



BALDON WIND FARM

# Blade Throw Assessment

Baldon Wind Farm Pty Ltd, care of Goldwind Australia Pty Ltd

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## 1 INTRODUCTION

Baldon Wind Farm Pty Ltd, care of Goldwind Australia Pty Ltd (“the Customer”) has commissioned DNV to assess the potential blade throw risks in the vicinity of the proposed Baldon Wind Farm (“the Project”) in New South Wales.

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. DNV notes that the risks posed by a blade throw incident potentially causing damage to existing electrical transmission infrastructure in the vicinity of the Project, or to infrastructure proposed to be constructed as part of the Project, have not been considered in this assessment.

## 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) for the Project [9] specify that the EIS 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 any 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 180 wind turbines with a rotor diameter of 245 m and tip height of 300 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 Customer 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 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] |   |
| <i>Detachment and throw of entire blade or large portion of blade</i>        |  |  |   |
| All operating conditions <sup>1</sup>  | $6.3 \times 10^{-4}$   | $6.3 \times 10^{-4}$                         | $8.4 \times 10^{-4}$<br>(1 incident per year per 1,190 turbines)  |
| Normal operating conditions (rated rotor speed) <sup>2</sup>                 | $3.1 \times 10^{-4}$   | $6.2 \times 10^{-4}$                         | $8.4 \times 10^{-4}$<br>(1 incident per year per 1,190 turbines)  |
| Mechanical braking conditions (1.5 times the rated rotor speed) <sup>2</sup> | $3.1 \times 10^{-4}$   | Included with normal operating conditions    | Not applicable to modern turbines   |
| Overspeed conditions (2 times the rated rotor speed) <sup>3</sup>            | Less than $5.0 \times 10^{-6}$                                     | Less than $5.0 \times 10^{-6}$               | $5.0 \times 10^{-6}$<br>(1 incident per year per 200,000 turbines)  |
| <i>Detachment and throw of blade tip or other small blade fragment</i>       |  |  |   |
| All operating conditions <sup>1</sup>  | $1.2 \times 10^{-4}$   | Not explicitly considered                    | $2.6 \times 10^{-4}$ [2]<br>(1 incident per year per 3,846 turbines)  |
| Overspeed conditions (2 times the rated rotor speed) <sup>3</sup>            | Less than $5.0 \times 10^{-6}$                                     | Not explicitly considered                    | $5.0 \times 10^{-6}$ [2]<br>(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  $6.3 \times 10^{-4}$ . 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  $3.5 \times 10^{-4}$  incidents per turbine per year (1 incident per

year per 2,857 turbines) in 2001-2005 to less than  $2.5 \times 10^{-4}$  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 3674 wind turbines installed and operating in Australia, 863 of which are located in New South Wales [16]. For this number of turbines, based on the conservative blade throw frequency of  $8.4 \times 10^{-4}$  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 New South Wales could be expected to occur in a year. If the conservative frequency of a blade fragment being thrown is also considered (being  $2.6 \times 10^{-4}$  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 since 2005, which was last updated in early 2023, based on 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 2024 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 1837. Based on the conservative blade throw frequencies of  $8.4 \times 10^{-4}$  incidents per turbine per year (1 incident per year per 1,190 turbines) for an entire blade and  $2.6 \times 10^{-4}$  incidents per turbine per year (1 incident per year per 3,846 turbines) for a blade fragment, it is expected that up to 40 blade throw incidents could have occurred in Australia in the 19-year period from 2005 to 2024. To DNV's knowledge, the actual number of blade throw incidents recorded in Australia since 2005 is notably less than 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

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

and could be closer to  $2.5 \times 10^{-4}$  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 180 turbines proposed to be installed at the Project, it is expected that one blade throw incident could occur approximately every 7 to 21 years on average. Although this indicates that one blade throw incident could 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  $8.4 \times 10^{-4}$  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 will 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 <i>et al.</i> [8] | Entire blade, 20% of entire blade by weight                                       | 47                          | 73.5             | 70.0               | 210 <sup>1</sup>           | 520 <sup>1</sup> |
|                          |   | 70                          | 115.0            | 80.5               | 260 <sup>1</sup>           | 750 <sup>1</sup> |
|                          |   | 90                          | 125.0            | 76.1               | 240 <sup>1</sup>           | 550 <sup>1</sup> |
| Cotton [13]              | Entire blade, 10% of entire blade by weight                                       | 90                          | 110.0            | 65.0               | 185 <sup>2</sup>           | 861 <sup>2</sup> |
| 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 <sup>3</sup>  | 140 <sup>1</sup>           | 450 <sup>1</sup> |
|                          |   | 147                         | 220.5            | 70.0 <sup>3</sup>  | 180 <sup>1</sup>           | 500 <sup>1</sup> |
|                          |   | 208                         | 312.0            | 70.0 <sup>3</sup>  | 200 <sup>1</sup>           | 580 <sup>1</sup> |
|                          |   | 294                         | 441.0            | 70.0 <sup>3</sup>  | 210 <sup>1</sup>           | 610 <sup>1</sup> |
|                          |   | 100                         | 150.0            | 100.0 <sup>4</sup> | 200 <sup>1</sup>           | 510 <sup>1</sup> |
|                          |   | 147                         | 220.5            | 100.0 <sup>4</sup> | 220 <sup>1</sup>           | 860 <sup>1</sup> |
|                          |   | 208                         | 312.0            | 100.0 <sup>4</sup> | 250 <sup>1</sup>           | 930 <sup>1</sup> |
| 294                      | 441.0   | 100.0 <sup>4</sup>          | 300 <sup>1</sup> | 1000 <sup>1</sup>  |                            |                  |

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 <sup>1</sup>           | 886 <sup>1</sup>  |
| 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                        | -                 |
| Sarлак & Sørensen [4]   | Entire blade, 20% of entire blade by length                                       | 100                         | 150.0          | 150.0           | 390 <sup>2</sup>           | 780 <sup>2</sup>  |
|                         |   | 147                         | 220.5          | 150.0           | 450 <sup>2</sup>           | 1450 <sup>2</sup> |
|                         |   | 208                         | 312.0          | 150.0           | 480 <sup>2</sup>           | 1800 <sup>2</sup> |
|                         |   | 294                         | 441.0          | 150.0           | 500 <sup>2</sup>           | 2000 <sup>2</sup> |

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 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  $8.4 \times 10^{-4}$  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 | 245          | 300            | Not Specified                                     |

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 distances in the order of 480 m for an entire blade or 1800 m for a blade fragment. For the high-level blade throw risk assessment presented in Section 4, a slightly larger maximum throw distance of 1886 m for a blade fragment under overspeed conditions has been used to account for the larger turbine dimensions under consideration for the Project compared to the dimensions modelled by Sarlak and Sørensen.

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 frequency at which those scenarios are expected to occur [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 <sup>-5</sup> per year (1-in-100,000)   | 10 <sup>-6</sup> per year (1-in-1 million) |
| 141                         | 190.5          | 120            | 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<sup>-12</sup> 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 x 10 <sup>-4</sup> (1-in-6,667)  |  |
| Death on Australian roads, per head of population (2022 data) [18]   |                                      |  |
| - Nationally   | 4.6 x 10 <sup>-5</sup> (1-in-21,739) |  |
| - Inner regional areas   | 7.5 x 10 <sup>-5</sup> (1-in-13,333) |  |
| - Outer regional areas   | 1.26 x 10 <sup>-4</sup> (1-in-7,936) |  |
| Death due to lightning strike, per head of population (1980-1989 data) [19]  | 10 <sup>-7</sup> (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] | <i>continuously for a year</i>       | <i>continuously for one working day per year (8 hours)</i> |
| - distance equal to half the turbine rotor diameter  | 10 <sup>-5</sup> (1-in-100,000)      | 10 <sup>-8</sup> (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 <sup>-6</sup> (1-in-1 million)    | 10 <sup>-9</sup> (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]**

| Consequence to people               | Likelihood of risk occurring |  |  |   |   |  |
|-------------------------------------|------------------------------|--|--|---|---|--|
|                                     | “Frequent”                   | “Reasonably probable”                          | “Occasional”   | “Remote”  | “Extremely remote”  | “Improbable”   |
|                                     | 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 <sup>-4</sup> per year (1-in-10,000) | Less than 10 <sup>-4</sup> per year (1-in-10,000) to 10 <sup>-6</sup> per year (1-in-1 million) | Less than 10 <sup>-6</sup> 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 122.5 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 122.5 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 300 m is greater 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. 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 300 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 New South Wales, 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 <sup>-6</sup> per year (1-in-1 million)<br>"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 <sup>-6</sup> per year (1-in-1 million)<br>"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 <sup>-5</sup> per year (1-in-100,000)<br>"Extremely remote" likelihood and "low" risk              |
| National roads under the jurisdiction of the Dutch Ministry for Infrastructure and Water Management <sup>1</sup> | Individual risk          | 10 <sup>-6</sup> per person per year (1-in-1 million)<br>"Extremely remote" likelihood and "low" risk |
|  | Societal risk            | 2 x 10 <sup>-3</sup> persons per year (one death every 500 years) <sup>2</sup>                        |

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 1 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 1 also shows regions around the proposed turbine locations at distances equal to:

- 122.5 m, corresponding to half the turbine rotor diameter and hence the distance at which the location-specific risk is 10<sup>-5</sup> per year (1-in-100,000) based on the guidance in the Dutch Handbook
- 300 m, corresponding to the turbine tip height (which is larger than the expected maximum throw distance for an entire blade under normal operating conditions at the maximum rated rotor speed for similarly-sized turbines, as discussed in Section 3.3.3) and hence the distance at which the location-specific risk is 10<sup>-6</sup> per year (1-in-1 million) based on the guidance in the Dutch Handbook
- 1886 m, corresponding to the expected maximum theoretical blade throw distance for a blade fragment under overspeed conditions 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<sup>-12</sup> per year (1-in-1 trillion).

Distances between the proposed turbine locations and existing dwellings or other sensitive locations within 1886 m of turbines at the Project are given in Table 9.

**Table 9 Dwellings and other sensitive locations within 1886 m of the proposed turbine locations for the Project**

| Building ID <sup>1</sup> | Easting <sup>2</sup> [m] | Northing <sup>2</sup> [m] | Nearest turbine ID | Distance to nearest turbine [m] |
|--------------------------|--------------------------|---------------------------|--------------------|---------------------------------|
| Shed <sup>3</sup>        | 223613                   | 6133424                   | 115                | 696                             |
| R21                      | 223630                   | 6133581                   | 115                | 855                             |
| R14                      | 236374                   | 6147851                   | 56                 | 955                             |
| R23                      | 233544                   | 6131027                   | 162                | 1228                            |
| R22                      | 233092                   | 6131248                   | 138                | 1247                            |

1. All dwellings featured in this table are associated with the Project. Additionally, the Customer has advised that all dwellings featured in this table are uninhabited and derelict or demolished.
2. Coordinate system: MGA zone 55, GDA94.
3. The Customer has advised that this property is a shearing shed, which is affiliated with associated dwelling R21 [20].

#### 4.3.1 Blade throw risks at dwellings and other sensitive locations

Figure 1 and Table 9 show that there are no dwellings or other sensitive locations within 300 m of the proposed turbine locations. All dwellings are more than 696 m from the nearest proposed turbine location, which is 396 m beyond the expected maximum throw distance for an entire blade under normal operating conditions at the maximum rotor speed (being 300 m as discussed in Section 3.2.2). At distances of 696 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 1 shows that there are no neighbouring properties located within the expected maximum throw distance for an entire blade under normal operating conditions at the maximum rotor speed, or 300 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  $10^{-6}$  per year (1-in-1 million). 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 “improbable” likelihood and “routine” risk using the NREL risk classification shown in Table 7.

#### 4.3.3 Blade throw risks on nearby roads

Figure 1 shows that there are no roads located within half the turbine rotor diameter, or 122.5 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 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 Sturt Highway passing within 1886 m of the proposed turbine locations as shown in Figure 1. Sturt Highway was chosen for this review as it is a major primary road and is the only primary, arterial or sub-arterial road that passes through the Project site boundary. Although there are several minor roads that pass close to the proposed turbine locations within the Project boundary, DNV understands that these roads are seldom used and (with the exception of Baldon Road, which crosses the southeast corner of the site and has an estimated traffic volume of less than 15 vehicles per day [21]) are locked at the Project boundary. Therefore, DNV expects the blade throw risks for Sturt Highway 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 Sturt Highway was evaluated according to the steps outlined in Figure 2, based on the following assumptions:

- The location-specific risk at all points in the region between 122.5 m and 300 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 300 m and 1886 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 90 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 will 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. This is expected to be a conservative assumption, as DNV understands that vehicles travelling on this section of the Sturt Highway are predominantly trucks or people passing through the area rather than daily commuters.
- 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 will depend 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 2.

**Table 10 Location-specific risk assumptions used to estimate the individual and societal blade throw risks for people travelling on nearby roads**

| 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 122.5 m      | Greater than $10^{-5}$ per year (1-in-100,000)  | Not applicable – no roads located within this distance       |
| 122.5 m to 300 m       | Varies from $10^{-5}$ per year (1-in-100,000) at 122.5 m to $10^{-6}$ per year (1-in-1 million) at 300 m                  | $10^{-5}$ per year (1-in-100,000) throughout entire region   |
| 300 m to 1886 m        | Varies from $10^{-6}$ per year (1-in-1 million) at 300 m to approximately $10^{-12}$ per year (1-in-1 trillion) at 1886 m | $10^{-6}$ per year (1-in-1 million) throughout entire region |

According to this analysis, the individual risk along Sturt Highway for death caused by a blade throw incident is  $9.22 \times 10^{-9}$  per person per year (1-in-108 million). This is approximately 108 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 volumes on Sturt Highway have been estimated at approximately 896 vehicles per day [22]. Based on this estimated traffic volume, 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 3. The societal risk on Sturt Highway is  $8.26 \times 10^{-6}$  deaths per year, or one death every 121,015 years, which is approximately 242 times less than the limit identified as acceptable in the Dutch Handbook and shown in Table 8 ( $2 \times 10^{-3}$  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 much lower traffic volumes expected on those roads.

#### 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**

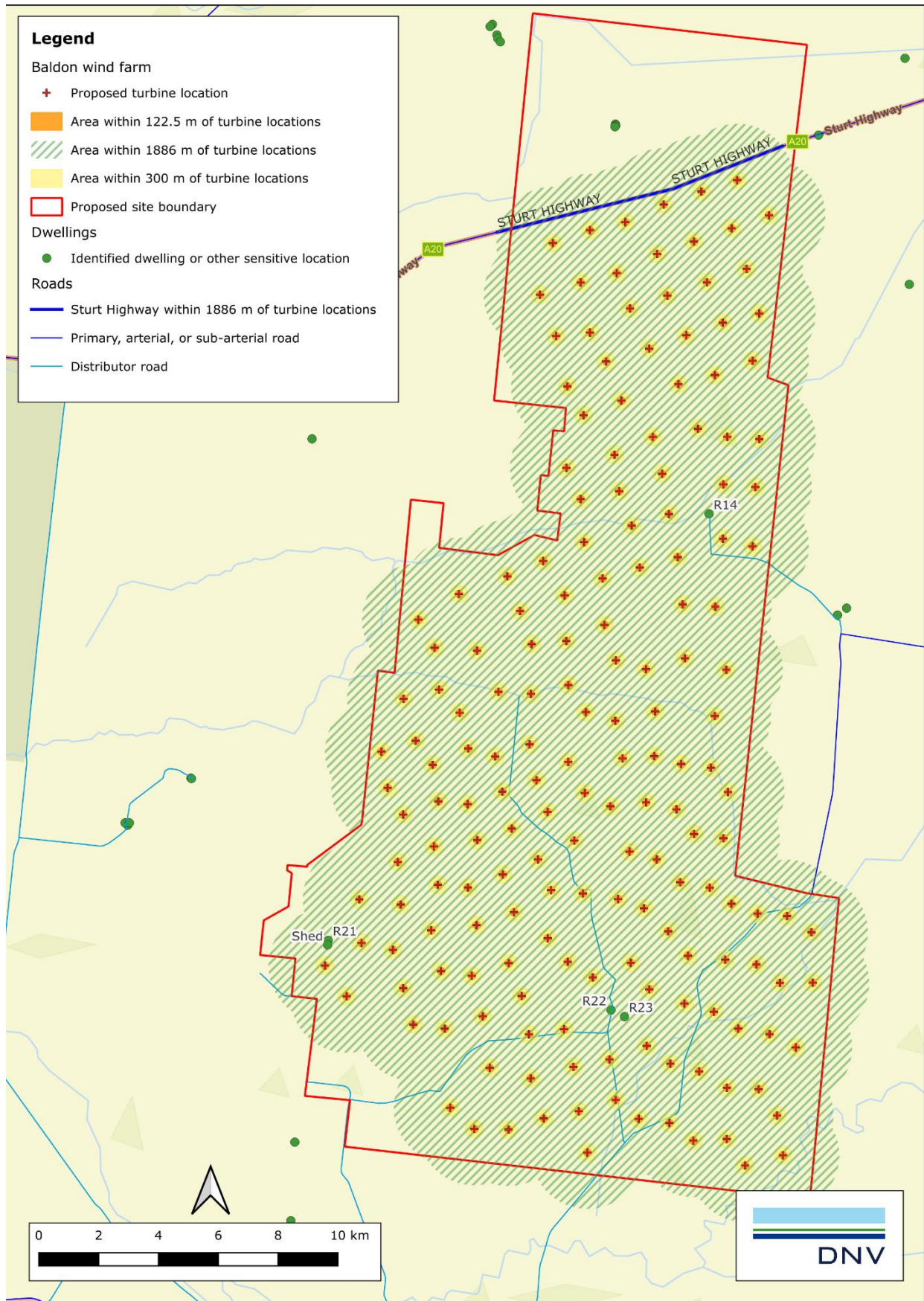
| Risk category   | Blade throw risk evaluated for the Project and corresponding NREL risk classification [12]   | Blade throw risk limit presented in the Dutch Handbook [1]      | Existing risk  |
|---|--|---|--|
| <i>At dwellings and other sensitive locations such as schools and childcare facilities</i>                                      |  |   |  |
| 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)                             | -  |
| <i>At neighbouring properties</i>   |  |   |  |
| Location-specific risk (for an unprotected person remaining at a fixed location for a whole year)                               | Less than $10^{-6}$ per year (1-in-1 million) "Improbable" likelihood and "routine" risk   | -   | Risk of death for people working in agriculture in Australia:<br>$1.5 \times 10^{-4}$ per year (1-in-6,667)  |
| <i>For road users on Sturt Highway (representing the worst-case scenario for all road users in the vicinity of the Project)</i> |  |   |  |
| Individual risk (for a typical person travelling on that section of road)   | $9.22 \times 10^{-9}$ per person per year (1-in-108 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:<br>$4.6 \times 10^{-5}$ per year (1-in-21,739) |
| Societal risk (total number of people at risk)  | $8.26 \times 10^{-6}$ persons per year (one death every 121,015 years) <sup>1</sup>  | $2 \times 10^{-3}$ 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.

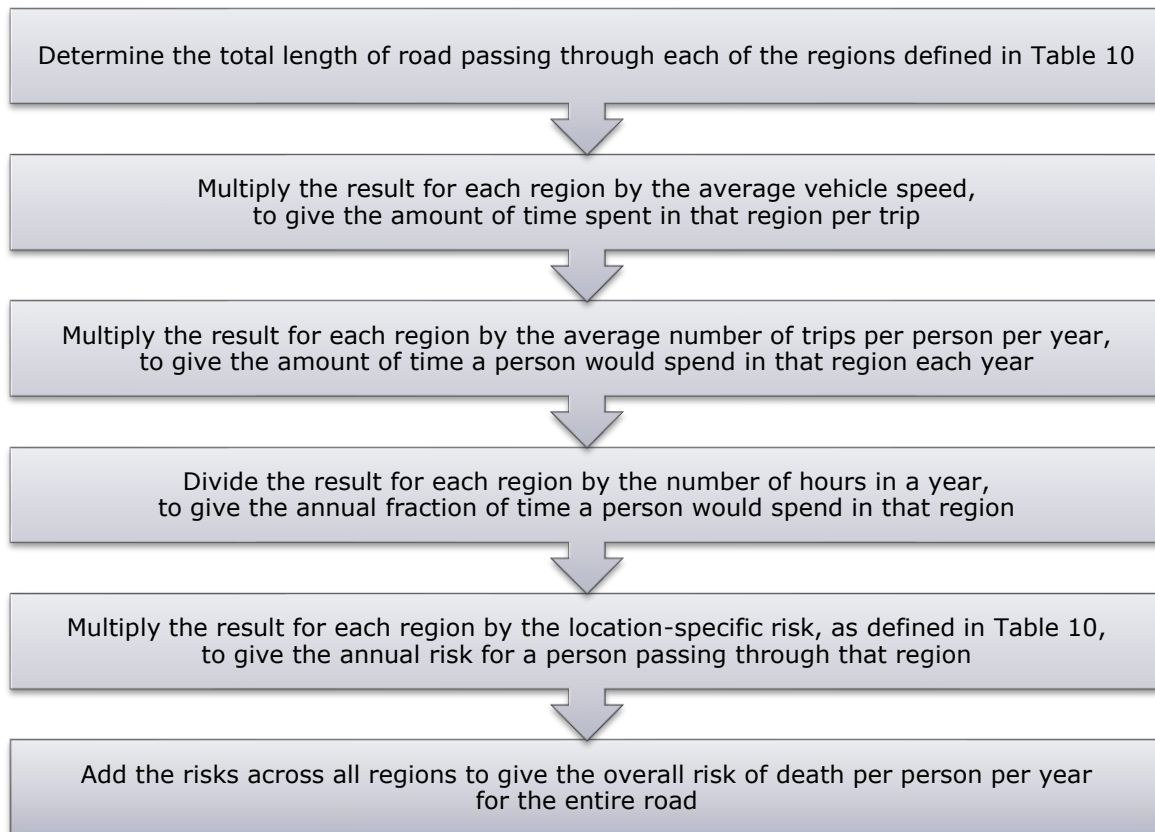
## 5 CONCLUSIONS

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.

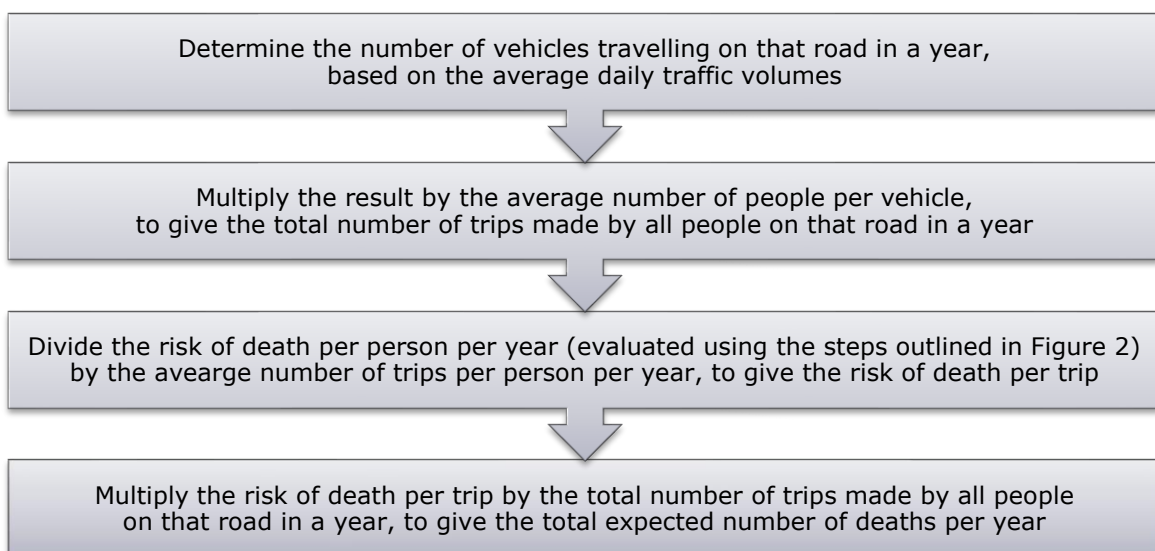
Based on a conservative assessment methodology and assumptions, DNV has evaluated the risks of death caused by a blade throw incident at dwellings, roads, and neighbouring properties in the vicinity of the Project. The results show that the potential risks are at least 108 times less than the blade throw 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 1 Locations of nearby dwellings and other sensitive locations, properties, and roads in relation to the proposed Project**



**Figure 2 Steps involved in estimating the individual risk of death caused by blade throw from the Project for people travelling on nearby roads**



**Figure 3 Steps involved in estimating the societal risk of death caused by blade throw from the Project for people travelling on nearby roads**

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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.

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