Technical Report - Blade Throw Assessment

Virya Energy

Yanco Delta Wind Farm
14 July 2022

Executive summary

Virya Energy is proposing to construct, operate and maintain the Yanco Delta Wind Farm (the Project). Approval is sought under Division 4.7 of Part 4 of the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act) and Part 9, Division 1 of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The Project would involve the construction, operation and maintenance of a wind farm with up to 208 wind turbine generators (WTGs), a battery energy storage system (BESS) and associated electrical infrastructure. The generating capacity of the wind farm is approximately 1,500 megawatts (MW).

This blade throw assessment has been prepared to address the Secretary's Environmental Assessment Requirements (SEARs) relating to blade throw and will assist the Minister for Planning to make a determination on whether or not to approve the Project. This assessment provides an assessment of potential blade throw risks from the Project and outlines proposed management measures.

Assessment methodology

A blade throw incident is a structural failure of the blade in a WTG, which results in either the full blade or a segment of the blade detaching from the structure and being thrown from the turbine. This can occur due to physical damage caused by erosion or lightning, material defects or fatigue, amongst other failure modes. This blade throw assessment looks at the risk levels given a portion of the blade being thrown from the structure into the surrounding area. With proper controls in place, such as manufacturing quality controls and operational inspections, it is unlikely that such an incident will occur.

The assessment herein has calculated the maximum throw distance for a full blade and a blade tip fragment in overspeed conditions as 734 metres and 2470 metres, respectively. These distances have been used to conservatively calculate the site-specific risk at dwellings and roads adjacent to the Project using the Dutch Wind Turbine Risk Zoning Guide published in May 2020 (Waterstaat, May 2020).

Overview of blade throw risks

The risk established at the two dwellings within the blade tip fragment throw area is significantly lower than the applicable limit set out within the Dutch Guide. The risk for three typical road journeys in the area was also calculated. The highest risk-generating road journey was Wilson Road, however, a single person could undertake this journey 11,210 within a year and still be within the applicable limit of the Dutch Guide. If a person were to undertake this journey twice a day for a year, the risk of death to that person would be similar to that of being struck by lightning.

Management measures

Management measures implemented during construction, operation and decommissioning of the Project would avoid, mitigate or manage potential blade throw risk. Measures include the requirement for WTGs manufactured and certified to current best practice Australian and international (IEC 61400-23) safety standards and are equipped with sensors that can react to any imbalance in the rotor blades and shut down the WTG if necessary. Further to this, WTGs will be subject to stringent safety and security measures including regular maintenance and servicing (within an ISO90001 Quality Assurance system).

Conclusion

Following the implementation of environmental management measures, the probability of a blade being thrown from a WTG and the thrown object resulting in a person being struck and/or injured or damage occurring to property is expected to be very low.

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Glossary and Terms

Term	Definition
BESS	Battery Energy Storage System
EPBC	Environment Protection and Biodiversity Conservation
EIS	Environmental Impact Statement
EP&A	Environmental Planning and Assessment
LGA	Local Government Area
REZ	Renewable Energy Zone
WTG	Wind Turbine Generator

1. Introduction

1.1 Background

Virya Energy is proposing to construct, operate and maintain the Yanco Delta Wind Farm (the Project). Approval is sought under Division 4.7 of Part 4 of the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act) and Part 9, Division 1 of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The Project would involve the construction, operation and maintenance of a wind farm with up to 208 wind turbine generators (WTGs), a battery energy storage system (BESS) and associated electrical infrastructure. The generating capacity of the wind farm is approximately 1,500 megawatts (MW). The Project would be located within the South-West Renewable Energy Zone (REZ), 10 kilometres north-west of the town of Jerilderie, within the Murrumbidgee Council and Edward River Council Local Government Areas (LGAs) (refer to **Figure 1-1**).

The Project area is defined as the property boundaries of Project landowners (i.e. landowners that have entered into agreements with Virya Energy to have WTGs or associated infrastructure on their properties).

The Project area is zoned RU1 – Primary Production under the Conargo Local Environmental Plan 2013 and Jerilderie Local Environmental Plan 2012. The Project area is used predominately for sheep grazing and agriculture. There are three rural residential dwellings within the Project area, which are all owned by Host Landowners. There are 14 dwellings owned by Associated Landowners within eight kilometres of a WTG, which have signed a neighbour or participation agreement. The nearest neighbouring dwelling that is Non-associated with the Project is 3.6 kilometres from the nearest WTG.

1.2 Project description

The Project would include the following key features:

- Up to 208 WTGs to a maximum tip height of 270 metres
- Generating capacity of approximately 1,500 MW
- BESS, approximately 800 MW/800 megawatt-hours (MWh) (type yet to be determined)
- Permanent ancillary infrastructure, including operation and maintenance facility, internal roads, hardstands, underground and overhead cabling, wind monitoring masts, central primary substation and up to eight collector substations
- Temporary facilities, including site compounds, laydown areas, stockpiles, gravel borrow pit(s) and concrete batch plants.

An indicative Project layout is provided in **Figure 1-2.**

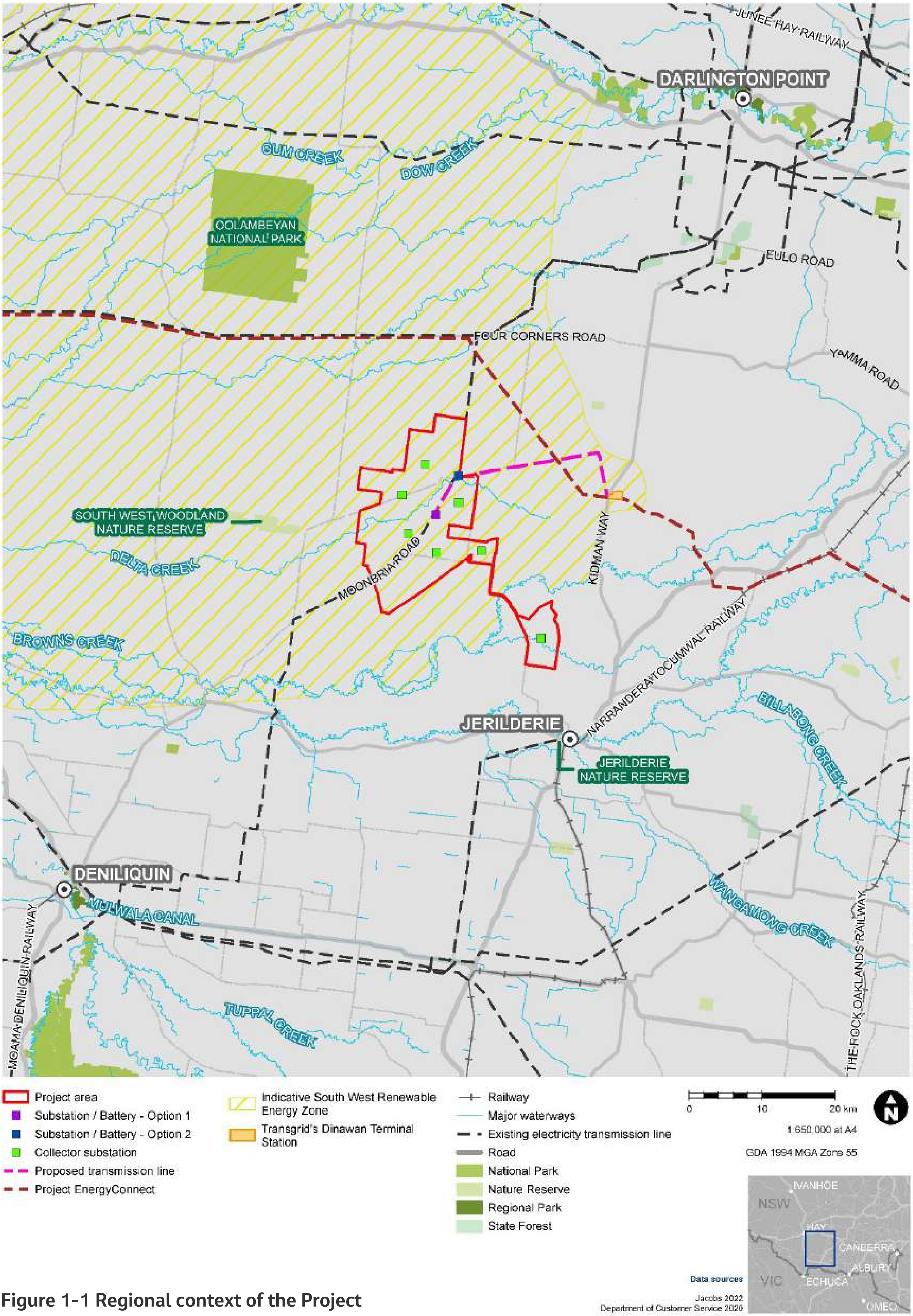

Figure 1-1 Regional context of the Project

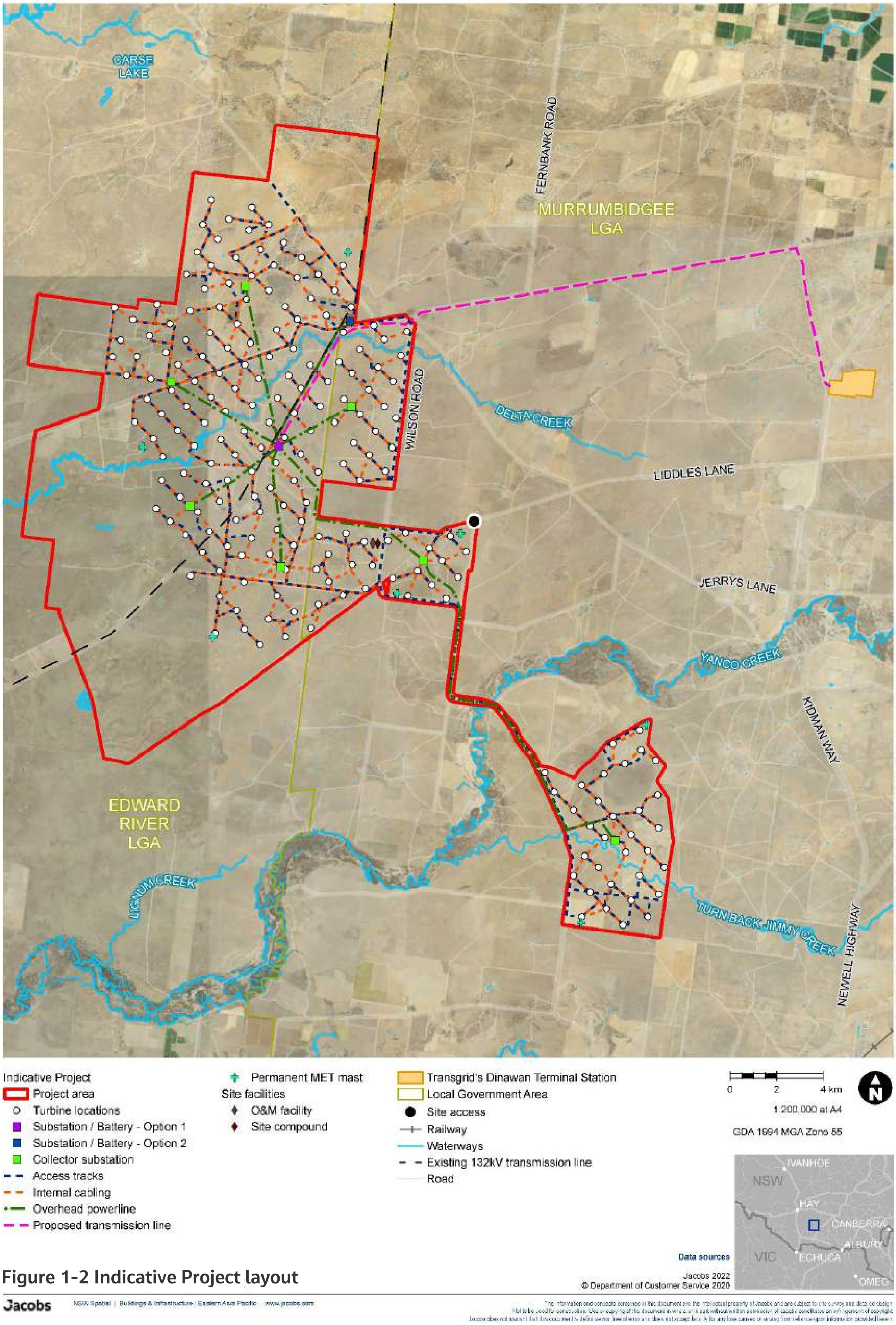

Figure 1-2 Indicative Project layout

1.3 Secretary's Environmental Assessment Requirements

This assessment forms part of the environmental impact statement (EIS) for the Project. The EIS has been prepared under Division 4.7 of the EP&A Act. This assessment has been prepared to address the Secretary's Environmental Assessment Requirements (SEARs) (SSD-41743746) relating to blade throw risks and will assist the Minister for Planning to make a determination on whether or not to approve the Project.

Table 1-1 outlines the SEARs relevant to this assessment along with a reference to where these are addressed.

Table 1-1 SEARs relevant to blade throw risks

Secretary's Requirement	Where addressed in this report
Hazards and Risks – including:	
• Blade Throw – assess blade throw risks.	An assessment of blade throw risks is provided in **Chapter 5**.

1.4 Report Structure

The structure and content of this report are outlined in **Table 1-2**.

Table 1-2 Structure and content of this report

Chapter	Description
Chapter 1 Introduction	Outlines key elements of the Project and the structure of this report (this Chapter)
Chapter 2 Regulatory requirements	Outlines the regulatory requirements that apply to the Project for blade throw and what is applied in this assessment
Chapter 3 Assessment methodology	Provides a description of the methodology used to assess the blade throw impacts of the Project and the acceptable level of risk for differing types of infrastructure in relation to a blade throw incident
Chapter 4 Maximum throw calculation	Provides detail on the maximum throw calculated of the WTGs, a comparison of these to available literature and how this affects the infrastructure in the vicinity of the Project
Chapter 5 Assessment of blade throw risks	Provides the risk at dwellings in the Project area, the risk when travelling on roads in the Project area and a comparison of these risks to other activities
Chapter 6 Environmental management measures	Provides management measures to specifically manage potential blade throw impacts during construction and operation of the Project
Chapter 7 Conclusion	Summarises the findings of this report
References	Provides details of external resources used

2. Regulatory requirements

The *Planning & Environment Wind Energy Guideline* (Wind Energy Guideline for state significant wind energy development, December 2016) guides the planning framework for assessing large-scale wind energy development proposals. These guidelines state that hazards and risks associated with the Project must be suitably managed. One of the hazards identified is blade throw, however, these guidelines do not provide any guidance on assessing the risk associated with a blade throw incident.

Jacobs is unaware of any regulatory requirements or guidelines applicable to a blade throw assessment within Australia. The most pertinent guideline adopted for this assessment is the Dutch Wind Turbine Risk Zoning Guide (The Dutch Guide) (Waterstaat, May 2020). Jacobs is aware that this guide has been used to assess wind farm infrastructure within the Australian context. The Dutch Guide provides a methodology for conservative site-specific assessment of risk as well as recommended allowable individual risks based on infrastructure type.

3. Assessment methodology

A blade throw incident is a structural failure of the blade in a WTG, which results in either the full blade or a segment of the blade detaching from the structure and being thrown from the turbine. This can occur due to physical damage caused by erosion or lightning, material defects or fatigue, amongst other failure modes. This blade throw assessment looks at the risk levels given a portion of the blade being thrown from the structure into the surrounding area. With proper controls in place, such as manufacturing quality controls and operational inspections, it is unlikely that such an incident will occur.

This assessment aims to assess the potential impacts of a blade throw on the Project. This assessment looks at the risk of the Project related to:

- Blades falling from the turbine whilst in a stationary form
- Full blade snapping from the hub and being thrown based on its rotational velocity
- Small fragment of the blade being thrown from the tip of the blade based on its rotational velocity.

A methodology for conservative site-specific assessment of risk and recommended allowable individual risks based on infrastructure type is provided in the Dutch Guide. This methodology has been broadly followed within this assessment, with the exception of some further conservative measures taken. The following steps have been taken to assess the site-specific risk of the Project for blade throw:

1. Calculation of the maximum throw of a blade and tip fragment of the proposed WTG is based on a projectile equation of motion with no drag or aerodynamic effects. This is calculated for a normal running speed, overspeed and a variety of WTG sizes, given the WTG's flexibility at this project stage (refer to **Section 4.1** and **Section 4.2**)
2. Maximum throw distances are then compared to the literature on the maximum throw of a blade and tip fragment to ensure they are realistic and conservative (refer to **Section 4.3**)
3. The maximum throw of a full blade and tip fragment is then plotted across the site based on the proposed WTG locations. This allows all potentially impacted infrastructure to be identified (refer to **Section 4.4.2**)
4. The site-specific risk for an individual is then calculated for each of the potentially impacted infrastructure locations (refer to **Section 5.1** and **Section 5.2**)
5. This individual risk is compared against the recommended allowable risks at each location to determine if the risk of a blade throw incident is acceptable. The individual risk is also compared against some other common activities to illustrate the risk level of blade throw on the Project (refer to **Section 5.3**).

Further details on the methodology are provided in the sections below.

3.1 Risk Limit

Table 3-1 provides the acceptable risk limits for relevant infrastructure to the Project as detailed in the Dutch Guide (Waterstaat, May 2020). The acceptable levels set out here are the risk of death per year for a location or for an individual, dependent on the type of infrastructure. For example, a risk of 10^{-6} per year equates to a risk of 0.00001 (0.001%) probability of an individual dying in a year.

Table 3-1 Dutch Guide Acceptable Risk Limits

Type of infrastructure	Risk Limit
Dwellings	10^{-6} per year as a risk to the location
Road	10^{-6} per year as a risk to an individual

3.2 Project elements

The following specific details have been used to inform this assessment:

- WTG locations as set out in **Figure 1-2**
- Maximum rotor diameter of 220 metres
- Maximum tower height of 180 metres
- Normal operating blade tip speed of 100 metres per second; extrapolated from the top end of a plot of tip speeds at wind-energy-the-facts.org (Supported by the European Wind Energy Association, 2009).

4. Maximum throw calculation

This chapter provides detail on the maximum throw calculated for the WTGs, a comparison of these to available literature and how this affects the existing infrastructure in the vicinity of the Project.

4.1 Full blade throw

Table 4-1 provides the maximum distance a full blade is thrown at normal operating speed (tip speed of 100 m/s) at varying rotor diameters and tower heights. This distance is calculated using ballistic equations, assuming no drag or aerodynamic effects. The distances provided are the maximum throw from the central point of the tower. The maximum distance a full blade can be thrown at a normal operating speed is calculated as 399 metres, and is presented in red in the table below.

Table 4-1 Maximum full blade throw distance at normal operating speed

Tower Height [m]	Rotor Diameter [m]				
	140	160	180	200	220
100	343	344			
120	358	358	359	359	
140	372	372	373	373	374
160	385	386	386	387	387
180	398	**399**	**399**		

Table 4-2 provides the maximum distance a full blade could be thrown at an overspeed of 1.5 times the normal speed (tip speed 150 m/s) at varying rotor diameters and tower heights. This distance is calculated using projectile equations of motion, assuming no drag or aerodynamic effects. The distance provided here is the maximum throw from the central point of the tower. The maximum distance a full blade can be thrown at an overspeed of 1.5 is calculated as 734 metres, and is presented in red in the table below.

Table 4-2 Maximum full blade throw distance at 1.5 overspeed.

Tower Height [m]	Rotor Diameter [m]				
	140	160	180	200	220
100	668	668			
120	685	685	685	686	
140	701	702	702	702	703
160	718	718	718	719	719
180	**734**	**734**	**734**		

4.2 Tip fragment throw

Table 4-3 provides the maximum distance a tip fragment could be thrown at a normal operating speed (tip speed 100 m/s) at varying rotor diameters and tower heights. This calculation assumes a small fragment at the very tip of the blade snaps off without losing any of the kinetic energy of blade rotation. This distance is calculated using projectile equations of motion, assuming no drag or aerodynamic effects. The distance provided here is the maximum throw from the central point of the tower. The maximum distance a tip fragment can be thrown at a normal operating speed is calculated as 1191 metres, and is presented in red in the table below.

Table 4-3 Maximum tip fragment throw distance at normal operating speed

Tower Height [m]	Rotor Diameter [m]				
	140	160	180	200	220
100	1119	1119			
120	1137	1137	1138	1139	
140	1155	1155	1156	1157	1158
160	1172	1173	1173	1174	1175
180	1189	1190	1191		

Table 4-4 provides the maximum distance a tip fragment is thrown at an overspeed of 1.5 (tip speed 150 m/s) at varying rotor diameters and tower heights. The distance provided here is the maximum throw from the central point of the tower. The maximum distance a tip fragment can be thrown at an overspeed of 1.5 is calculated as 2471 metres, and is presented in red in the table below.

Table 4-4 Maximum tip fragment throw distance at a 1.5 overspeed.

Tower Height [m]	Rotor Diameter [m]				
	140	160	180	200	220
100	2395	2396			
120	2414	2415	2415	2415	
140	2433	2434	2434	2434	2435
160	2452	2452	2453	2453	2454
180	2471	2471	2471		

4.3 Comparison to literature

Table 4-5 provides a comparison of the calculated maximum throw distances at 1.5 overspeed within this assessment to published literature. As seen from the maximum throw distances published in the literature, the assessment herein provides a conservative view of the distance a blade and tip fragment can be thrown. The closest comparative in the published literature is the 264-metre rotor diameter turbine in the Sarlak and Sorensen paper (Sorensen, February 2015). The distances for this turbine are in the order of 70-80% of the calculation in this assessment (i.e. this assessment is conservative). This paper calculates the throw distances with drag and aerodynamic effects, which could account for this difference.

The literature comparison has proven the calculation herein to be conservative; therefore, the risk assessment will progress with the throw distances calculated. If any risk is identified as unacceptable, then a re-evaluation of the calculated throw distances is possible.

Table 4-5 Blade throw calculation comparison to published literature

Study	Modelled WTG parameters			Maximum throw distance	
	Tower Height [m]	Rotor Diameter [m]	Tip speed [m/s]	Full blade [m]	Tip fragment [m]
This Project Assessment	180	220	150	734	2470
Sarlak and Sorensen[1]	55	90	150	380[1]	780 [1]
	81	132	150	420 [1]	1450 [1]
	115	186	150	450 [1]	1800 [1]
	162	264	150	500 [1]	2000 [1]
Cotton [2]	65	90	217	198 [2]	1462 [2]

[1] Research Article – Sarlak and Sorensen – Analysis of throw distances of detached objects from horizontal axis WTGs, February 2015 (Sorensen, February 2015). Throw distances are estimates from graphically presented results. Tip fragment calculation relates to 20% of the blade mass being thrown.
[2] Research Article – Cotton – Numerical Modelling of Wind Turbine Blade Throw, April 2007 (Cotton, April 2007). Throw distances are the 99th percentile of a Monte Carlo simulation in very low drag conditions. Tip fragment calculation relates to 10% of the blade mass being thrown.

4.4 Location-specific risks

This section looks at location-specific risks dependent on distance from the turbine and how that translates to the Project area.

4.4.1 Risks for throw distances

The Dutch Guide (Waterstaat, May 2020) sets out the risk of death at specified distances away from the WTGs. These are set out in **Table 4-6**

Table 4-6 Location-specific risks around a single WTG

Radius from the WTG	Location-specific risk	Radius from any WTG used within this assessment [m]
Half the rotor diameter	10^{-5} per year	110
Maximum throw distance for a full blade at 1.5 overspeed	10^{-6} per year	734 [1]
Maximum throw distance for a tip fragment at 1.5 overspeed	10^{-12} per year [2]	2471 [1]

[1] The Dutch Guide suggests that these risks are for the turbine operating in normal conditions. The radius used in this assessment is for the 1.5 overspeed blade throw. This is seen as a conservative measure.
[2] The Dutch Guide from 2020 does not detail this limit, however previous assessments seen have used this figure for tip fragment risk - DNV Thunderbolt Energy Hub – Stage 1 Blade Throw Assessment, December 2021 (DNV, December 2021). This risk is based on the lower frequency of a tip fragment throw than a full blade throw and the smaller fragment being thrown over a wider area means the chance of it hitting a person is much lower. Furthermore, the chances of it severely injuring anyone if it were to hit a person are also lower than the same for a full blade throw.

4.4.2 Site-specific throws

Figure 4-1 shows the throw distances plotted for the Project (as detailed in **Table 4-6**). It shows that a number of dwellings would be in the tip fragment throw zone, and a number of roads pass through the blade throw area. These are discussed further in **Section 4.4**.

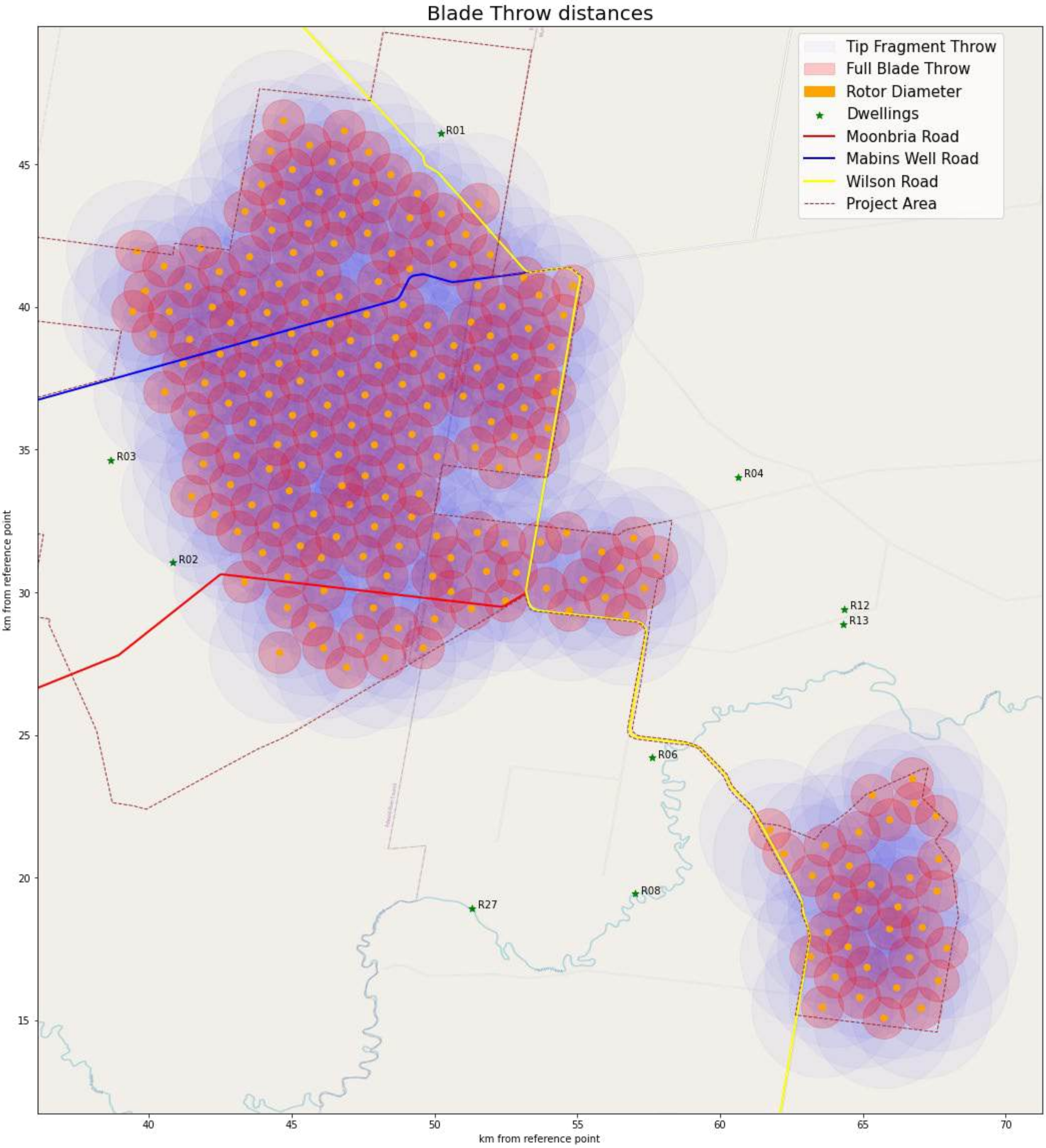

Figure 4-1 Blade throw areas for the Project

5. Assessment of blade throw risks

5.1 Dwellings

The assessment for dwellings has been based on a site-specific risk as determined by the acceptable limits. The risk is detailed on an annual basis.

Two dwellings (R01 and R02) have been identified within the maximum throw distance for a tip fragment, as set out in **Table 4-2** and shown in **Figure 4-1**. These properties are located on Moonbria Road and Goolgumbla Road. The risk associated with these properties is assessed in **Table 5-1**. As described in **Table 5-1**, the specific risk at each dwelling is much lower than the acceptable risk detailed for dwellings of 10^{-6} per year (refer to **Table 3-1**). Therefore, the site-specific risk at each dwelling is considered to be acceptable from a blade throw perspective.

Table 5-1 Dwellings location-specific risk

Dwelling	Distance to nearest WTG [m]	# of tip fragment throw areas located within	Location Specific Risk	# of full blade throw areas located within	# of rotor diameter areas located within	Overall Annual Blade Throw Risk at Dwelling
Goolgumbla Road [R01]	2030	3	3×10^{-12}	0	0	**3×10^{-12}**
Moonbria Road [R02]	2063	3	3×10^{-12}	0	0	**3×10^{-12}**

5.2 Roads

A number of small roads pass through the Project area. Three indicative routes through the site have been used to assess the blade throw risk when on the road network. These are shown in **Figure 4-1**. The three routes are:

- Moonbria Road – travelling from Wilson Road to the west; outside the Project area
- Mabins Well Road – travelling from outside the Project area to the west through to Wilson Road
- Goolgumbla Road and Wilson Road – travelling south on Goolgumbla Road from north of the Project area through to Wilson Road and following Wilson Road until outside the Project area to the south.

This road infrastructure assessment is based on the time spent within each area of risk. The calculation of risk here is undertaken on a per journey basis. This can be compared to the individual risk limit for roads as detailed in **Table 4-1** to determine how many journeys one person can take on any journey in one year before an unacceptable limit is reached.

An average road speed of 30 km/h was used to determine how much time would be spent within each area of risk. This is taken as a conservative estimate; the slower the speed, the longer the time spent within the risk area.

5.2.1 Moonbria Road

Figure 5-1 shows the number of WTGs that would impact Moonbria Road for each risk area as you travel along the road from Wilsons Road to the west. The associated risk for one individual taking this one journey is **4.1** x **10**$^{-11}$. This would allow one person to take this journey 24,400 times a year and remain within the acceptable limits. Therefore, it is deemed that this road journey meets the acceptable limits set out in **Table 3-1.**

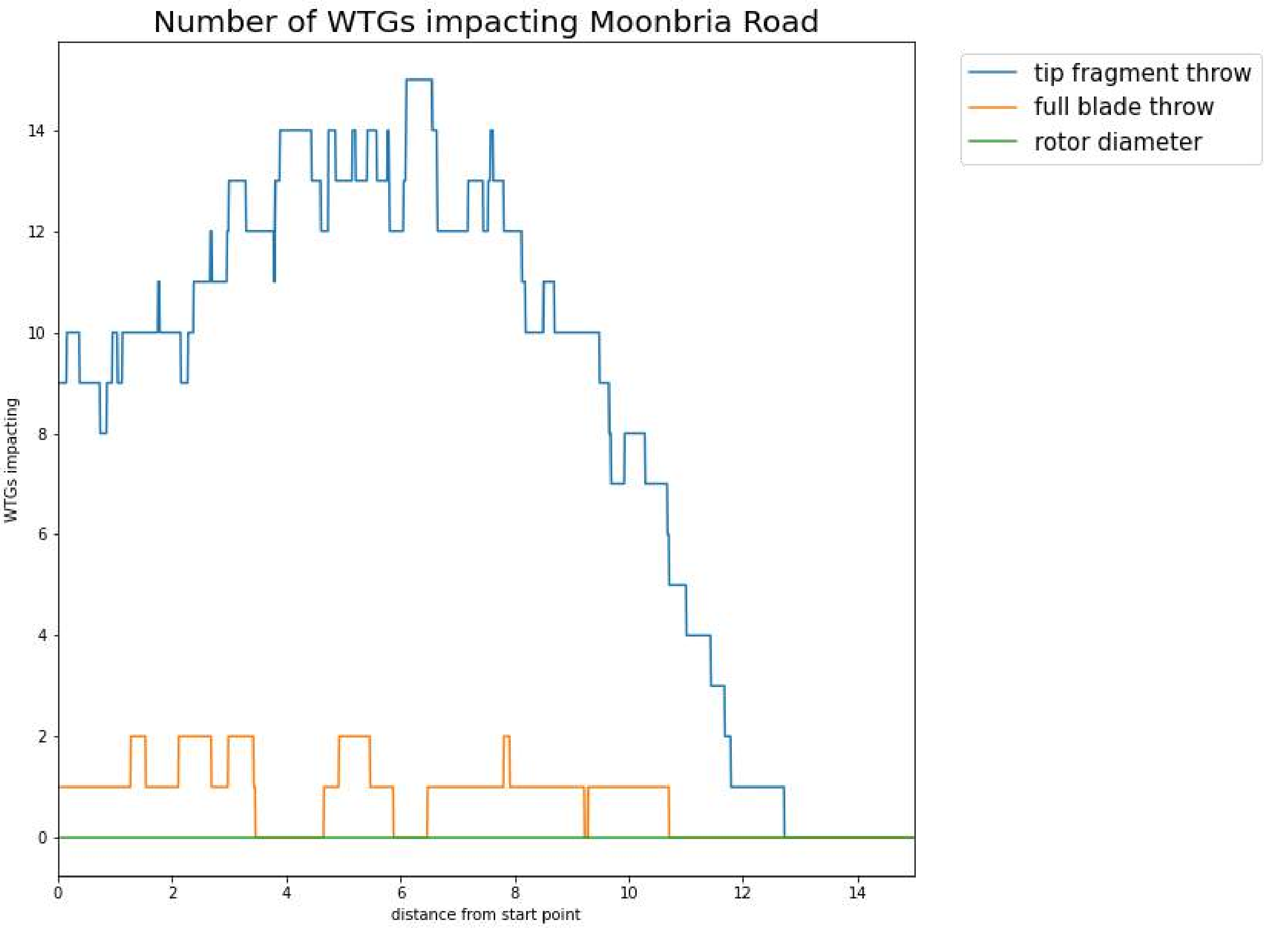

Figure 5-1 Number of WTGs impacting the journey on Moonbria Road within each risk area

5.2.2 Mabins Well Road

Figure 5-2 shows the number of WTGs that impact Mabins Well Road for each risk area as you travel along the road from outside the project area eastwards to Wilsons Road. The associated risk for one individual taking this one journey is **6.0×10^{-11}**. This would allow one person to take this journey 16,770 times a year and remain within the acceptable limits. Therefore, it is deemed that this road journey meets the acceptable limits set out in **Table 3-1**.

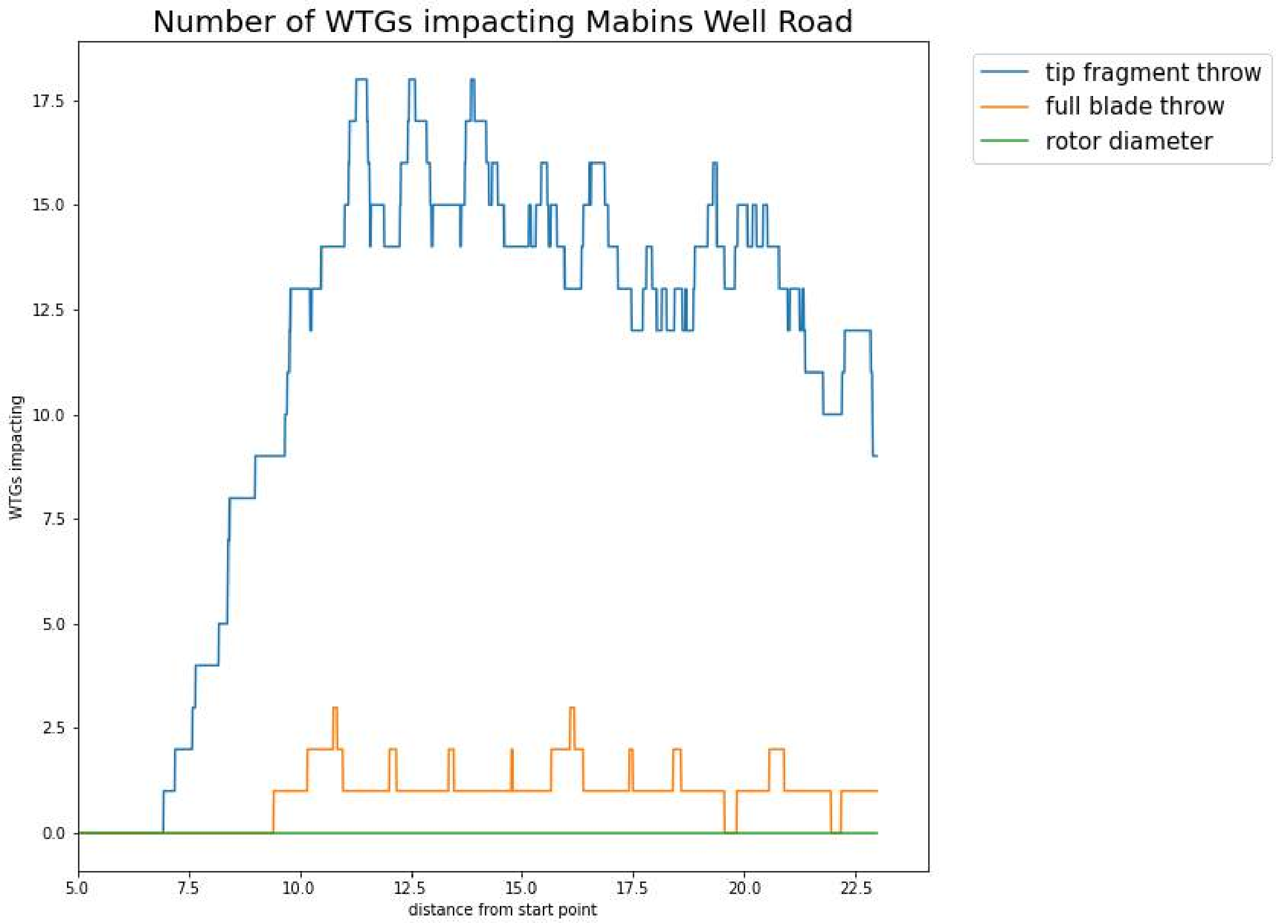

Figure 5-2 Number of WTGs impacting the journey on Mabins Well Road within each risk area

5.2.3 Wilson Road

Figure 5-3 shows the number of WTGs that would impact Wilson Road for each risk area as you travel along the road from outside the project area southwards across the full Project area. The associated risk for one individual taking this one journey is **8.9×10^{-11}**. This would allow one person to take this journey 11,210 times a year and remain within the acceptable limits. Therefore, it is deemed that this road journey meets the acceptable limits set out in **Table 3-1**.

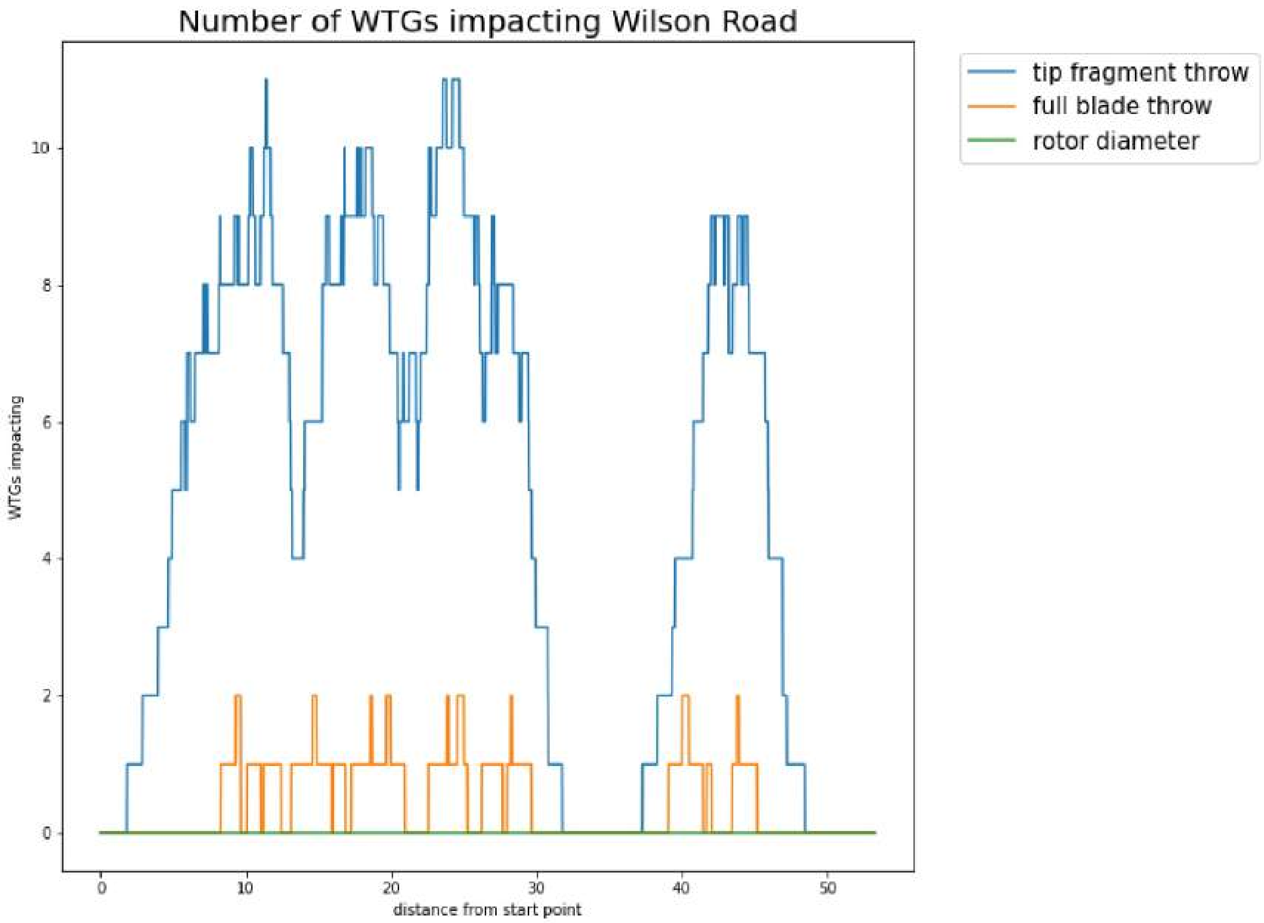

Figure 5-3 Number of WTGs impacting the journey on Wilson Road within each risk area

A further assessment was undertaken for a person who walks the Wilson Road route at 3 km/h (noting that this is a near 50 km stretch of road). The risk for a single person walking the extent of the road is 8.9×10^{-10}. Therefore, a single person could walk the route 1,120 times per year and remain within the acceptable road limits.

5.3 Comparison of risk

Table 5-2 provides a comparison of the risks associated with the Project and those associated with other activities in Australia. It shows that the risks at dwellings that would be neighbouring the Project are significantly less than that of a being a victim of a lightning strike. It also shows that a person who drives the length of Wilson Road twice a day for a full year has a similar risk of lighting strike. It is, however, significantly less than being involved in a transport accident on all roads otherwise.

Table 5-2 Comparison of risks of blade throw against other risks

Location	Risk
Dwellings on Moonbria Road [R02] and Goolgumbla Road [R01]	3×10^{-12} per year
Single person who drives the length of Wilson Road twice a day every day for a year	6.5×10^{-8} per year
Transport accident in Australia per population head (2011-2020)[1]	5.6×10^{-5} per year
Victim of lightning in Australia per population head (2011-2020)[1]	8.2×10^{-8} per year

[1] Australian Bureau of Statistics Causes of Death 2020 released in September 2021 (Australian Bureau of Statistics, 2022).

6. Environmental management measures

The following management measures detailed in **Table 6-1** have been developed to specifically manage potential blade throw risk associated with the Project.

Table 6-1 Blade throw environmental management measures

Impact	Reference	Environmental management measure	Responsibility	Timing
Blade throw risk	BT1	Wind turbine components will be manufactured and certified to current best practice Australian and international (IEC 61400-23) safety standards and are equipped with sensors that can react to any imbalance in the rotor blades and shut down the turbine if necessary.	Contractor	Prior to construction, construction, operation
	BT2	Wind turbines will be subject to stringent safety and security measures including regular maintenance and servicing (within an ISO90001 Quality Assurance system).	Contractor	Prior to construction, construction, operation
	BT3	Contactors certified in the manufacture, delivery, build, inspection, maintenance and repair of turbine components will be employed.	Contractor	Prior to construction, construction, operation

7. Conclusion

A blade throw incident is a structural failure of the blade in a WTG, which results in either the full blade or a segment of the blade detaching from the structure and being thrown from the turbine. This can occur due to physical damage caused by erosion or lightning, material defects or fatigue, amongst other failure modes. This blade throw assessment looks at the risk levels given a portion of the blade being thrown from the structure into the surrounding area. With proper controls in place, such as manufacturing quality controls and operational inspections, it is unlikely that such an incident would occur.

This assessment has calculated the maximum throw distance for a full blade and a blade tip fragment in overspeed conditions as 734 m and 2470 m, respectively. These distances have been used to conservatively calculate the site-specific risk at dwellings and roads adjacent to the Project using the Dutch Wind Turbine Risk Zoning Guide published in May 2020 (Waterstaat, May 2020).

The risk established at the two dwellings that would be within the blade tip fragment throw area (R01 and R02) is significantly lower than the applicable limit set out within the Dutch Guide. The risk for three typical road journeys in the area was also calculated. The highest risk-generating road journey was Wilson Road, however, a single person could undertake this journey 11,210 within a year and still be within the applicable limit of the Dutch Guide. If a person were to undertake this journey twice a day for a year, the risk of death to that person would be similar to that of being struck by lightning.

Following the implementation of environmental management measures, the probability of a blade being thrown from a WTG and the thrown object resulting in a person being struck and/or injured or damage occurring to property is expected to be very low.

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