TAS	1	2017	6	6
Coober Pedy	SA	2	2017	6	12
Coonooer Bridge	VIC	6	2016	7	42
Bald Hills Wind Farm	VIC	52	2015	8	416
Boco Rock Wind Farm	NSW	67	2015	8	536
Portland 4	VIC	23	2015	8	184
Taralga Wind Farm	NSW	51	2015	8	408
Mount Mercer Wind Farm	VIC	64	2014	9	576
Snowtown 2	SA	90	2014	9	810
Gullen Range Wind Farm	NSW	73	2013	10	730
Macarthur Wind Farm	VIC	140	2013	10	1400
Mortons Lane Wind Farm	VIC	13	2013	10	130
Mumbida Wind Farm	WA	22	2013	10	220
Musselroe Wind Farm	TAS	56	2013	10	560
Karakin	WA	10	2013	10	100
Sumich West Hills	WA	10	2013	10	100
Hallett 5	SA	25	2012	11	275
Oaklands Hill Wind Farm	VIC	32	2012	11	352
Woodlawn Wind Farm	NSW	23	2012	11	253
Hepburn	VIC	2	2012	11	22
Collgar Wind Farm	WA	111	2011	12	1332
Grasmere WF	WA	6	2011	12	72
Hallett 4	SA	63	2011	12	756
Waterloo Wind Farm	SA	37	2011	12	444
Mount Barker	WA	3	2011	12	36
Gunning WF	NSW	31	2011	12	372
Clements Gap Wind Farm	SA	27	2010	13	351
Hallett 2	SA	34	2010	13	442
Lake Bonney 3	SA	13	2010	13	169
Capital Wind Farm	NSW	67	2009	14	938
Portland 3	VIC	22	2009	14	308
Snowtown 1	SA	47	2009	14	658
Waubra Wind Farm	VIC	128	2009	14	1792
Cullerin Range	NSW	15	2009	14	210
Hallett 1	SA	45	2008	15	675
Lake Bonney 2	SA	53	2008	15	795
Portland 2	VIC	29	2008	15	435
Sassafras	TAS	1	2008	15	15
Cathedral Rocks Wind Farm	SA	33	2007	16	528
Portland 1	VIC	20	2007	16	320

Wind Farm	State	No of WTGs	Year of Commencement	Years of Operation	WTG Years
Woolnorth Studland Bay	TAS	25	2007	16	400
Emu Downs Wind Farm	WA	48	2006	17	816
Mount Millar Wind Farm	SA	35	2006	17	595
Walkaway Wind Farm	WA	54	2006	17	918
Canunda Wind Farm	SA	23	2005	18	414
Lake Bonney 1	SA	46	2005	18	828
Wattle Point Wind Farm	SA	55	2005	18	990
Wonthaggi WF	VIC	6	2005	18	108
Woolnorth Wind Farm	TAS	37	2004	19	703
Rottnest	WA	1	2004	19	19
Challicum Hills Wind Farm	VIC	35	2003	20	700
Starfish Hill Wind Farm	SA	22	2003	20	440
Nine Mile Beach	WA	6	2003	20	120
Huxley Hill 2	TAS	2	2003	20	40
Toora	VIC	12	2002	21	252
Albany WF	WA	12	2001	22	264
Hampton Wind Park	NSW	2	2001	22	44
Codrington	VIC	14	2001	22	308
Windy Hill	QLD	20	2000	23	460
Blayney Wind Farm	NSW	15	2000	23	345
Huxley Hill 1	TAS	3	1998	25	75
Crookwell 1	NSW	8	1998	25	200
Thursday Island	QLD	2	1997	26	52
Ten Mile Lagoon	WA	9	1993	29	261
TOTAL		**3,840**		**1,125**	**34,091**