Valley of the Winds

APPENDIX L
BLADE THROW ASSESSMENT

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VALLEY OF THE WINDS WIND FARM

Blade Throw Assessment

UPC Renewables Australia Pty Ltd

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Objective: Review relevant literature and assess the potential blade throw risks for the proposed Valley of the Winds Wind Farm.

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1 INTRODUCTION

1.1 Project information

The following information has been supplied by the Proponent.

1.1.1 Project overview

UPC Renewables Australia Pty Ltd, operating as UPC\AC Renewables Australia (UPC\AC) (the Proponent), proposed to construct and operate the Valley of the Winds Wind Farm (the Project).

The Project would consist of approximately 148 wind turbines and supporting infrastructure, including a high voltage transmission line which would run approximately 13 kilometres (km) from the Girragulang Road cluster to a connection point with the Central-West Orana REZ Transmission line proposed by TransGrid and the NSW Government. The project would supply approximately 800 megawatts (MW) of electricity into the National Electricity Market (NEM).

The wind farm would be located close to the townships of Coolah and Leadville, with the transmission line running generally south to its connection with the Central-West Orana REZ Transmission line. The project would be entirely within the Warrumbungle Local Government Area (LGA).

The project would involve the construction, operation and decommissioning of three clusters of wind turbines, that would be connected electrically. These are:

- Mount Hope cluster – approximately 76 turbines
- Girragulang Road cluster – approximately 51 turbines
- Leadville cluster – approximately 21 turbines.

The Project includes the following key components:

- approximately 148 wind turbines with a maximum tip height of 250 metres (m) and a hardstand area at the base of each turbine
- electrical infrastructure, including:
  - substations in each cluster and a step-up facility at the connection to the Central-West Orana REZ Transmission line
  - underground 33 kilovolt (kV) electrical reticulation connecting the turbines to the substations in each cluster
  - overhead transmission lines (up to 330 kV) dispatching electricity from each cluster
  - other electrical infrastructure as required including a potential battery energy storage system (BESS)
  - a high voltage transmission line (up to 500 kV) connecting the wind farm to the Central-West Orana Transmission line
- other permanent on-site ancillary infrastructure:
  - permanent operation and maintenance facilities
  - meteorological masts (up to thirteen)
- access track network:
  - access and egress points to each cluster from public roads
  - operational access tracks and associated infrastructure within each cluster on private property
- temporary construction ancillary facilities:
  - potential construction workforce accommodation on site
  - construction compounds
  - laydown areas
  - concrete batching plants

- quarry sites for construction material (rock for access tracks and hardstands).

At the end of its practical life, the wind farm would be decommissioned, and the site returned to its pre-existing land use in consultation with the affected landholders.

1.1.2 Site context

The Project location is shown in Figure 1. Land surrounding the wind farm site is characterised by rolling pastoral hills, open flat valleys and ridgelines with scattered vegetation. The hill slopes are generally gentle in gradient and predominantly cleared of vegetation, except for patches of denser remnant vegetation on steeper terrain, near rocky outcrops and between saddles.

The townships of Coolah and Leadville are the closest population centres to the proposed site. These townships are located on gently sloping to level land within valleys near creeks. Most built structures are of low to moderate scale. The main street of Coolah is the focus for local retail and community services in the local area.

Land uses within the locality include:

- **farming** – predominantly grazing cattle and sheep, with small patches of cropping (cereal and fodder)
- **rural living** – scattered rural dwellings and sheds present throughout the landscape, with a higher density of dwellings in the townships.

1.1.3 Purpose of this technical note

The capital value of the Project would be more than $30 million. Accordingly, the Project is a State Significant Development (SSD) under the *State Environmental Planning Policy (State and Regional Development) 2011* (SEPP SR&D) and Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). Under Section 4.12(8) of the EP&A Act, a development application (DA) for SSD must be accompanied by an environmental impact statement (EIS) that is lodged with the NSW Department of Planning, Industry and Environment for Development Consent.

The Project was also referred to the Commonwealth Department of Agriculture, Water and the Environment for potential impacts to matters of national environmental significance protected by the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). On 13 July 2020, a delegate of the Federal Minister for the Department of Agriculture, Water and the Environment determined that the Project was a controlled action under section 75 of the EPBC Act and therefore requires assessment and approval under the EPBC Act. This assessment is to be undertaken under the *Amended Bilateral Agreement* between the Department of Agriculture, Water and the Environment and the Department of Planning, Industry and Environment.

This technical note has been prepared to inform the environmental impacts statement (EIS) and development application (DA) for the Project.

1.2 Overview of this technical note

The typical risks of blade throw incidents are discussed in this technical note, based on a review of the available literature and guidelines, and the potential risks at dwellings, roads, and neighbouring properties in the vicinity of the Project are evaluated.

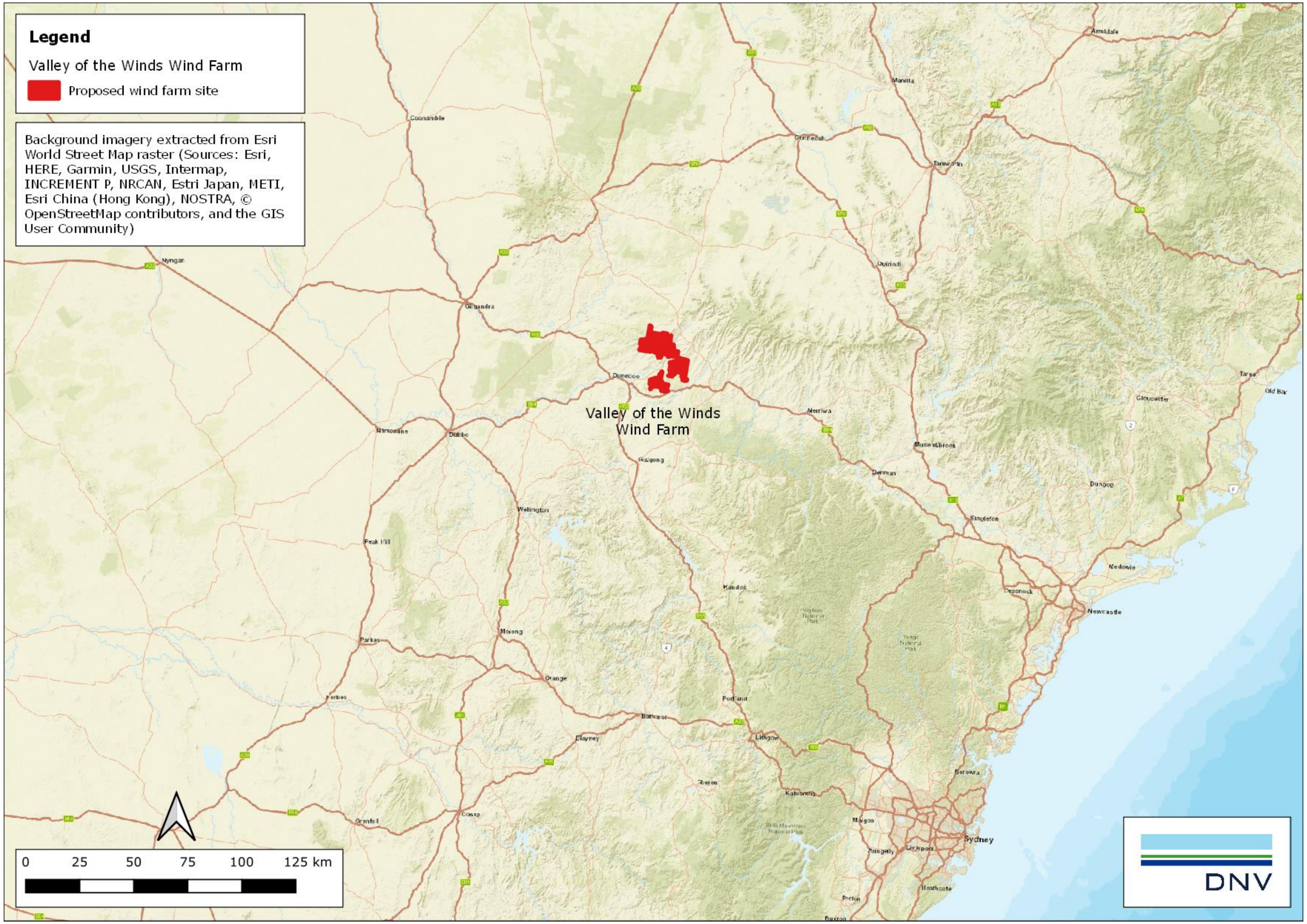

Figure 1 Location of the proposed Project

2 BACKGROUND AND OVERVIEW

2.1 What is blade throw?

Blade throw describes an incident in which a structural failure occurring in the blade of a wind turbine during operation results in parts of the blade detaching and being thrown into the surrounding area. Such incidents may involve the detachment of the entire blade or a large portion of the blade (if the failure occurs at or near the base of the blade where it attaches to the hub of the turbine rotor) or a relatively smaller blade fragment, such as a blade tip section or a piece of the outer shell of the turbine blade [1, 2, 3, 4]. It is also possible for a structural failure to occur without causing parts of the turbine blade to detach, in which case there is no danger to the surrounding area, or for a blade or blade fragment to detach and fall close to the turbine while the rotor is not in motion.

Reasons for wind turbine blade failure may include physical damage to the blade caused by external factors such as erosion or lightning, extreme wind conditions that cause the loads on the turbine to exceed the loads that the turbine has been designed to withstand, material or manufacturing defects, and material fatigue [1, 2, 3]. If left untreated, surface damage caused by erosion can eventually progress into the blade or allow water to seep between the material layers, weakening the blade structure. Similarly, damage caused by a lightning strike may affect the structural strength of the blade. The mechanical stresses experienced by a turbine blade during normal operation and under extreme weather conditions can, over time, lead to weak points or cracks in the material structure, while flaws in the design or materials used may make the blades more susceptible to failure.

2.2 Mitigating factors for blade throw risks

Modern wind turbines and turbine components supplied by major manufacturers are generally designed and certified in accordance with recognised international standards to ensure structural integrity and safe operation over the lifetime of the turbine. International Standard IEC 61400-1 [5] establishes the minimum requirements for the design of wind turbines and turbine components with the objective of avoiding structural failure and the consequential risk of personal injury or damage to property. Other international standards that apply to the design and certification of wind turbine blades include IEC 61400-23 [6], which specifies the requirements for testing the structural integrity of turbine blades, and IEC 61400-24 [7], which describes the requirements for lightning protection systems installed on wind turbines.

Besides meeting the required design and manufacturing standards, modern wind turbines incorporate sophisticated control systems that are designed to shut the turbine down during high wind speed conditions and in response to a range of faults or abnormalities detected during operation. These control systems include redundant monitoring and protection systems that are intended to prevent situations where the turbine rotor could accelerate to speeds higher than its rated speed (described as overspeed conditions) and to therefore be subjected to excessive or unbalanced loads [1, 2, 8]. Other conditions that may indicate a structural blade failure and which would cause a turbine to automatically shut down include abnormal vibration, rotor imbalance, or reduced power output [3]. Furthermore, due to the lightning protection systems used in modern wind turbines, damage caused by lightning strikes is usually limited to the blade surface where it can be seen and repaired during preventative maintenance operations [2, 3]. High-quality operational monitoring and maintenance programs at wind farms help to increase the likelihood that turbine faults or minor damage are prevented or are detected and rectified at an early stage, thus reducing the risk of serious or dangerous problems developing.

On account of these safeguards, blade throw incidents are relatively rare events for modern wind turbines. However, due to the potential consequences arising from a blade throw incident, there is still a need to recognise and evaluate the associated risks. An understanding of the likelihood, dynamics, and risk associated with blade throw has been developed within the wind energy industry through a combination of investigation into historical blade throw incidents and theoretical research.

2.3 Regulatory requirements and guidelines for assessing blade throw risks

The Secretary's Environmental Assessment Requirements (SEARs) provided by the NSW Department of Planning, Industry and Environment on 9 June 2020 [9] specify that the EIS for the Project must "*assess blade throw risks*".

However, neither the SEARs or the NSW Wind Energy Guideline for State specific wind energy development (NSW Wind Energy Guideline) [10] provide guidance on the methodology that should be used to assess blade throw risks, or the blade throw risks that would be considered acceptable. DNV is not aware of additional regulatory requirements or guidelines related to the assessment of blade throw risks in other Australian jurisdictions.

In the absence of any relevant guidance in the SEARs or NSW Wind Energy Guideline, DNV has adopted the guidance provided in the 2014 edition of the Dutch Wind Turbine Risk Zoning Handbook ("the Dutch Handbook") [1], which forms the basis of the 2020 Dutch Wind Turbine Risk Zoning Guide [11]. The Dutch Handbook is distinctive in that it presents both a methodology for performing a detailed site-specific analysis of blade throw risks and a methodology for conducting a conservative high-level risk assessment which can be used as a screening assessment to evaluate the potential risks for a wind farm and hence determine whether a more detailed assessment is needed. These methodologies have been developed based on conservative assumptions and thorough, well-documented research into the frequency of a blade throw incident occurring, the distances that a blade or blade fragment may be thrown, and the risks of impact to people in the area around a turbine. The results of the research presented in the Dutch Handbook are broadly consistent with other literature and with observations made from historical blade throw incidents. DNV also understands that the methodologies given in the Dutch Handbook have been used to inform blade throw risk assessments in other jurisdictions in Europe outside of the Netherlands. Based on these factors, DNV considers that the Dutch Handbook provides an appropriate basis for the blade throw assessment presented in this document.

For the purposes of this assessment, DNV has also applied a classification of blade throw risks published by the United States Renewable Energy Laboratory (NREL) [12]. The NREL classification categorises the risks associated with a blade throw incident in terms of the likelihood of occurrence and potential consequences to people, and provides a consistent way of describing each likelihood and risk. Further details about the NREL classification are presented in 3.3.2.

2.4 Outline of this document

This document begins with a review of existing studies that have considered the risks of blade throw for wind farm developments, based on the likelihood of a blade throw incident occurring, the distance that a blade or blade fragment may be thrown, and the potential for a thrown blade to cause injury or death to people in the surrounding area. The purpose of this review is to establish typical blade throw risks in the vicinity of a wind turbine, and to consider these risks in relation to the proposed Project.

A high-level, site-specific risk assessment for the proposed Project is then presented, based on the methodology outlined in the 2014 Dutch Handbook [1]. As discussed in Section 2.3, this methodology has been developed in a conservative manner based on statistical analyses of historical blade throw incidents, mathematical modelling of the maximum potential blade throw distances for generic turbine models, and calculation of the corresponding risks at varying distances from the turbine. The methodology is considered applicable to a wide range of modern wind turbines and can therefore be used to make an initial assessment of the potential risks for a proposed wind farm development in situations where the approximate turbine dimensions are known but a specific turbine model has not yet been chosen. Based on the results of the high-level assessment, the need for a more detailed site-specific assessment considering the specific turbine parameters and expected wind conditions can then be determined. The use of a site-specific risk-analysis approach to evaluate the likely risks of blade throw, rather than generic setback distances, is consistent with the recommendations and approaches presented in the relevant literature [8, 4, 13, 3].

2.5 Project configuration considered in this assessment

A Project layout consisting of 148 wind turbines with a rotor diameter of 180 m and tip height of 250 m (defined as the turbine hub height plus half the turbine rotor diameter) has been considered in this assessment. These dimensions represent the maximum tip height and rotor diameter under consideration for the Project. The locations of dwellings and other sensitive locations such as schools and childcare facilities, roads, and neighbouring properties in the vicinity of the Project have been provided by the Proponent and obtained from publicly available data [14].

3 POTENTIAL RISKS OF BLADE THROW INCIDENTS

The risk posed to people, property, or infrastructure by a potential blade throw incident is determined by three factors [15]:

1. the frequency of a blade or blade fragment detaching and being thrown from a turbine, and the circumstances under which this happens
2. the probability of the blade or blade fragment landing at a given location
3. the probability of a blade or blade fragment landing at a given location causing injury or death to a person, or damage to property or infrastructure.

The frequency of a blade throw incident occurring, the maximum distance that a blade or blade fragment may be thrown, and the risk of death posed to people in the vicinity of a wind farm (being the most serious consequence of a potential blade throw incident) is discussed further in the following sections.

3.1 Frequency of a blade throw incident occurring

Detailed, publicly available information about actual blade throw incidents is limited. There is currently no comprehensive database of blade throw incidents that includes accurate measurements of the throw distance and fragment size, details of the wind turbine model and the environmental and operating conditions involved, or information about the consequences of the incident [1, 2, 3, 13]. In response to these limitations, most studies reported in the literature have adopted a conservative interpretation of the available historical data and have supplemented this with theoretical modelling where appropriate.

To aid in the development of the risk assessment methodology presented in the Dutch Handbook, two detailed reviews of historical records were conducted with the aim of quantifying blade throw incident rates. In the initial analysis undertaken for the 2005 edition of the Dutch Handbook, two categories of blade throw incidents were considered: detachment and throw of an entire blade or large portion of a blade, and detachment and throw of a small blade fragment [2]. The relative risks associated with blade fragments were subsequently found to be insignificant compared to the risks of blade throw incidents involving large portions of the blade [2], as will be discussed further in Section 3.3.1. Consequently, blade throw scenarios involving small blade fragments were not explicitly considered in the updated analysis described in the 2014 edition of the Dutch Handbook [1]. The estimated blade throw frequencies derived from the data are summarised in Table 1.

The results presented in Table 1 suggest that a blade throw scenario involving the detachment of a small blade fragment is less likely than the detachment and throw of a whole blade. The composite fibre materials and manufacturing methods used for wind turbine blades mean that it is relatively unlikely for fragments of the blade to detach under normal operating conditions [3]. According to the 2005 Dutch Handbook, many of the blade throw incidents classified as a detachment and throw of a blade fragment actually involved the detachment of a mobile blade tip mechanism used to control the turbine speed [2]. Such mechanisms are not commonly used on modern wind turbines, which would further reduce the expected frequency of blade throw events involving small blade fragments.

Table 1 also shows that the number of all blade throw incidents that are expected to occur under overspeed conditions (in which the failure of multiple safety mechanisms allows the turbine rotor speed to increase to approximately twice the rated speed) is much lower than the number of incidents occurring under normal operating conditions. Although blade failure and blade throw may be more likely to occur if a turbine is operating under overspeed conditions, compared to normal operating conditions, the probability of those conditions actually being experienced is very low [1, 2, 8]. For the purposes of the analysis undertaken for the Dutch Handbook, the researchers made the conservative assumption that the overall frequency of a blade throw incident occurring under overspeed conditions would be equal to the frequency of any overspeed event, based on expected likelihood of complete failure of the turbine overspeed protection systems.

Based on the estimated blade throw frequencies determined for the Dutch Handbook, the researchers proposed conservative values for the frequency of a blade throw incident occurring that could then be used in blade throw risk analyses [1, 2]. These frequencies, which take into account the limitations of the historical data and the subsequent uncertainty in the estimated blade throw frequencies, are also presented in Table 1.

Table 1 Frequency and probability of a blade throw incident occurring

Blade throw scenario	Estimated frequency of occurrence (incidents per turbine per year)		Frequency (per year per turbine) recommended for use in blade throw risk analyses, considering uncertainty in estimated frequencies [1]
	Based on data recorded from 1984 to 2000 [1, 2]	Based on data recorded from 2001 to 2010 [1]	
Detachment and throw of entire blade or large portion of blade			
All operating conditions [1]	6.3×10^{-4}	6.3×10^{-4}	8.4×10^{-4} (1 incident per year per 1,190 turbines)
Normal operating conditions (rated rotor speed) [2]	3.1×10^{-4}	6.2×10^{-4}	8.4×10^{-4} (1 incident per year per 1,190 turbines)
Mechanical braking conditions (1.5 times the rated rotor speed) [2]	3.1×10^{-4}	Included with normal operating conditions	Not applicable to modern turbines
Overspeed conditions (2 times the rated rotor speed) [3]	Less than 5.0×10^{-6}	Less than 5.0×10^{-6}	5.0×10^{-6} (1 incident per year per 200,000 turbines)
Detachment and throw of blade tip or other small blade fragment			
All operating conditions [1]	1.2×10^{-4}	Not explicitly considered	2.6×10^{-4} [2] (1 incident per year per 3,846 turbines)
Overspeed conditions (2 times the rated rotor speed) [3]	Less than 5.0×10^{-6}	Not explicitly considered	5.0×10^{-6} [2] (1 incident per year per 200,000 turbines)

1. Derived directly from the number of recorded blade throw incidents. For the detachment and throw of an entire blade under all operating conditions, the actual rate of blade throw incidents observed in the data recorded from 2001 to 2010 was slightly less than 6.3×10^{-4}. However, for the sake of conservatism, the researchers conducting the review chose to retain the blade throw frequency derived in the previous analysis [1].
2. Assumed, based on frequency of a blade throw incident under all operating conditions and expected proportion of incidents occurring for turbines operating under normal conditions, under mechanical braking, and under overspeed conditions.
3. Assumed, based on expected likelihood of complete failure of the turbine overspeed protection systems.

The Dutch Handbook notes that the frequencies presented in Table 1 are likely to be conservative in comparison to the actual frequency of a blade throw incident occurring for a modern wind turbine [1]. The underlying data sets used to derive the frequency of a blade throw incident contain information for turbines that may not have been certified to modern standards and are therefore unlikely to have had the sophisticated control and safety systems of a modern wind turbine. This is supported by statistical analysis presented in the Dutch Handbook, which shows a downward trend in the frequency of recorded blade throw incidents over time, with the five-year average frequency for the detachment and throw of an entire blade decreasing from approximately 3.5×10^{-4} incidents per turbine per year (1 incident per year per 2,857 turbines) in 2001-2005 to less than 2.5 x 10^{-4} incidents per turbine per year (1 incident per year per 4,000 turbines) in 2006-2010 [1].

3.1.1 Comparison of blade throw frequencies to Australian incidents

According to the Australian Energy Market Operator (AEMO), there are currently 3,238 wind turbines installed and operating in Australia, 759 of which are located in NSW [16]. For this number of turbines, based on the conservative blade throw frequency of 8.4 x 10^{-4} incidents per turbine per year (1 incident per year per 1,190 turbines) presented in Table 1 for an entire blade or large portion of blade, up to approximately three blade throw incidents on average across Australia or less than one blade throw incident on average in NSW could be expected to occur in a year. If the conservative frequency of a blade fragment being thrown is also considered (being 2.6 x 10^{-4} incidents per turbine per year or 1 incident per year per 3,846 turbines, as shown in Table 1), up to approximately one additional blade throw incident on average could be expected to occur in Australia in a year. Therefore, the total number of blade throw incidents that may be expected to occur in Australia is up to approximately four incidents on average in a year.

DNV maintains a database of wind turbine incidents that have occurred in Australia from 2005 onwards, based on details recorded in public databases, reports made in industry journals and other media, and information received from participants in the wind industry. Assuming that all of the turbines currently operating in Australia were installed between 2005 and 2020 at a constant number of turbines per year (which is expected to give a reasonable representation of the increase in the number of turbines over time), the average number of turbines in Australia during this period is approximately 1,500. Based on the conservative blade throw frequencies of 8.4 x 10^{-4} incidents per turbine per year (1 incident per year per 1,190 turbines) for an entire blade and 2.6 x 10^{-4} incidents per turbine per year (1 incident per year per 3,846 turbines) for a blade fragment, it is expected that up to 28 blade throw incidents could have occurred in Australia in the 16-year period from 2005 to 2020. To DNV's knowledge, the actual number of blade throw incidents recorded in Australia since 2005 is potentially less than half the value predicted according to the conservative frequencies presented in Table 1 and is therefore within the expected frequency of a blade throw incident occurring.

3.1.2 Implications for the proposed Project

As discussed above, the frequencies presented in Table 1 are expected to represent conservative estimates of the frequency of blade throw incidents for modern wind turbines such as those proposed for the Project. Therefore, it is reasonable to assume that the frequency of a blade throw incident occurring at the Project would be less than the conservative estimates shown in Table 1 of

- 8.4 x 10^{-4} incidents per turbine per year (1 incident per year per 1,190 turbines) for an entire blade
- 2.6 x 10^{-4} incidents per turbine per year (1 incident per year per 3,846 turbines) for a blade fragment

and could be closer to 2.5 x 10^{-4} incidents per turbine per year (1 incident per year per 4,000 turbines, as evaluated in the 2014 Dutch Handbook for the five-year period from 2005 to 2010). To state this another way, for the 148 turbines proposed to be installed at the Project, it is expected that one blade throw incident could occur approximately every 8 to 27 years on average. Although this indicates that at least one blade throw incident is likely to occur at the Project during its lifetime, the occurrence of a blade throw incident does not necessarily correspond to the blade or blade fragment landing at a location that would result in injury or death to a person or damage to property or infrastructure as discussed in the following sections.

Nevertheless, for the high-level blade throw risk assessment presented in Section 4, the methodology recommended in the 2014 Dutch Handbook based on the more conservative blade throw frequency of 8.4 x 10^{-4} incidents per turbine per year (1 incident per year per 1,190 turbines) has been used.

3.2 Maximum theoretical blade throw distance

A number of theoretical studies have been undertaken to assess the likely distribution of turbine blade fragments in the event of a blade throw incident, or the probability that if a blade or section of blade is thrown it would land at a specific location. These have been performed using mathematical modelling to simulate the motion of thrown blades or blade fragments of various sizes for a range of turbine parameters, operating behaviours, wind speeds, and other conditions.

The results of several such studies are summarised in Table 2, for the case of turbines operating under normal conditions (referring to operation at the rated rotor speed), and Table 3, for the case of turbine operating under overspeed conditions of 2 to 2.5 times the rated rotor speed. Although the results of these studies are not directly comparable due to the different modelling parameters and assumptions used in each investigation, it is possible to draw some general conclusions.

Table 2 shows that, for turbines operating under normal conditions with a tip speed of approximately 70-80 m/s, the maximum theoretical throw distances predicted in the literature for an entire blade or large portion of a blade range from 140 m to 260 m. At higher tip speeds of around 100 m/s, the predicted maximum theoretical throw distances for an entire blade or large portion of blade range from 200 m to 300 m. As would be expected, smaller blade fragments are predicted to travel further than an entire blade, with maximum throw distances ranging from 450 m to 861 m under normal operating conditions and 510 m to 1000 m for higher tip speeds.

The predicted throw distances increase slightly as the size of the turbine increases, but are not directly proportional to the turbine dimensions. In other words, a doubling of the turbine rotor diameter or tip height does not correspond to a doubling of the predicted throw distance for either an entire blade or a blade fragment. The results of the theoretical studies therefore suggest that the turbine dimensions do not significantly influence the maximum blade throw distance under normal operating conditions [8, 4].

Instead, the results presented in Table 2 indicate that, for similar turbine dimensions, the blade throw distance is primarily dependent on the tip speed of the turbine. A higher tip speed means that the blade or blade fragment would be travelling at a higher velocity when it detaches, and therefore would have the potential to be thrown a greater distance from the turbine. The same observation was made by Rogers *et al.* [8] and Sarlak and Sørensen [4], who both concluded that the blade tip speed plays the most important role in determining the maximum potential throw distance for any turbine.

Table 2 Theoretical maximum blade throw distances for wind turbines operating under normal conditions (rated rotor speed)

Study reference	Blade fragment sizes considered	Modelled turbine parameters			Maximum throw distance (m)	
		Diameter (m)	Tip height (m)	Tip speed (m/s)	Entire blade	Blade fragment
Rogers *et al.* [8]	Entire blade, 20% of entire blade by weight	47	73.5	70.0	210 [1]	520 [1]
		70	115.0	80.5	260 [1]	750 [1]
		90	125.0	76.1	240 [1]	550 [1]
Cotton [13]	Entire blade, 10% of entire blade by weight	90	110.0	65.0	185 [2]	861 [2]
2014 Dutch Handbook [1]	Entire blade or large portion of blade only, small blade fragments not considered	141	190.5	96.7	214	-
		156	198.0	107.0	245	-
Sarlak & Sørensen [4]	Entire blade, 20% of entire blade by length	100	150.0	70.0 [3]	140 [1]	450 [1]
		147	220.5	70.0 [3]	180 [1]	500 [1]
		208	312.0	70.0 [3]	200 [1]	580 [1]
		294	441.0	70.0 [3]	210 [1]	610 [1]
		100	150.0	100.0 [4]	200 [1]	510 [1]
		147	220.5	100.0 [4]	220 [1]	860 [1]
		208	312.0	100.0 [4]	250 [1]	930 [1]
		294	441.0	100.0 [4]	300 [1]	1000 [1]

1. Value has been approximated from graphed results presented in the original source.
2. 99th percentile (1-in-100) result, assuming medium air drag. Throw distances of 203 m and 1395 m were predicted for an entire blade and a blade fragment respectively assuming very low air drag, but it is unclear whether these conditions would be experienced in reality.
3. Representing normal operating conditions.
4. Representing high tip speed conditions.

The maximum theoretical throw distances presented in Table 3 for turbines operating under overspeed conditions, where the turbine rotor speed is 2 to 2.5 times the rated speed, support the observation that the throw distance is primarily dependent on the turbine tip speed. For the same turbine dimensions, the predicted maximum throw distance for an entire blade under overspeed conditions is typically around 2.5 to 3 times the distance predicted for normal operating conditions. Although the predicted maximum throw distances for entire blades and blade fragments under overspeed conditions are more sensitive to the turbine dimensions than the distances for normal operating conditions, the influence of the turbine diameter and tip height on the throw distance appears to decrease as the turbine size increases [4].

Table 3 Theoretical maximum blade throw distances for wind turbines operating under overspeed conditions (2 to 2.5 times the rated rotor speed)

Study reference	Blade fragment sizes considered	Modelled turbine parameters			Maximum throw distance (m)	
		Diameter (m)	Tip height (m)	Tip speed (m/s)	Entire blade	Blade fragment
Cotton [13]	Entire blade, 10% of entire blade by weight	90	110.0	216.8	183 [1]	886 [1]
2014 Dutch Handbook [1]	Entire blade or large portion of blade only, small blade fragments not considered	141	190.5	193.4	602	-
		156	198.0	214.0	716	-
Sarlak & Sørensen [4]	Entire blade, 20% of entire blade by length	100	150.0	150.0	390 [2]	780 [2]
		147	220.5	150.0	450 [2]	1450 [2]
		208	312.0	150.0	480 [2]	1800 [2]
		294	441.0	150.0	500 [2]	2000 [2]

1. 99th percentile (1-in-100) result, assuming medium air drag and a 1-in-50 year extreme wind speed. Throw distances of 198 m and 1462 m were predicted for an entire blade and a blade fragment respectively assuming very low air drag, but it is unclear whether these conditions would be experienced in reality.
2. Value has been approximated from graphed results presented in the original source.

The maximum throw distances presented in Table 2 and Table 3 represent low probability events in themselves and, to determine the overall frequency of a blade or blade fragment being thrown that distance, this probability must be combined with the frequency of a blade throw incident occurring. As discussed in Section 3.1, the 2014 Dutch Handbook proposes a conservative blade throw frequency of 8.4×10^{-4} incidents per turbine per year for the detachment and throw of an entire blade under normal operating conditions. For blade throw incidents involving a blade fragment or occurring under overspeed conditions, which generally correspond to larger theoretical throw distances as discussed above, the expected frequency of a blade throw incident occurring is lower again. If these frequencies were to be combined with the probability of a thrown blade or blade fragment reaching the maximum theoretical distances shown in Table 2 and Table 3, the overall frequency at which a blade or blade fragment would be thrown to the maximum distances predicted by theoretical modelling is expected to be very low.

3.2.1 Comparison of blade throw distances to recorded incidents

As noted in Section 3.1, information about the distances that blades or blade fragments have travelled in actual blade throw incidents is very limited. Based on incident data recorded from 1984 to 2000, researchers for the 2005 Dutch Handbook were able to confirm blade throw distances of up to 150 m for an entire blade (for a turbine with a rotor diameter of approximately 50 m) and up to 500 m for a blade tip or small fragment [2]. The authors of that review also noted that throw distances of up to 600 m for entire blades had been reported in some publications, but were unable to verify those reports. Similarly, a 2006 review of 37 reported instances of blade throw where a distance was recorded found that most incidents resulted in fragments being thrown to within 600 m of the turbine location [13]. Only one incident identified in that review exceeded a throw distance of 600 m, with a blade fragment reaching an estimated distance of "almost 1000 m" [13], although the size of the fragment and other circumstances of the incident were not specified. Despite the limitations of the data, these recorded distances are broadly consistent with the range of predicted blade throw distances under normal operating conditions given in Table 2.

3.2.2 Implications for the proposed Project

The turbine parameters under consideration for the Project are summarised in Table 4.

Table 4 Turbine parameters proposed for the Project

Turbine	Diameter (m)	Tip height (m)	Tip speed under normal operating conditions (m/s)
Theoretical turbine representing maximum turbine dimensions	180	250	Not specified (theoretical turbine only)

These parameters are closest to those modelled by Sarlak and Sørensen [4] for a theoretical turbine with a rotor diameter of 208 m and tip height of 312 m, and tip speeds of 70 m/s under normal operating conditions and 100 m/s under high tip speed conditions, as shown in Table 2. Therefore, the maximum potential throw distances for the turbines at the Project are expected to be in the order of 200 m for an entire blade and 580 m for a blade fragment under normal operating conditions at the nominal rated rotor speed, and 250 m for an entire blade and 930 m for a blade fragment at the maximum rated rotor speed. In the unlikely event of overspeed conditions, the throw distances for turbines of this size could potentially reach 480 m for an entire blade or 1800 m for a blade fragment.

However, it is important to note that these potential blade throw distances are theoretical maximum values based on assumed scenarios for the turbine behaviour and wind conditions at the time of the blade throw incident, and do not consider the probability of those scenarios actually occurring [4]. As discussed above, the frequency at which a blade or blade fragment would be thrown from a turbine at the Project and reach the maximum throw distances presented here is expected to be very low.

3.3 Frequency of a blade throw incident causing injury or death

Most investigations into the risks associated with a potential blade throw incident have focussed on the risk of harm being caused to people by a blade or blade fragment thrown from a turbine, either through direct impact or impact with another object. These risks represent the most serious potential consequences of a blade throw incident, and also may be the subject of public policy or regulations, although DNV is not aware of any such policies or regulations in Australia. The likelihood of a turbine blade throw incident resulting in injury or death to a person in the vicinity of a wind farm through direct impact is determined by the frequency of the blade throw incident occurring, combined with the probability of a blade fragment actually hitting a person who is in the surrounding area.

A common way of expressing the risk of injury or death from a blade throw incident occurring at a wind farm is in terms of the *location-specific risk* (also called the location-specific individual risk, or LSIR) [1, 2, 3]. The location-specific risk is defined as the frequency at which a person remaining at a fixed location in the vicinity of the wind farm continuously for a year would be hit and killed by a blade or blade fragment thrown from a turbine. This measure is useful for visualising and comparing the blade throw risks in the area around a wind farm, but does not consider the probability that a person would in fact be present in that area when a blade throw incident occurs. Although the work presented in this document is not intended to assess the likelihood of a blade throw incident causing damage to property, the location-specific risk may also be considered as a measure of the frequency at which a blade or blade fragment would impact a building or other fixed infrastructure in the area around a wind farm.

For situations where a person may be moving through the area in the vicinity of a wind farm, such as on a road or rail network, two further measures of blade throw risk can be considered [1]:

- The *individual risk* (also called the individual risk per annum, or IRPA) is defined as the annual frequency at which a typical person passing by the wind farm would be hit and killed by a blade or blade fragment. At any given location, the individual risk is given by the combination of the fraction of time in a year the person spends at that location, the frequency at which a blade or blade fragment would land at that location, and the probability of the impact causing death. To determine the overall individual risk of death from a blade throw incident, the individual risks at each location must be summed over all locations in the vicinity of the wind farm.
- The *societal risk* is defined as the annual risk to the entire population expressed as the total number of deaths that would be caused by a blade throw incident per year.

While the location-specific blade throw risk in the area around a wind farm can be estimated based on the turbine characteristics alone, the individual risk and societal risk must be assessed on a site-specific basis using information about the amount of time that people are likely to spend in the vicinity of the wind farm.

3.3.1 Location-specific blade throw risks

To understand how the location-specific blade throw risk varies with the turbine parameters, researchers for the Dutch Handbook modelled the risk of being hit and killed by an entire blade thrown from turbines of various sizes and how that risk changed with increasing distance from the turbine [1, 2]. These calculations were based on the conservative blade throw frequencies and maximum blade throw distances derived in the Dutch Handbook as discussed in Sections 3.1 and 3.2. The size of the blade and the area it could potentially impact upon landing was also considered, and it was assumed that every impact would be fatal for a person at that location. The location-specific risk for a blade throw incident was then combined with the risks of death caused by a turbine tower collapsing or a turbine rotor or nacelle falling from the tower, which were determined in a similar way, to obtain the overall location-specific risk at each point in the vicinity of the turbine.

Based on the results of the modelling, two observations were made [1, 2]:

- The risk became less than 10^{-5} per year (1-in-100,000) at a distance of half the rotor diameter for all turbine parameters and conditions considered.
- The risk became less than 10^{-6} per year (1-in-1 million) at a distance of either the turbine tip height or the maximum theoretical throw distance for an entire blade under normal operating conditions for that turbine, depending on the turbine parameters and conditions in which blade throw was assumed to have occurred.

Given the conservative assumptions and generic turbine parameters considered in the modelling, the researchers concluded that the location-specific risk for any turbine similar to those considered would be 10^{-5} per year (1-in-100,000) at a distance equal to half the rotor diameter, and 10^{-6} per year (1-in-1 million) at a distance equal to either the turbine tip height or the maximum theoretical throw distance for an entire blade under normal operating conditions, whichever is greater. As defined in Section 3.3, these risks describe the frequency at which a person who remains at a fixed location at the specified distance from the turbine for a whole year would be hit and killed by a blade thrown from the turbine. These results are summarised in Table 5 for the two largest turbine models considered in the 2014 Dutch Handbook.

Table 5 Results of location-specific risk modelling for two generic turbine models [1]

Modelled turbine parameters			Maximum theoretical throw distance for an entire blade under normal operating conditions (m)	Distance from turbine where the location-specific risk drops below the given value (m)	
Diameter (m)	Tip height (m)	Hub height (m)		10^{-5} per year (1-in-100,000)	10^{-6} per year (1-in-1 million)
141	190.5	100	214	71	214
156	198.0	120	245	78	245

In the 2005 Dutch Handbook, researchers also investigated how the location-specific risk would vary with the distance from the turbine for a blade fragment with a length of 3 m and a width of 1 m [2]. The results of the analysis showed that the risk of being hit and killed by a blade fragment at a particular location is approximately 100 to 1000 times less than the risk of being hit and killed by an entire blade at the same distance from the turbine. This is partly due to the lower probability that a blade throw incident would involve a small blade fragment, as discussed in Section 3.1, but also due to the size of the thrown section of blade. Although a blade fragment can potentially be thrown a long way, its smaller size means that it would impact a smaller area and so there is a reduced chance of the fragment hitting and killing a person at any given location compared to an entire blade. Additionally, given the larger potential throw distances for a blade fragment, the area around the turbine in which a blade fragment could land is larger than the area for an entire blade and so there is a reduced chance of any specific location being impacted. At distances greater than the maximum throw distance for the blade fragment under normal operating conditions (approximately 650 m for the turbine parameters considered in the 2005 Dutch Handbook), the results showed that the location-specific risk of being hit and killed is in the order of 10^{-12} per year (1-in-1 trillion). Therefore, the location-specific risks associated with a blade fragment being thrown from a turbine are insignificant compared to the risks posed by an entire blade and can be assumed to be encompassed in the risk levels described above.

3.3.2 Comparison of blade throw risks to other common activities

The typical fatality risks for several common activities are presented in Table 6, along with the risks of being hit and killed by a turbine blade or blade fragment as given in the 2014 Dutch Handbook. Even considering the conservative assumptions made in the calculations performed for the Dutch Handbook, and the hypothetical scenario of a person who spends the entire year in close proximity to a turbine, the risk of death due to a blade throw incident is less than the annual risk of death on Australian roads or for people working in agriculture.

For the purpose of comparison, DNV has also converted the location-specific blade throw risks for a person remaining in the specified location continuously for a whole year into the risk for a person spending the equivalent of one working day (8 hours) per year at that location. This duration is considered to represent a more realistic estimate of the amount of time that a person may spend in the vicinity of a turbine. When this hypothetical scenario of a person being in close proximity to a turbine for 8 hours per year is taken into account, the risk of death due to a blade throw incident is lower than the risk of being killed by a lightning strike. The risk of death due to a blade throw incident can therefore be considered very small, particularly when compared to the likelihood of accidents occurring during everyday activities.

Table 6 Typical risks of common activities compared to blade throw risks

Risk	Annual frequency	
Death to people working in agriculture in Australia, per agricultural worker (2001-2011 data) **[17]**	1.5×10^{-4} (1-in-6,667)	
Death on Australian roads, per head of population (2019 data) [18]		
- Nationally	4.5×10^{-5} (1-in-22,222)	
- Inner regional areas	7.8×10^{-5} (1-in-12,821)	
- Outer regional areas	1.35×10^{-4} (1-in-7,407)	
Death due to lightning strike, per head of population (1980-1989 data) [19]	10^{-7} (1-in-10 million)	
Death from impact by a turbine blade or blade fragment, for an unprotected person remaining at a fixed location at the specified distance for the specified time [1]	*continuously for a year*	*continuously for one working day per year (8 hours)*
- distance equal to half the turbine rotor diameter	10^{-5} (1-in-100,000)	10^{-8} (1-in-100 million)
- distance equal to the turbine tip height or maximum blade throw distance for an entire blade under normal operating conditions, whichever is greater	10^{-6} (1-in-1 million)	10^{-9} (1-in-1 billion)

To provide further context, the NREL [12] has published a classification of blade throw risks in terms of the annual frequency or likelihood of an event and the potential consequences. The NREL risk classification for consequences to people is shown in Table 7. Based on this classification, the risk of death for a person who spends a whole year in the vicinity of a turbine at a fixed location at either of the distances specified in Table 6 can be described as an "extremely remote" likelihood and "low" overall risk. For the potentially more realistic scenario of a person who spends the equivalent of 8 hours per year at a fixed location at the specified distances from a turbine, the risk of death due to a blade throw incident becomes "improbable" and a "routine" overall risk. For the purposes of their own assessments, the NREL considers any risks which are classified as "low" or "routine" to be acceptable.

Table 7 NREL classification of blade throw risks [12]

	Likelihood of risk occurring					
	"Frequent"	"Reasonably probable"	"Occasional"	"Remote"	"Extremely remote"	"Improbable"
Consequence to people	More than 1 per year	Less than 1 per year to 0.1 per year (1-in-10)	Less than 0.1 per year (1-in-10) to 0.01 per year (1-in-100)	Less than 0.01 per year (1-in-100) to 10^{-4} per year (1-in-10,000)	Less than 10^{-4} per year (1-in-10,000) to 10^{-6} per year (1-in-1 million)	Less than 10^{-6} per year (1-in-1 million)
Death or permanent total disability	"High" risk	"High" risk	"High" risk	"Moderate" risk	"Low" risk	"Routine" risk
Partial disability	"High" risk	"High" risk	"Moderate" risk	"Low" risk	"Low" risk	"Routine" risk
Injury	"Moderate" risk	"Moderate" risk	"Low" risk	"Low" risk	"Routine" risk	"Routine" risk
Minor injury	"Routine" risk	"Routine" risk	"Routine" risk	"Routine" risk	"Routine" risk	"Routine" risk

3.3.3 Implications for the proposed Project

Based on the location-specific risk modelling presented in the 2014 Dutch Handbook, the risk of a person who remains at a fixed location continuously for a whole year being hit and killed by a blade or blade fragment thrown from a turbine at the Project is expected to be 10^{-5} per year (1-in-100,000) or less at a distance of 90 m (being half the maximum proposed turbine rotor diameter, based on the turbine dimensions given in Table 4). For the hypothetical case of a person who spends the equivalent of one working day (8 hours) per year at a fixed location at a distance of 90 m from the turbine, the risk of being hit and killed by a blade or blade fragment is expected to be 10^{-8} (1-in-100 million).

As stated in the Dutch Handbook, the location-specific blade throw risk drops below 10^{-6} per year (1-in-1 million) at a distance equal to either the turbine tip height or the maximum theoretical throw distance for an entire blade under normal operating conditions, whichever is greater. For the turbines proposed for the Project, the maximum proposed tip height of 250 m is equal to the maximum potential throw distance for an entire blade established in the literature for similar sized turbines at the maximum rated rotor speed, as discussed in Section 3.2.2, and greater than the maximum throw distance under normal operating conditions for all turbine models considered in the Dutch Handbook (245 m, as shown in Table 5). Therefore, the risk of being hit and killed by a blade or blade fragment is expected to be 10^{-6} per year (1-in-1 million) or less for a person who remains at a fixed location at a distance of 250 m from the turbines continuously for a whole year, and 10^{-9} per year (1-in-1 billion) for the hypothetical case of a person who spends the equivalent of 8 hours per year at that location.

A high-level assessment of the site-specific risks of blade throw for the Project (including the location-specific, individual, and societal risks), based on the maximum turbine dimensions proposed for the Project and the conservative risk assumptions used in the Dutch Handbook, is presented in Section 4.

4 SITE-SPECIFIC BLADE THROW RISK ASSESSMENT

4.1 Methodology for evaluating site-specific blade throw risks

The 2014 Dutch Handbook provides a practical methodology for evaluating the site-specific blade throw risks for a wind farm, based on the results of the location-specific risk modelling described in Section 3.3.1. Because the methodology draws on conclusions derived from conservative assumptions and modelling of generic turbines, it is suitable for conducting an initial risk assessment in situations where a specific turbine model has not yet been chosen [1]. Although the Dutch Handbook proposes some limits to the applicability of these conclusions, the results of the risk modelling suggest that they are valid for a wide range of modern wind turbines regardless of the turbine parameters. DNV therefore considers that this methodology is appropriate for use in a high-level site-specific assessment of the blade throw risks for the proposed Project, as presented here. DNV is not aware of any similar methodologies or guidelines for blade throw assessments that have been published in Australia.

The first step in performing a site-specific risk assessment based on this methodology is to determine the location-specific risks in the area around the turbines, in accordance with the guidance given in the Dutch Handbook, whereby:

- the distance from the turbines at which the location-specific risk is 10^{-5} per year or 1-in-100,000 (also called the 10^{-5} risk contour) is equal to half the turbine rotor diameter
- the distance from the turbines at which the location-specific risk is 10^{-6} per year or 1-in-1 million (also called the 10^{-6} risk contour) is equal to either the turbine tip height or the maximum throw distance for an entire blade under normal operating conditions, whichever is greater.

Once these distances have been established, the risks associated with specific locations, infrastructure, or activities in the vicinity of the wind farm can be evaluated and compared to the levels of risk that are considered acceptable in the relevant jurisdiction. Where information is available about the amount of time that people who are passing through the area are likely to spend in the vicinity of the wind farm, such as travellers on a road or rail network, the corresponding individual risk and societal risk can also be estimated based on the definitions given in Section 3.3.

Although the assessment presented here is aimed at evaluating the blade throw risks for the Project, it is noted that the methodology and risk levels given in the Dutch Handbook include the risks associated with a turbine tower collapsing or a turbine rotor or nacelle falling from the tower.

4.2 Recommended blade throw risk limits

The Dutch Handbook also presents specific limits for the acceptable levels of blade throw risk at various types of infrastructure [1], as summarised in Table 8. The corresponding NREL risk classification for each blade throw risk limit identified in the Dutch Handbook, based on the definitions given in Table 7, is also shown in Table 8. In the Netherlands, these limits are imposed by national legislation (in the case of dwellings and other buildings and facilities) or are specified in policies applied by the relevant authority (in the case of roads).

DNV is not aware of any published guidance on the blade throw risk that would be considered acceptable in NSW, or any other Australian jurisdiction. In the absence of such guidance, the blade throw risks estimated for the Project have been compared to the risk limits given in Table 8 and the existing risks to people in the vicinity of the Project.

Table 8 Blade throw risk limits presented in the Dutch Handbook [1]

Type of building or infrastructure	Relevant measure of risk	Risk limit and corresponding NREL risk classification [12]
Dwellings and other sensitive buildings and facilities (schools, childcare facilities, hospitals)	Location-specific risk	10^{-6} per year (1-in-1 million) "Extremely remote" likelihood and "low" risk
Other buildings and facilities where large numbers of people may be present for most of the day	Location-specific risk	10^{-6} per year (1-in-1 million) "Extremely remote" likelihood and "low" risk
Buildings and facilities which are occupied by fewer people or for shorter periods of the day	Location-specific risk	10^{-5} per year (1-in-1 million) "Extremely remote" likelihood and "low" risk
National roads under the jurisdiction of the Dutch Ministry for Infrastructure and Water Management [1]	Individual risk	10^{-6} per person per year (1-in-1 million) "Extremely remote" likelihood and "low" risk
	Societal risk	2 x 10^{-3} persons per year (one death every 500 years) [2]

1. In the Netherlands, requirements for other types of roads (whether provincial, municipal, local, or private) are the responsibility of the local authority and there is no general guidance on the levels of blade throw risk that would be considered acceptable. However, the Dutch Handbook notes that the relevant authority may choose to apply the risk limits set by the Ministry for Infrastructure and Water Management for national roads [1].
2. The NREL risk classifications are only applicable for risks expressed as a likelihood or frequency per year, as in the case of a location-specific or individual risk.

4.3 Assessment of blade throw risks for the Project

DNV has conducted a high-level assessment of the site-specific risks for the proposed Project, based on the methodology and risk levels presented in the Dutch Handbook.

Figure 2 shows the locations of nearby dwellings and other sensitive locations, roads, and neighbouring properties in relation to the Project boundaries and proposed turbine locations. Figure 2 also shows regions around the proposed turbine locations at distances equal to:

- 90 m, corresponding to half the turbine rotor diameter and hence the distance at which the location-specific risk is 10^{-5} per year (1-in-100,000) based on the guidance in the Dutch Handbook
- 250 m, corresponding to the turbine tip height (which is equal to the expected maximum throw distance for an entire blade under normal operating conditions at the maximum rated rotor speed, as discussed in Section 3.3.3) and hence the distance at which the location-specific risk is 10^{-6} per year (1-in-1 million) based on the guidance in the Dutch Handbook
- 1800 m, corresponding to the expected maximum theoretical blade throw distance for turbines at the Project, as discussed in Section 3.2.2. The location-specific risk at this distance is expected to be in the order of 10^{-12} per year (1-in-1 trillion).

Distances between the proposed turbine locations and existing dwellings or other sensitive locations within 1800 m of turbines at the Project are given in Table 9.

Table 9 Dwellings and other sensitive locations within 1800 m of the proposed turbine locations for the Project

Building ID	Easting[1] [m]	Northing[1] [m]	Nearest turbine ID	Distance to nearest turbine [m]
250	749022	6473369	MH49	860
256	755133	6457788	GR35	1294
257	758006	6458421	GR13	1236
258	758930	6458666	GR13	1037
297	749296	6473388	MH44	923
303	744499	6452361	LV12	1040
304	747967	6452124	LV5	1359
305	750133	6449337	LV4	1478
306	749757	6449493	LV4	1125
309	740935	6471801	MH74	1440
310	749622	6449493	LV4	1058
329	753159	6462751	GR47	1611

1. Coordinate system: MGA zone 55, GDA94

4.3.1 Blade throw risks at dwellings and other sensitive locations

Figure 2 and Table 9 show that there are no dwellings or other sensitive locations within 250 m of the proposed turbine locations. All dwellings are more than 860 m from the nearest proposed turbine location, which is 610 m beyond the expected maximum throw distance for an entire blade under normal operating conditions at the maximum rotor speed (being 250 m as discussed in Section 3.2.2). At distances of 860 m or more from a turbine, the risk of an unprotected person who remains at a fixed location continuously for a whole year being hit and killed by a blade or blade fragment thrown from the Project is expected to be considerably less than 10^{-6} per year (1-in-1 million), which would be described as an "extremely remote" to "improbable" likelihood and "low" to "routine" risk using the NREL risk classification shown in Table 7. Therefore, the location-specific risk at all dwellings in the vicinity of the Project is expected to be well below the acceptable risk limit of 10^{-6} per year (1-in-1 million) identified in the Dutch Handbook and shown in Table 8.

4.3.2 Blade throw risks at nearby properties

Figure 2 shows that there are no neighbouring properties located within half the turbine rotor diameter, or 90 m, of the proposed turbine locations, which suggests that the frequency at which a person who remains at any fixed location on a neighbouring property for a whole year would be hit and killed by a blade or blade fragment thrown from the Project is less than 10^{-5} per year (1-in-100,000). This is lower than the annual risk of death for people working in agriculture in Australia, as discussed in Section 3.3, and would be described as an "extremely remote" likelihood and "low" risk using the NREL risk classification shown in Table 7.

4.3.3 Blade throw risks on nearby roads

Figure 2 shows that there are no roads located within half the turbine rotor diameter, or 90 m, of the proposed turbine locations, which suggests that the frequency at which a person who remains at any fixed location on a neighbouring road for a whole year would be hit and killed by a blade or blade fragment thrown from the Project is less than 10^{-5} per year (1-in-100,000). This is lower than the annual frequency of death for on Australian roads, as discussed in Section 3.3, and would be described as an "extremely remote" likelihood and "low" risk using the NREL risk classification shown in Table 7. Additionally, this frequency does not consider the probability that a person would be present on the road in a location where they are at risk of being hit by a blade or blade fragment at the time a blade throw incident occurs.

To provide a better understanding of the likely risks for road users in the vicinity of the Project, DNV has estimated the individual risk for the section of Mount Hope Road passing within 1800 m of the proposed turbine locations as shown in Figure 2. Although Mount Hope Road is an unsealed local road, it was chosen for this review as it has the largest number of turbines in close proximity to the road corridor of any roads in the vicinity of the Project. Therefore, DNV expects the blade throw risks for Mount Hope Road to represent the worst-case risk scenario for all road users in the vicinity of the Project.

The individual risk of blade throw for people travelling on Mount Hope Road was evaluated according to the steps outlined in Figure 3, based on the following assumptions:

- The location-specific risk at all points in the region between 90 m and 250 m from the turbines is assumed to be 10^{-5} per year (1-in-100,000). As shown in Table 10, this is equal to the maximum value for the location-specific risk throughout that region. Similarly, the location-specific risk at all points in the region between 250 m and 1800 m from the turbines is assumed to be 10^{-6} per year (1-in-1 million). These are conservative assumptions, as the actual value of the location-specific risk in these regions will decrease as the distance from the turbines increases, as indicated in Table 10.
- The average vehicle speed along that section of road is assumed to be 40 km per hour, based on the expected road conditions. A lower vehicle speed is a conservative assumption, as it increases the amount of time that each person would spend on the road in the vicinity of the turbines.
- On average, each vehicle is assumed to carry two people and to make two trips per day (or 730 trips per year) along that section of road.
- Every impact from a blade or blade fragment is assumed to be fatal. This is a conservative assumption, as the actual probability of an impact being fatal depends on a number of factors, including the size of the blade fragment, its speed at the time of impact, and the extent to which the person is protected by their vehicle [3]. Since the location-specific risks shown in Table 10 also assume that every impact is fatal, this assumption allows those values to be used directly in the calculation of the individual risk as outlined in Figure 3.

Table 10 Location-specific risk assumptions used to estimate the individual and societal blade throw risks for people travelling on Mount Hope Road

Distance from turbines	Location-specific blade throw risk in this region (decreases as distance from turbines increases)	Assumption used to estimate risk to road users
Less than 90 m	Greater than 10^{-5} per year (1-in-100,000)	Not applicable – no roads located within this distance
90 m to 250 m	Varies from 10^{-5} per year (1-in-100,000) at 90 m to 10^{-6} per year (1-in-1 million) at 250 m	10^{-5} per year (1-in-100,000) throughout entire region
250 m to 1800 m	Varies from 10^{-6} per year (1-in-1 million) at 250 m to approximately 10^{-12} per year (1-in-1 trillion) at 1800 m	10^{-6} per year (1-in-1 million) throughout entire region

According to this analysis, the individual risk along Mount Hope Road for death caused by a blade throw incident is 3.20 x 10^{-8} per person per year (1-in-31 million). This is approximately 30 times less than the limit identified as acceptable in the Dutch Handbook and shown in Table 8 (10^{-6} per person per year or 1-in-1 million), even with conservative assumptions made for the location-specific risk in each region as outlined above, and would be described as an “improbable” likelihood and “routine” risk using the NREL risk classification shown in Table 7.

Traffic volume surveys undertaken for the Project indicate that traffic volumes on Mount Hope Road are less than 50 vehicles per day [20]. Taking this as the maximum possible upper limit for traffic volumes on Mount Hope Road, and assuming an average of two people travelling in each vehicle, DNV has evaluated the potential societal risk of death caused by a blade throw incident according to the steps outlined in Figure 4. For a traffic volume of 50 vehicles per day, the societal risk on Mount Hope Road is 1.60×10^{-6} deaths per year, or one death every 625,000 years, which is approximately 1250 times less than the limit identified as acceptable in the Dutch Handbook and shown in Table 8 (2×10^{-3} deaths per year, or one death every 500 years). The societal risk of blade throw for other roads in the vicinity of the Project is expected to be lower again, due to the increased distance from the proposed turbine locations.

4.3.4 Summary of blade throw risks for the Project

The blade throw risks evaluated for the Project as described in Sections 4.3.1 and 4.3.2 are summarised and compared to the risk limits identified in the Dutch Handbook and existing risks in Table 11. The corresponding NREL risk classifications for these risks, as defined in Table 7, are also shown in Table 11. As discussed in Section 3.3.2, the NREL considers "low" and "routine" levels of risk to be acceptable. Given the conservative methodology and assumptions used throughout this high-level risk assessment, it is expected that the blade throw risks presented here are also highly conservative. Since these risks are already very low, and well below the risk limits considered acceptable in other jurisdictions and existing risks, DNV considers that a more detailed site-specific assessment of the blade throw risks is not required for this Project.

Table 11 Summary of blade throw risks evaluated for the Project and comparison to relevant risk limits and existing risks

Risk category	Blade throw risk evaluated for the Project and corresponding NREL risk classification [12]	Blade throw risk limit presented in the Dutch Handbook [1]	Existing risk
At dwellings and other sensitive locations such as schools and childcare facilities			
Location-specific risk (for an unprotected person remaining at that location for a whole year)	Considerably less than 10^{-6} per year (1-in-1 million) "Extremely remote" to "improbable" likelihood and "low" to "routine" risk	10^{-6} per year (1-in-1 million)	-
At neighbouring properties			
Location-specific risk (for an unprotected person remaining at a fixed location for a whole year)	Less than 10^{-5} per year (1-in-100,000) "Extremely remote" likelihood and "routine" risk	-	Risk of death for people working in agriculture in Australia: 1.5×10^{-4} per year (1-in-6,667)
For road users on Mount Hope Road (representing the worst-case scenario for all road users in the vicinity of the Project)			
Individual risk (for a typical person travelling on that section of road)	3.20×10^{-8} per person per year (1-in-31 million) "Improbable" likelihood and "routine" risk	10^{-6} per person per year (1-in-1 million)	Risk of death on all Australian roads per head of population: 4.5×10^{-5} per year (1-in-22,222)
Societal risk (total number of people at risk)	1.60×10^{-6} persons per year (one death every 625,000 years) [1]	2×10^{-3} persons per year (one death every 500 years)	-

1. The NREL risk classifications are only applicable for risks expressed as a likelihood or frequency per year, as in the case of a location-specific or individual risk.

5 CONCLUSIONS

Wind turbine blade throw incidents are relatively rare events. Compliance with international standards, implementation of high-quality maintenance programs, and continual improvements in turbine design and materials mean that blade failure is relatively rare for modern wind turbines and does not typically result in the detachment of blades or blade fragments. The likelihood of a blade throw incident causing injury to a person in the vicinity of a wind farm depends on the frequency of a turbine blade failing, the probability of the blade or part of the blade detaching as a result of that failure, and the probability of a person being struck by the thrown object, all of which are very low.

Based on a conservative assessment methodology and assumptions, DNV has evaluated the risks of death caused by a blade throw incident at dwellings, roads, and neighbouring properties in the vicinity of the Project. The results show that the potential risks are at least 30 times less than the blade throw risks considered acceptable in other jurisdictions, and considerably lower than existing risks. Therefore, for the proposed turbine layout and parameters, the risk of injury or property damage associated with blade throw at the proposed Project is considered very low.

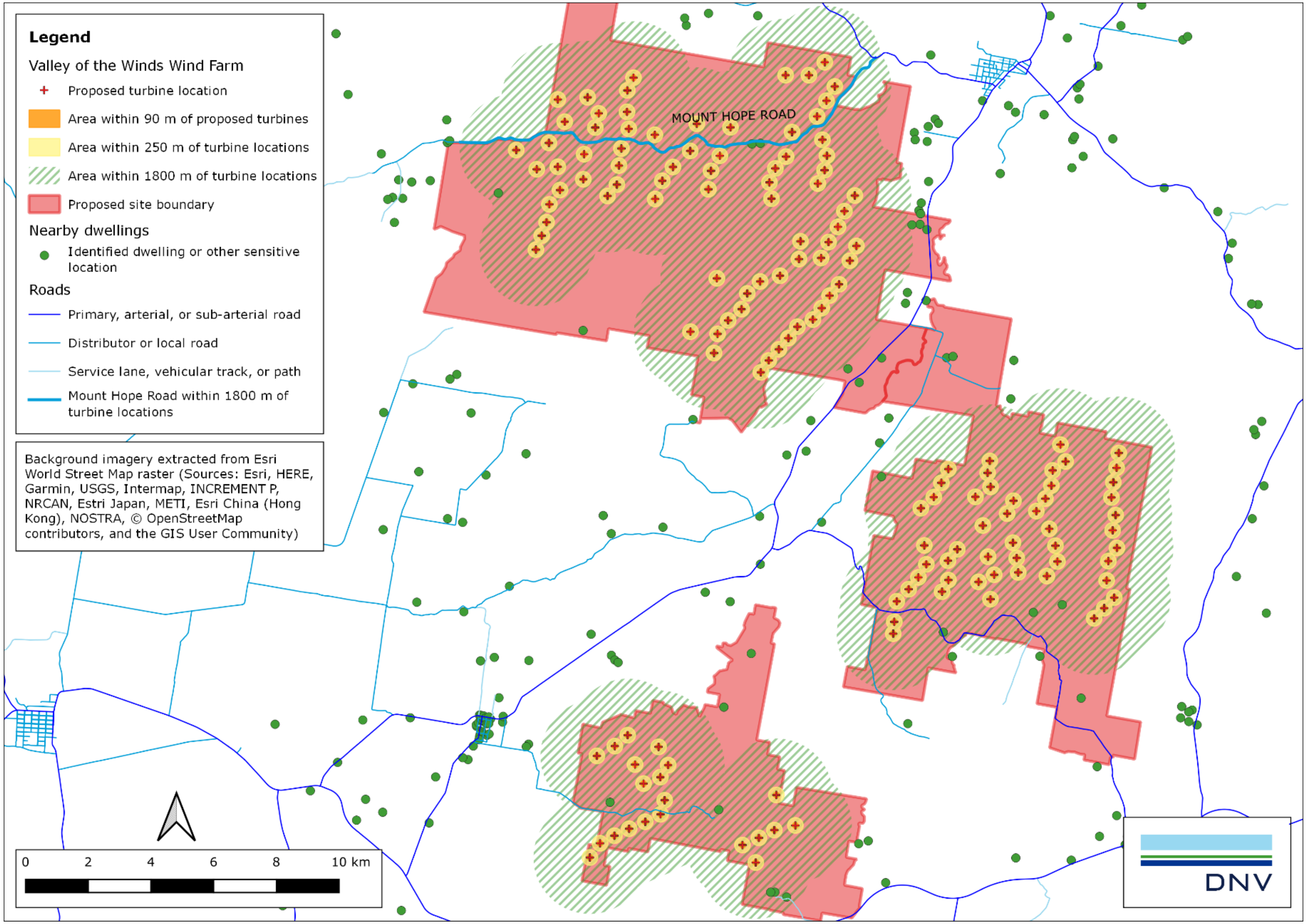

Figure 2 Locations of nearby dwellings and other sensitive locations, properties, and roads in relation to the proposed Project

Determine the total length of road passing through each of the regions defined in Table 10

↓

Multiply the result for each region by the average vehicle speed, to give the amount of time spent in that region per trip

↓

Multiply the result for each region by the average number of trips per person per year, to give the amount of time a person would spend in that region each year

↓

Divide the result for each region by the number of hours in a year, to give the annual fraction of time a person would spend in that region

↓

Multiply the result for each region by the location-specific risk, as defined in Table 10, to give the annual risk for a person passing through that region

↓

Add the risks across all regions to give the overall risk of death per person per year for the entire road

Figure 3 Steps involved in estimating the individual risk of death caused by blade throw from the Project for people travelling on Mount Hope Road

Determine the number of vehicles travelling on that road in a year, based on the average daily traffic volumes

↓

Multiply the result by the average number of people per vehicle, to give the total number of trips made by all people on that road in a year

↓

Divide the risk of death per person per year (evaluated using the steps outlined in Figure 3) by the avearge number of trips per person per year, to give the risk of death per trip

↓

Multiply the risk of death per trip by the total number of trips made by all people on that road in a year, to give the total expected number of deaths per year

Figure 4 Steps involved in estimating the societal risk of death caused by blade throw from the Project for people travelling on Mount Hope Road

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About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analysing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

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