# Blade Throw Risk Assessment

## Macorna Wind Farm

### Macorna SPV – Atmos MWV Pty Ltd

Prepared by:

**SLR Consulting Australia Pty Ltd**

SLR Project No.: 640.031876.00003

Revision: R02-v0.4

22 April 2026

## Revision Record

| Revision | Date | Prepared By | Checked By | Authorised By |
|---|---|---|---|---|
| R02-v0.4 | 22 April 2026 | Dr Peter Georgiou | Peter Hayman | Draft |
| R02-v0.4 | 17 April 2026 | Dr Peter Georgiou | Peter Hayman | Draft |
| R02-v0.2 | 20 February 2026 | Dr Peter Georgiou | Peter Hayman | Draft |
| R02-v0.4 | 18 February 2026 | Dr Peter Georgiou | Peter Hayman | Draft |
| | Click to enter a date. | | | |

# Basis of Report

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Macorna SPV – Atmos MWV Pty Ltd (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of the Client. No warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR.

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

# Executive Summary

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Macorna SPV – Atmos MWV Pty Ltd as trustee for the Atmos MHV Trust (the Client) to carry out a Blade Throw Risk Assessment for the proposed Macorna Wind Farm.

The assessment has reviewed the risks associated with both:

- A Blade Throw – Whole of Blade event; and
- A Blade Throw – Fragment of Blade event.

The assessment has determined potential risks in relation to the nearest sensitive receptors to the Project, comprising dwellings, carriageways (road and rail) and agricultural workers.

### Criteria

The acceptable risk limits used in this study are as follows (refer **Section 7.1** for background to the adopted risk criteria):

- Dwellings $1 \times 10^{-6}$ (risk to the dwelling)
- Agricultural Worker $1 \times 10^{-6}$ (risk to the individual)
- Road/Rail $1 \times 10^{-6}$ (risk to an individual)

### Outcomes of the Assessment

**Dwellings (worst-case risk for dwelling closest to any WTG)**

- Worst-case Risk Level: $6 \times 10^{-9}$

**Road Traffic – Major Roads (Loddon Valley Highway)**

- Worst-case Risk Level: $1 \times 10^{-9}$

**Road Traffic – Minor Roads (worst-case risk for closest minor roads to any WTG)**

- Worst-case Risk Level: $7.6 \times 10^{-8}$

**Yungera Rail Line (worst-case risk for nearest WTGs)**

- Worst-case Risk Level: $4.7 \times 10^{-10}$

**Agricultural Workers**

- Worst-case Risk Level: $1.7 \times 10^{-7}$

All Risk Levels are below the target (acceptable) risk of $1 \times 10^{-6}$
( 1 event per 1,000,000 years )

## Conclusion

On the basis of the above, the Blade Throw Risk Assessment has concluded that no mitigation will be required (eg re-positioning of any WTGs) to address the potential impact of a blade throw event from the Project.

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# Acronyms and Abbreviations

| | |
|---|---|
| BESS | Battery Energy Storage System |
| BoM | Bureau of Meteorology |
| BTRA | Blade Throw Risk Assessment |
| BT-f | Blade Throw – Fragment (of blade) |
| BT-w | Blade Throw – Whole (of blade) |
| EPA | Environment Protection Authority |
| HV | High Voltage |
| LGA | Local Government Area |
| LV | Low Voltage |
| MV | Medium Voltage |
| OSOM | Oversize Overmass |
| REZ | Renewable Energy Zone |
| SLR | SLR Consulting Australia Pty Ltd |
| VNI | Victoria to NSW Interconnector |
| WTG | Wind Turbine Generator |

# Units

| | |
|---|---|
| ha | Hectare ( 10,000 $m^2$ ) |
| km | Kilometre ( = 1,000 m ) |
| kV | Kilovolt ( = 1,000 volts ) |
| m | Metre |
| MW | Megawatt ( = $1x10^6$ watts ) |
| MWh | Megawatt-hour |
| rpm | Revolutions per Minute |
| W | Watt |

# 1.0 Introduction

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Macorna SPV – Atmos MWV Pty Ltd as trustee for the Atmos MHV Trust (the Client) to carry out a Blade Throw Risk Assessment (BTRA) for the proposed Macorna Wind Farm (the Project) within a land development area around the town of Macorna, Victoria.

The Project will comprise up to 114 wind turbine generators (WTGs) with a combined nameplate capacity of approximately 820.8 Megawatts (MW).

- The WTG model is anticipated to be a Vestas V172-7.2 MW unit, or similar.
- The Vestas V172-7.2 MW unit has a hub height of up to 166 metres (m) and a maximum blade tip height of approximately 252 m above ground level.

The focus of this assessment is to establish the likely impact zone of both Blade Throw – Whole of Blade (BT-w) and Blade Throw – Fragment of Blade (BT-f) events and potential risks in relation to the nearest sensitive receptors to the Project, comprising residential dwellings and surrounding carriageways (road and rail).

This assessment has been prepared to support the Project's Environment Effects Statement (EES) referral and associated planning and environmental approval processes.

## 1.1 Structure of Report

The remainder of this report is structured as follows:

| | |
|---|---|
| **Section 2** | Project description |
| **Section 3** | Risk assessment inputs |
| **Section 4** | Assessment methodology |
| **Section 5** | Blade throw failure rates |
| **Section 6** | Risk calculations |
| **Section 7** | Risk assessment |
| **Section 8** | Conclusions |
| **Section 9** | References |

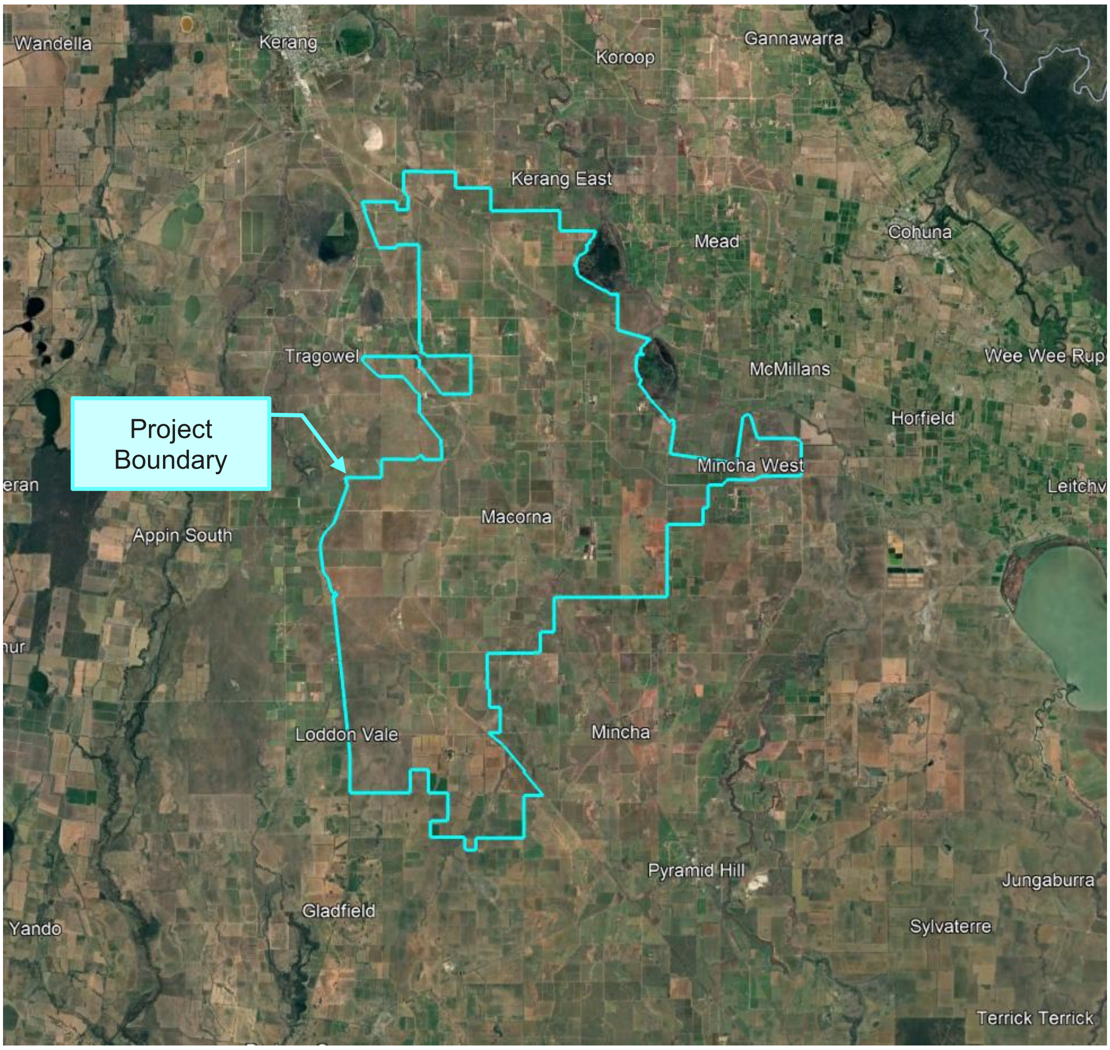
# 2.0 Description of the Project

## 2.1 Site Location

The Project is located within the Gannawarra and Loddon Shire Local Government Areas (LGAs), in the Loddon Mallee region of Victoria – refer **Figure 1**.

- The Project Area covers approximately 23,000 hectares (ha), across approximately 26 landholdings, with an expected development or construction footprint of 750 ha.
- The Project Area encompasses land within or near the localities of Macorna, Macorna North, Loddon Vale, Tragowel and Mincha West.
- The Project Area is located within the Draft North West Renewable Energy Zone (REZ) identified in the Victorian Transmission Plan.
- The landscape is generally flat and largely cleared of native vegetation, with small pockets of remnant vegetation remaining.

**Figure 1 Project Location**



## 2.2 Project Key Elements

The Project will consist of the following elements:

- Up to 114 WTGs.
- Up to seven permanent meteorological masts.
- Potential communications towers.
- Up to four collector substations located within the Project Area.
- Underground low voltage (LV) and medium voltage (MV) cabling connecting the WTGs to the collector substations.
- Internal overhead 500 kV transmission lines connecting the collector substations to the grid connection point at the nearby proposed Tragowel Victoria to NSW Interconnector (VNI) West substation.
- A 250 MW/500 MWh Battery Energy Storage System (BESS) facility.
- Access tracks within the project area and upgrades to the proposed transport access route, as required.
- A temporary batching plant to supply concrete and construction workers' accommodation facility.

## 2.3 Representative WTG Model

This BTRA has been based on a WTG turbine geometry representative of the likely chosen WTG with the "worst-case" geometrical properties from a blade throw point of view (eg highest hub height).

The likely Project WTG is the Vestas V172-7.2 – refer **Table 1**.

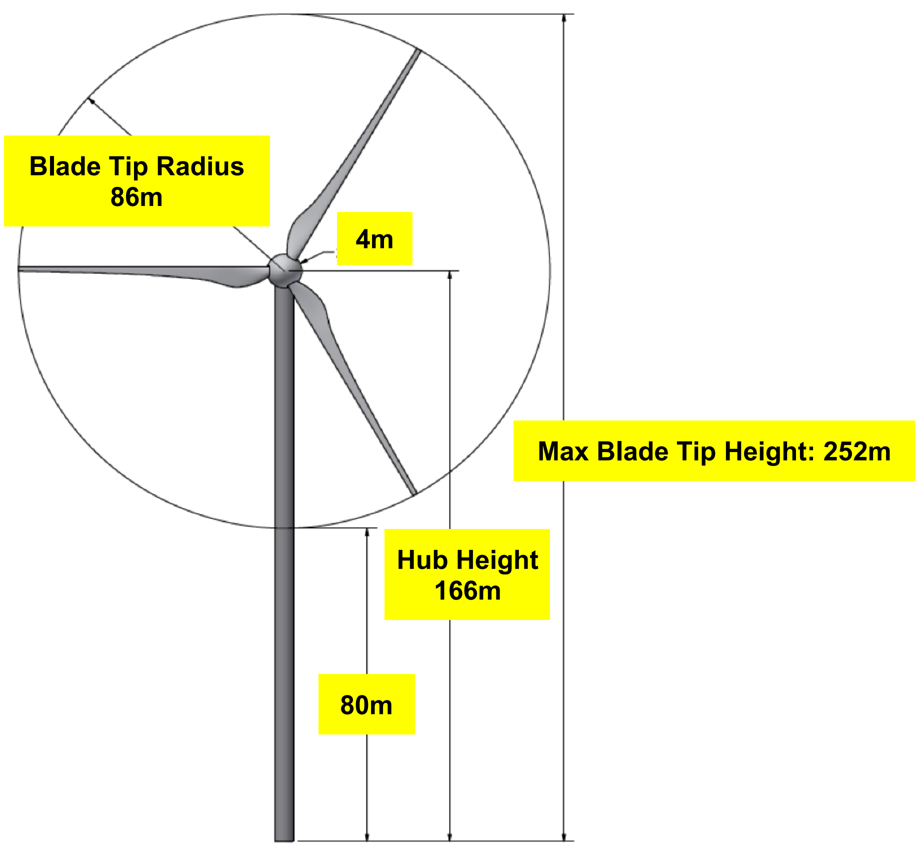
**Table 1 Representative WTG Details**

| Parameter | Representative Characteristics |
|---|---|
| Make model | Vestas V172-7.2 |
| Rated power | 7.2 MW |
| Hub height | Up to 166 m: **166 m** chosen for this study |
| Blade length | **86 m** |
| Rotor diameter | **172 m** |
| Maximum blade tip height | **252 m** |
| Cut-in / Cut-out wind speeds | 3 m/s / 25 m/s |
| Representative Rotor Speed | 10 rpm |
| Rotor swept area | 23,235 $m^2$ |
| Wind class | IEC S |

The likely Project representative WTG shown in **Figure 2** comprises the following:

- Foundation – in-ground mass concrete to support the WTG.
- Tower – a tapered steel support column.
- Rotor Hub and Nacelle – the nacelle houses the generator as well as other components and is attached to the rotor hub. The nacelle and hub can rotate to face the wind direction with the hub to the front and the nacelle to the rear.
- Blades – three blades attached to the rotor hub forming the rotor swept area.

**Figure 2 Key BTRA WTG Geometry Parameters**



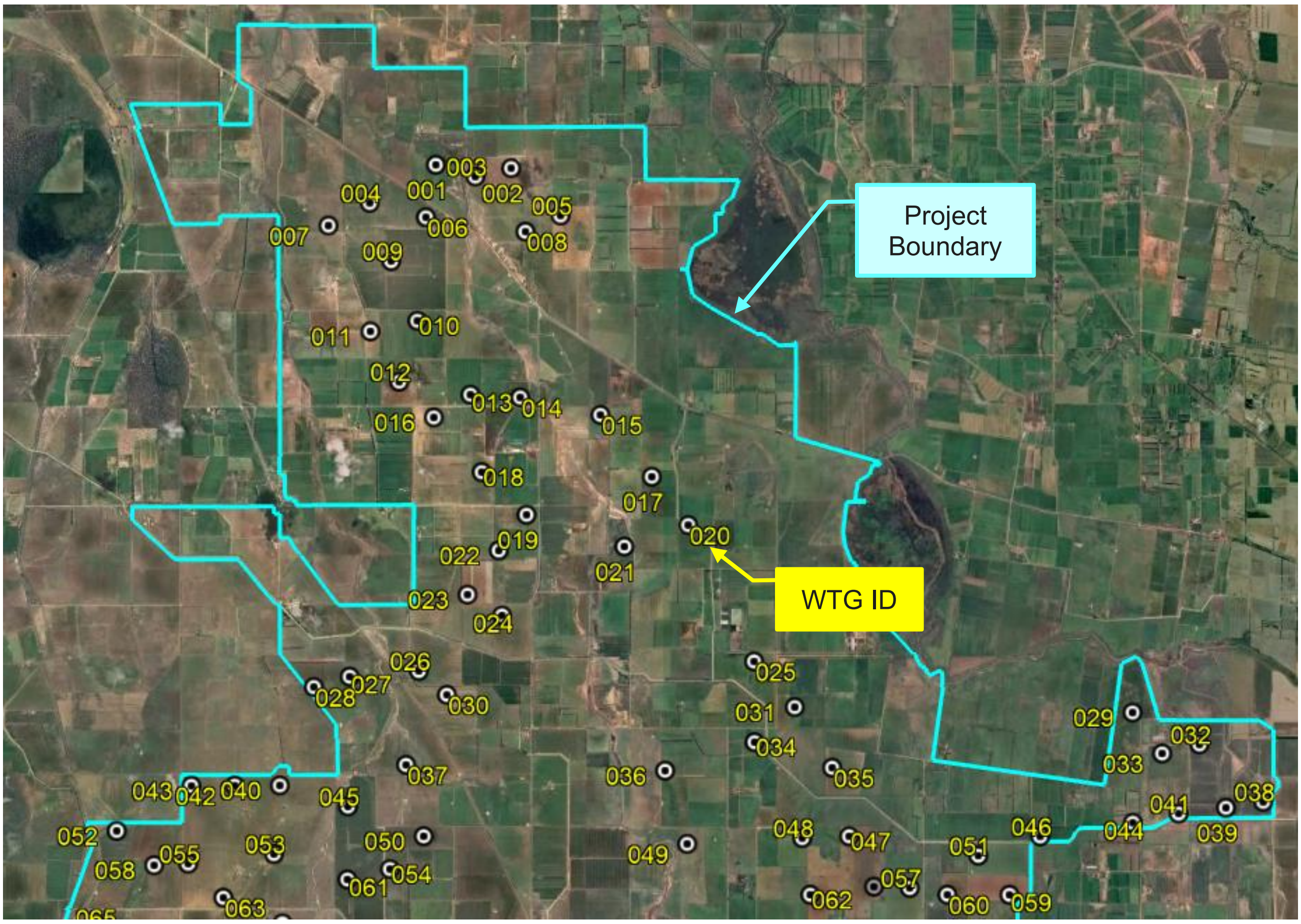
# 3.0 Blade Throw Risk Assessment Inputs

## 3.1 Concept WTG Layout

The concept turbine layout analysed in this BTRA is shown in **Figure 3**.

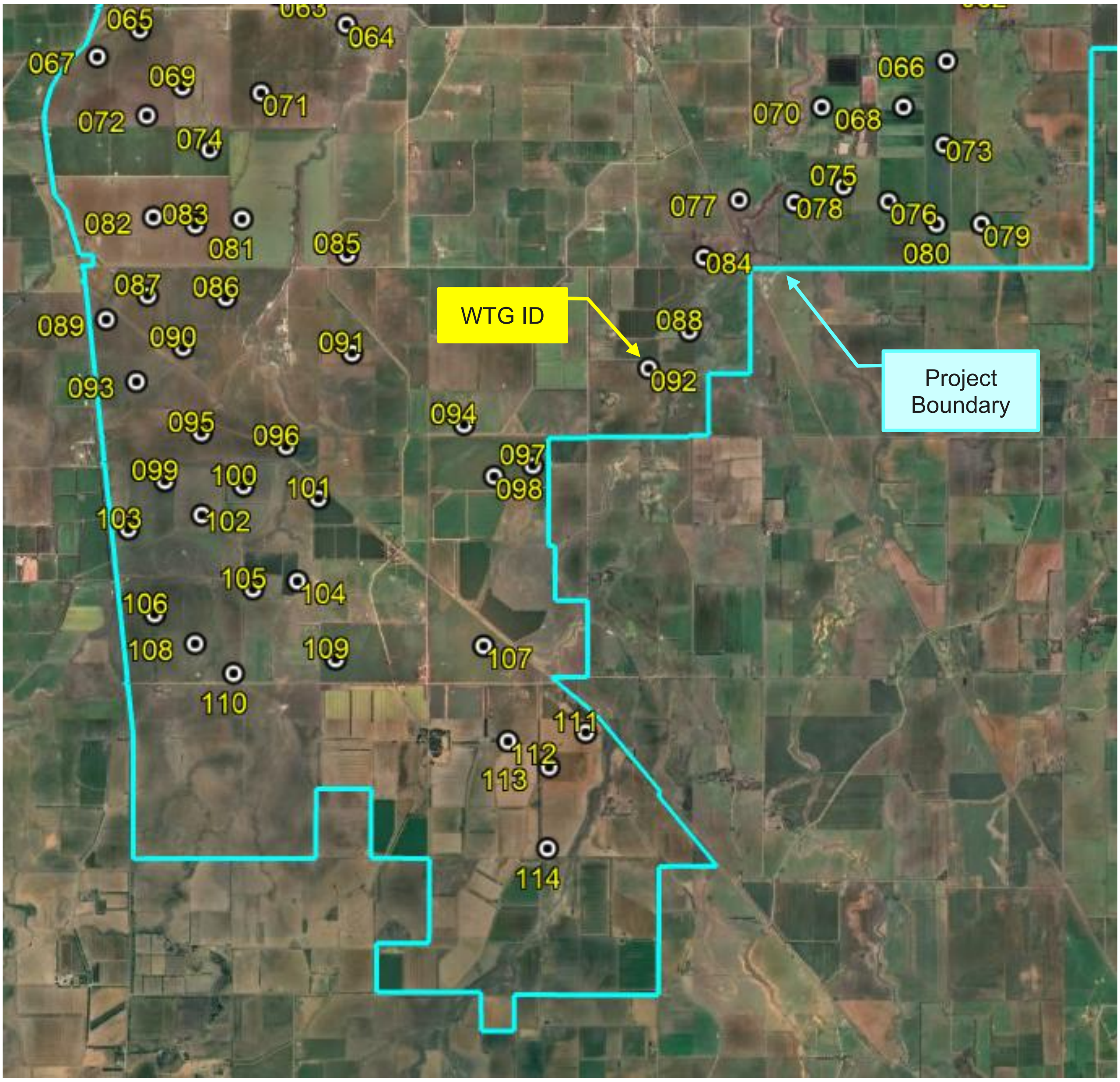
**Figure 3 Site Concept Turbine Layout**

Northern WTGs ( Nos 1-63 )



( Fig.3 cont'd )

**Southern WTGs ( Nos 64-114 )**

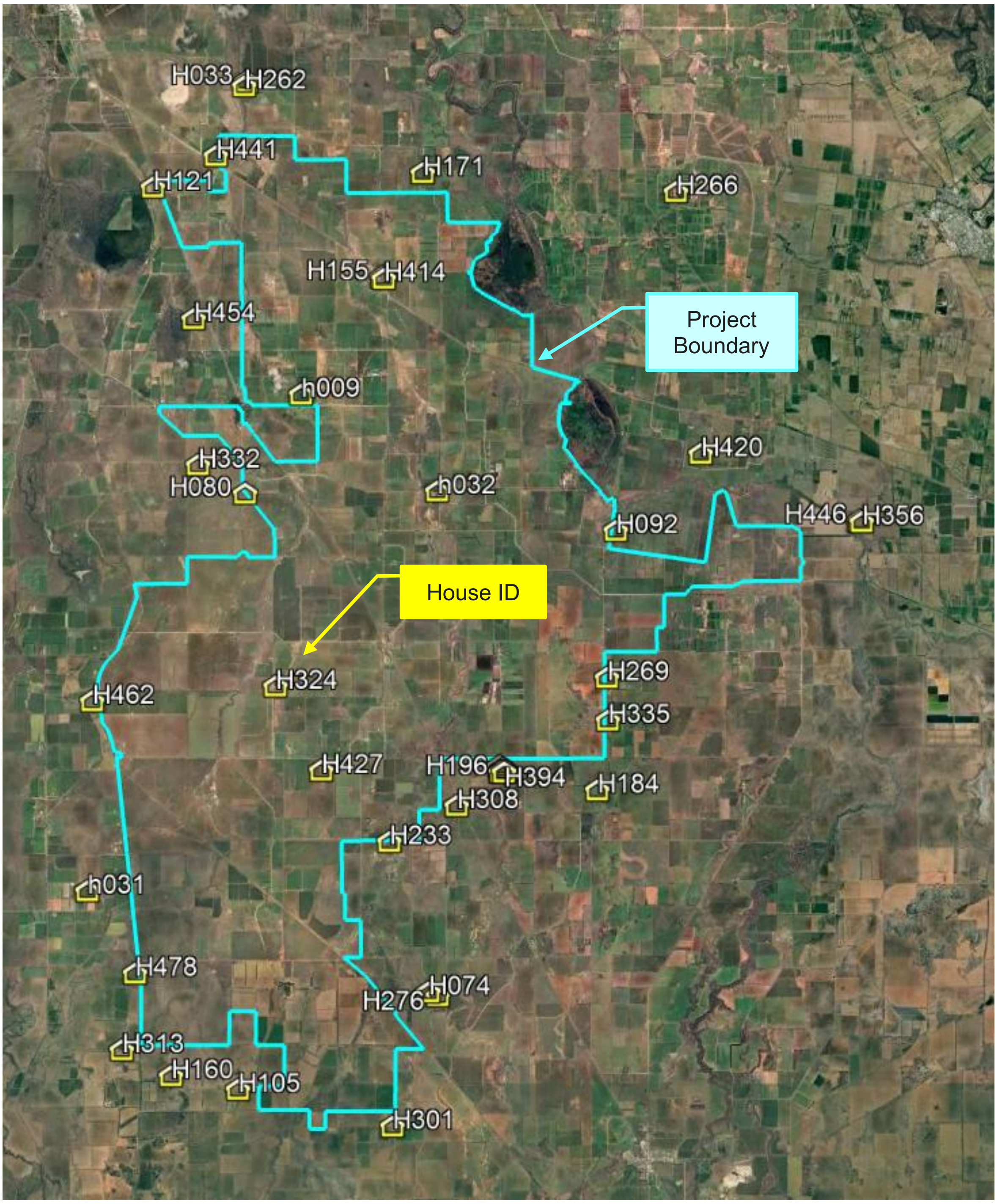


## 3.2 Nearest Sensitive Receptors

### 3.2.1 Dwellings

The nearest dwelling to each WTG (refer **Figure 4)** has been considered in this BTRA. Compliance in relation to blade throw for these dwellings would automatically ensure compliance with other dwellings a further distance away. It is noted that there are multiple WTGs that have the same corresponding nearest dwelling (refer **Table 2)**.

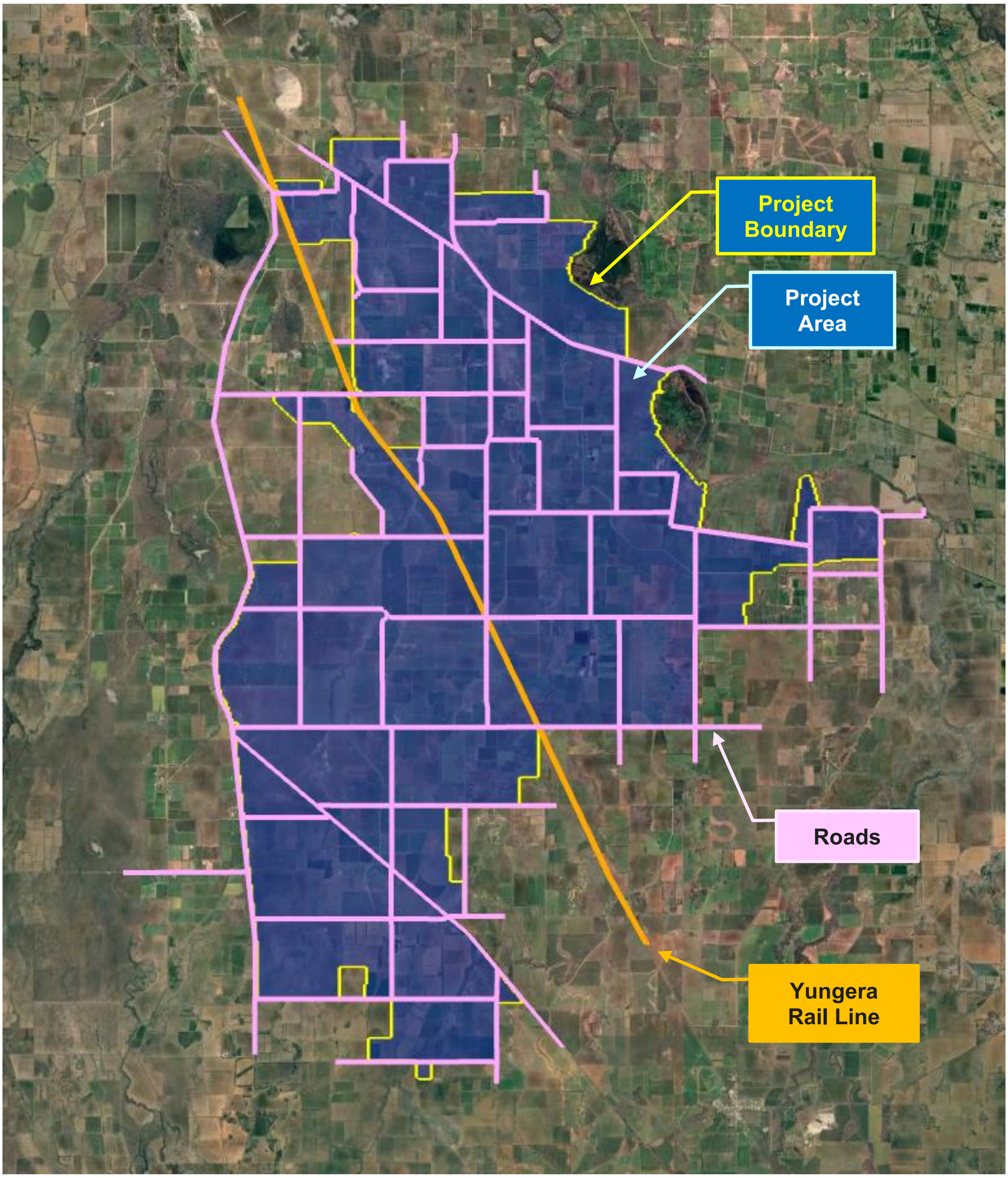
**Figure 4 Nearest Assessed Dwellings**



### 3.2.2 Nearest Carriageways

The roadways (shown in lilac) and the Yungera Rail Line (shown in orange) assessed in this BTRA are shown in **Figure 5**.

**Figure 5 Nearest Roadways and Rail Line**



## 3.3 Relationship of WTG Locations to Nearest Receptors

### 3.3.1 Distances from WTGs to Nearest Dwellings

The distances of the assessed dwellings to the nearest WTG are shown in **Table 2**. They range from 500 m (dwelling H080 & WTG028) to 4,710 m (dwelling H441 & WTG007).

**Table 2 WTG to Nearest Dwelling Separation Distances**

| Dwelling Identifier | Nearest WTG | Separation Distance (m) | Dwelling Identifier | Nearest WTG | Separation Distance (m) |
|---|---|---|---|---|---|
| H009 | 18 | 1,730 | H262 | 1 | 4,180 |
| H031 | 103 | 1,640 | H269 | 79 | 2,100 |
| H032 | 36 | 1,560 | H276 | 111 | 2,410 |
| H033 | 1 | 4,190 | H301 | 114 | 3,310 |
| H074 | 111 | 2,060 | H308 | 88 | 1,640 |
| H080 [1] | 28 | 500 | H313 | 110 | 3,770 |
| H081 | 80 | 1,670 | H324 | 85 | 1,770 |
| H092 | 51 | 1,740 | H332 | 28 | 2,040 |
| H105 | 114 | 3,580 | H335 | 79 | 1,660 |
| H121 | 7 | 3,730 | H356 | 39 | 2,200 |
| H155 | 8 | 1,200 | H394 | 80 | 1,630 |
| H160 | 110 | 4,000 | H414 | 8 | 1,250 |
| H171 | 2 | 1,750 | H420 | 29 | 1,660 |
| H184 | 79 | 2,380 | H427 | 94 | 1,560 |
| H196 | 80 | 1,660 | H441 | 7 | 4,710 |
| H204 | 80 | 1,590 | H446 | 39 | 2,180 |
| H212 | 80 | 1,550 | H454 | 11 | 3,050 |
| H230 | 80 | 1,560 | H462 | 82 | 1,830 |
| H233 | 92 | 1,470 | H478 | 108 | 1,760 |

Note 1 SLR understands that dwelling H080 has been abandoned

## 3.4 Relationship of WTG Locations to Nearest Carriageways

### 3.4.1 Distances from WTGs to Nearest Road or Rail Line

The distances of all WTGs to the nearest road or rail line are shown in **Table 3**. The relevant carriageways are not identified in the table. They are addressed in detail in the following analysis sections. It is noted that Atmos has proposed minimum buffer distances of WTGs of:

- Railways & Major Roads - 300 m
- Minor Roads - 100 m

**Table 3 Separation Distance of WTGs to Nearest Road or Rail Line**

| WTG | Separation Distance (m) | WTG | Separation Distance (m) | WTG | Separation Distance (m) | WTG | Separation Distance (m) |
|---|---|---|---|---|---|---|---|
| 1 | 480 | 31 | 320 | 61 | 525 | 91 | 1,060 |
| 2 | 280 | 32 | 340 | 62 | 490 | 92 | 1,000 |
| 3 | 165 | 33 | 370 | 63 | 200 | 93 | 545 |
| 4 | 490 | 34 | 170 | 64 | 210 | 94 | 175 |
| 5 | 530 | 35 | 580 | 65 | 260 | 95 | 420 |
| 6 | 190 | 36 | 610 | 66 | 320 | 96 | 120 |
| 7 | 740 | 37 | 170 | 67 | 300 | 97 | 370 |
| 8 | 620 | 39 | 135 | 68 | 290 | 98 | 520 |
| 8 | 840 | 40 | 140 | 69 | 640 | 99 | 320 |
| 10 | 140 | 41 | 120 | 70 | 1,050 | 100 | 310 |
| 11 | 315 | 42 | 135 | 71 | 475 | 101 | 140 |
| 12 | 415 | 43 | 150 | 72 | 1150 | 102 | 635 |
| 13 | 205 | 44 | 125 | 73 | 285 | 103 | 305 |
| 14 | 160 | 44 | 110 | 74 | 255 | 104 | 1,200 |
| 15 | 120 | 45 | 500 | 75 | 1,130 | 105 | 1,350 |
| 16 | 150 | 46 | 140 | 76 | 485 | 106 | 510 |
| 17 | 730 | 47 | 1220 | 77 | 305 | 107 | 235 |
| 18 | 570 | 48 | 1,260 | 78 | 900 | 108 | 545 |
| 19 | 135 | 49 | 640 | 79 | 600 | 109 | 375 |
| 20 | 735 | 50 | 920 | 80 | 180 | 110 | 150 |
| 21 | 275 | 51 | 900 | 81 | 190 | 111 | 200 |
| 22 | 645 | 52 | 510 | 82 | 710 | 112 | 750 |
| 23 | 195 | 53 | 930 | 83 | 430 | 113 | 930 |
| 24 | 140 | 54 | 950 | 84 | 140 | 114 | 145 |
| 25 | 335 | 55 | 125 | 85 | 170 | | |
| 26 | 180 | 56 | 640 | 86 | 400 | | |
| 27 | 590 | 57 | 210 | 87 | 380 | | |
| 28 | 140 | 58 | 430 | 88 | 850 | | |
| 29 | 350 | 59 | 800 | 89 | 140 | | |
| 30 | 505 | 60 | 410 | 90 | 250 | | |

# 4.0 Blade Throw – Assessment Methodology

## 4.1 General Approach

SLR has assessed the risk of a whole blade or blade fragment being thrown from a WTG towards a receptor (dwelling, roadway/railway) due to an operational failure. Hereafter in this report:

- BT-w: refers to whole-of-blade Blade Throw.
- BT-f: refers to fragment-of-blade Blade Throw.

A BTRA involves combining the following steps to determine the risk of a BT-w or BT-f event, which can then be compared to appropriate injury or fatality consequence criteria.

**Step 1:**

- For the specific WTG model geometry, the potential distances that a whole blade or blade fragment can be thrown is calculated. This will depend on:
  - WTG rotor diameter, hub height and angular speed.
  - Throw distances are nominally perpendicular to the oncoming wind direction plus a downwind component which is dependent on the upstream wind speed.

**Step 2:**

- Risk zones are is established around each WTG for BT-w and BT-f using a Monte-Carlo Simulation technique that takes into account the annual probability of wind speed and wind direction at the site.

**Step 3:**

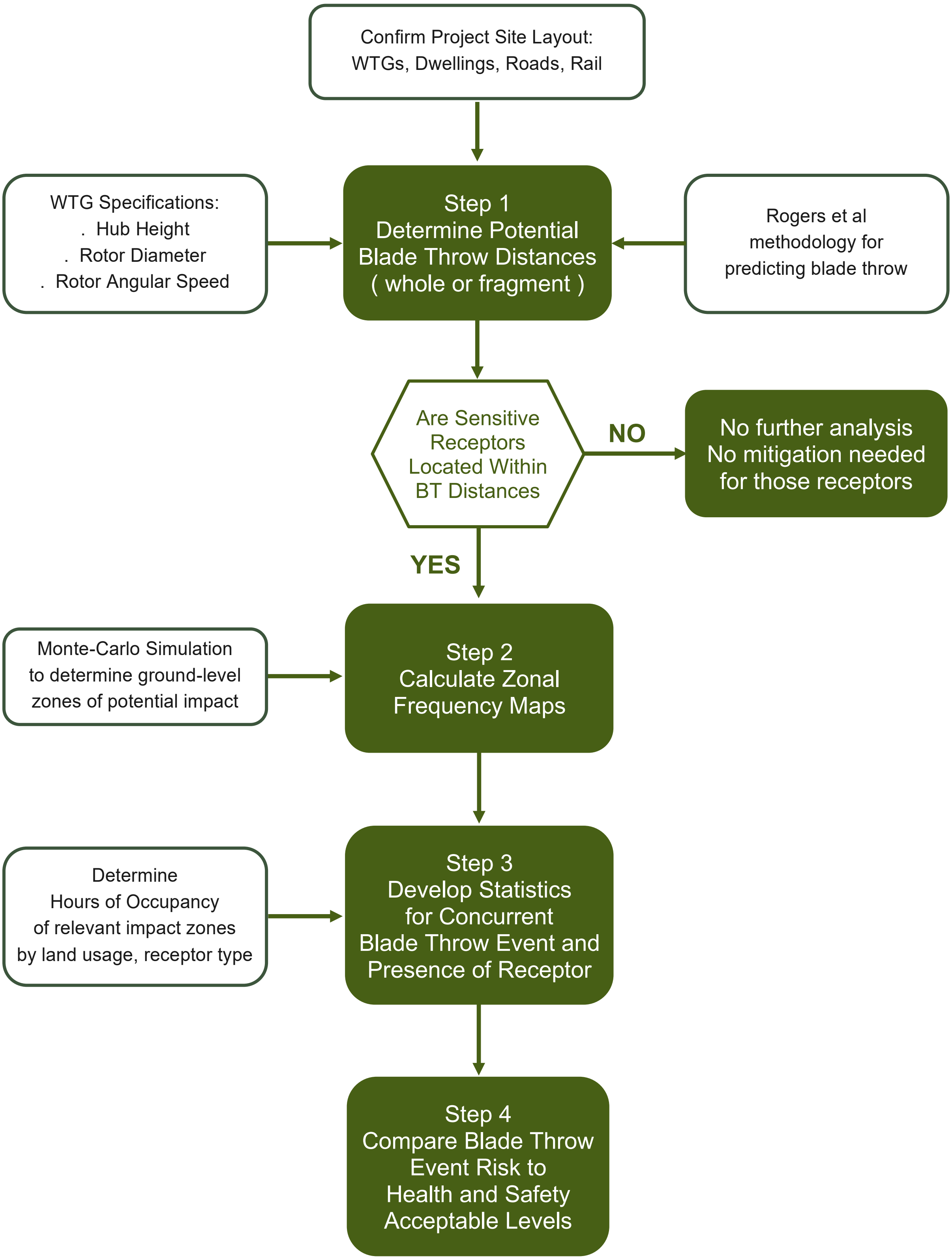
- Sensitive receptor occupancy usage within the Step 2 risk zones is then established.
- For this Project, sensitive receptors include residents, agricultural workers, motorists and the Yungara Rail Line that runs through the Project Area.
- Empirical data from documented WTG failures is used to calculate the likely return period of a WTG BT-w or BT-f event.
- The probability of a WTG BT-w or BT-f failure event is combined with the receptor occupancy statistics to determine the return period of a receptor (resident, rural worker, motorist, etc) being impacted by a WTG blade or debris.
  - Return period refers to the average time interval between occurrences of a given event, eg a motorist being impacted by a BT-w (or BT-f) occurrence.
  - Return period is also the inverse of the annual probability of exceedance of that event, eg a 100-year return period event has a 1% (=1/100) chance of occurring (or being exceeded) in any one year.

**Step 4:**

- Finally, the return periods calculated in Step 3 are compared to usual personal health and safety risk tolerances.

The above is illustrated in **Figure 6**.

**Figure 6 Blade Throw Risk Assessment Methodology**



## 4.2 Blade Throw Modelling

### 4.2.1 WTG Blade Throw Modelling Inputs

The inputs used for the calculation of BT-w and BT-f are shown in **Table 4**.

**Table 4 Representative WTG Details**

| Parameter | | Input Value |
|---|---|---|
| Hub height | | 166 m |
| BT-w | Rotor half-radius | 43 m |
| | Rotor half-tip speed\ | 40 m/s |
| BT-f | Rotor radius | 86 m |
| | Rotor tip speed | 80 m/s |
| Ejection Angle<br>( the angles where the whole blade or blade fragment is “launched from” ) | | 0° = top of rotor swept path<br>90° = level with hub, pointing downwards<br>180° = bottom of rotor swept path<br>270° = level with hub, pointing upwards |

For a single event, the potential blade throw distances are shown in **Figure 7**, given as a function of the launch angle where the blade throw occurs.

- Blade throw distances are NIL when the blade is level with the hub, where the blade throw is either pointing downwards towards the ground or vertically upwards.
- The maximum blade throw distances are:
  - BT-w: 305 m
  - BT-f: 855 m

**Figure 7 Blade Throw Distances for the Project WTG**

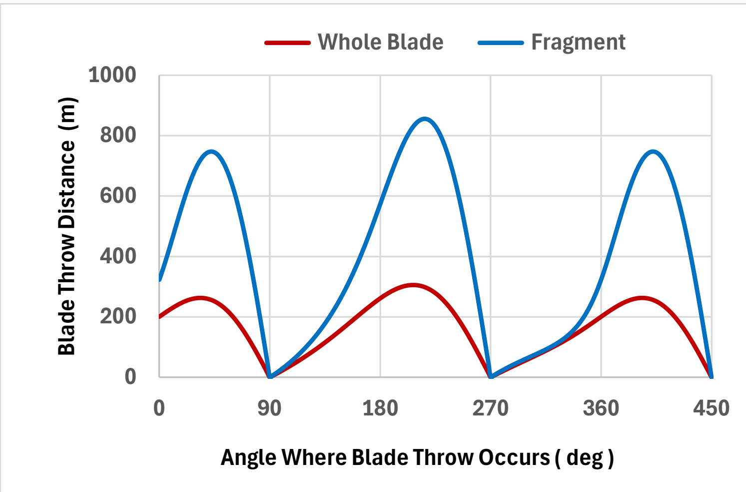


**Figure 8** shows the probability distribution of BT-w and BT-f throw distance based on a Monte-Carlo Simulation of 100,000 throws. It can be seen that, for both BT-w and BT-f, the throw distance probability is not uniform. Furthermore, these distances can occur either side of the WTG depending on the launch angle where blade throw occurs.

The location where the blade throw actually impacts the ground will then depend on the orientation of the WTG, assumed to be facing into the wind. The probability distribution of throw distance therefore needs to be combined with statistical wind information relevant to the Project Area.

**Figure 8 Probability Distribution of Throw Distance**


### 4.2.2 Wind Speed and Wind Direction Variations at the Site

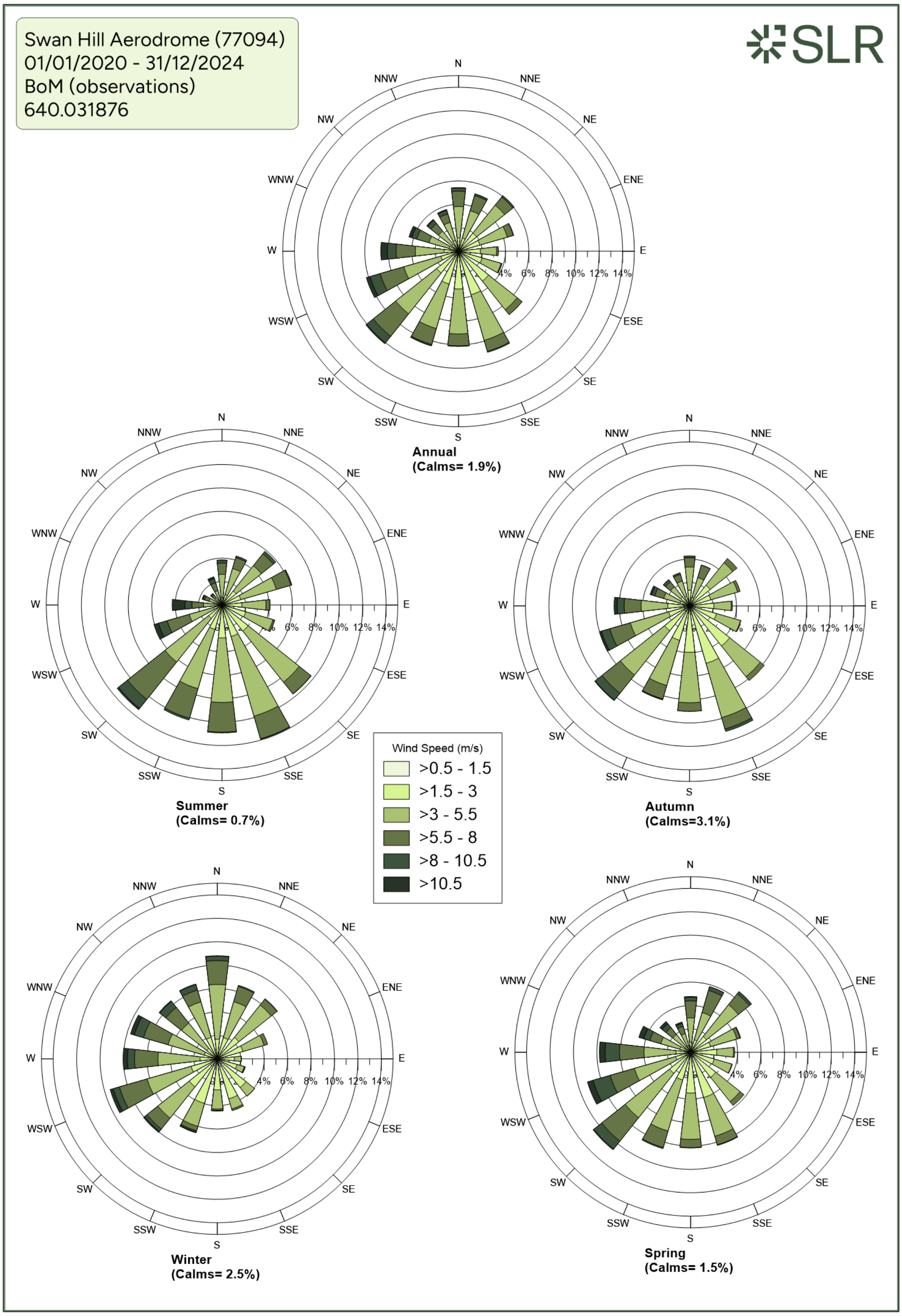
Wind direction and wind speed influence BT-w and BT-f as follows:

- The probability distribution of **wind direction** determines the relative proportion of time that a WTG will face a particular direction and hence the perpendicular direction in which the blade throw is firstly initiated.
  - Highly directional wind regions lead to a bias in the likely direction of blade throw.
- The probability distribution of **wind speed** determines the degree of blade motion in the direction of the wind after blade throw initiation takes place.
  - At low wind speeds, blade throw is essentially perpendicular to the wind direction.
  - At high wind speeds, blade throw will have a noticeable displacement in the direction of the wind as well as perpendicular to the wind (in the rotor plane axis).

The annual wind rose used in this study is shown in **Figure 9** – seasonal wind roses are also shown. The data was obtained from the Bureau of Meteorology station at Swan Hill for the years 2020 to 2024.

- On an annual basis, winds are dominated by southwest quadrant and southerly winds, with a secondary (less dominant) prevailing direction from the north-northeast.

## Figure 9 Swan Hill Annual Wind Rose

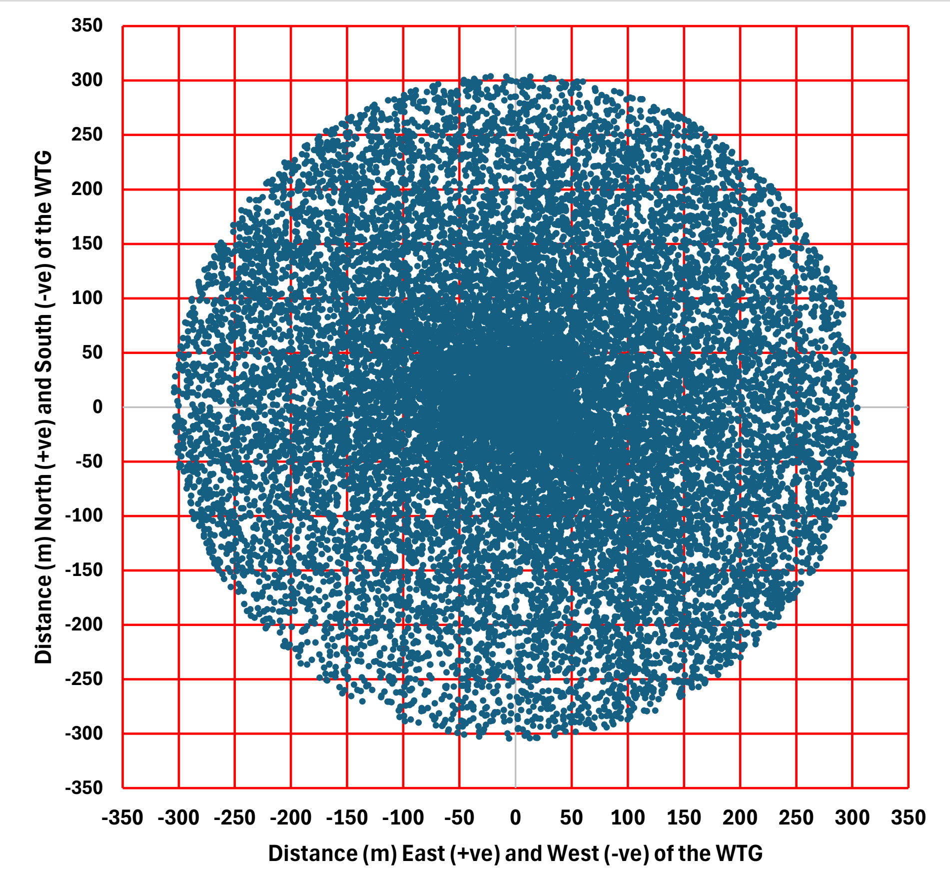


### 4.2.3 Blade Throw Zonal Impact

**Figure 10** shows a simulation involving 10,000 theoretical BT-w events.

- The simulation takes into account the wind statistics (wind speed magnitude and wind direction) shown in **Figure 9**.
- The strike zone shows the ground location where impact occurs for each BT-w event.
- A moderate bias in the BT-w strike zone can be discerned reflecting the bias in the wind climate for southwest and southerly winds.

**Figure 10 Monte-Carlo Simulation of BT-w Strike Zone**




The above simulation was used to determine the statistical occurrence probability of a BT-w event occurring within a particular 50 m x 50 m square area surrounding the WTG location.

The 50 m x 50 m probability values are shown in **Table 5** and **Figure 11**.

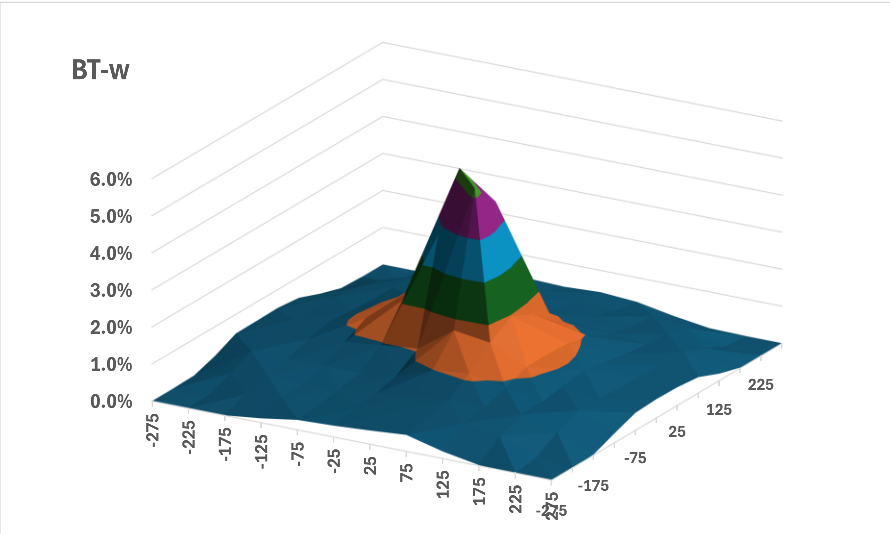
These probabilities can then be used to derive the overall return period of a BT-w injury/fatality by combining:

- The likelihood that a BT-w event occurs in the first place; times …
- The strike zone probability (refer **Table 5**); times …
- The likelihood of a receptor being in the same 50 m x 50 m zone at the same time that a BT-w event occurs.

## Table 5 Zonal Probabilities of BT-w Strike

| Grid Square Mid-Point | -275m | -225m | -275m | -175m | -75m | -25m | 25m | 75m | 125m | 175m | 225m | 275m |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **-275m** | 0.00% | 0.00% | 0.00% | 0.12% | 0.27% | 0.31% | 0.37% | 0.44% | 0.19% | 0.02% | 0.00% | 0.00% |
| **-225m** | 0.00% | 0.03% | 0.23% | 0.33% | 0.32% | 0.42% | 0.52% | 0.60% | 0.61% | 0.44% | 0.07% | 0.00% |
| **-175m** | 0.02% | 0.27% | 0.42% | 0.38% | 0.41% | 0.50% | 0.64% | 0.74% | 0.69% | 0.71% | 0.43% | 0.02% |
| **-125m** | 0.21% | 0.53% | 0.51% | 0.54% | 0.53% | 0.65% | 1.00% | 1.09% | 0.91% | 0.71% | 0.68% | 0.26% |
| **-75m** | 0.48% | 0.59% | 0.72% | 0.84% | 0.95% | 1.04% | 1.73% | 1.59% | 1.13% | 0.79% | 0.64% | 0.47% |
| **-25m** | 0.49% | 0.71% | 0.85% | 1.14% | 1.82% | 3.81% | 5.23% | 1.97% | 1.14% | 0.90% | 0.63% | 0.51% |
| **25m** | 0.51% | 0.63% | 0.80% | 1.17% | 1.97% | 5.25% | 4.53% | 1.69% | 1.09% | 0.79% | 0.59% | 0.49% |
| **75m** | 0.44% | 0.67% | 0.77% | 1.08% | 1.58% | 1.78% | 1.51% | 1.18% | 0.95% | 0.66% | 0.54% | 0.43% |
| **125m** | 0.22% | 0.58% | 0.77% | 0.92% | 1.15% | 1.04% | 0.90% | 0.81% | 0.68% | 0.59% | 0.57% | 0.19% |
| **175m** | 0.03% | 0.43% | 0.73% | 0.77% | 0.79% | 0.74% | 0.65% | 0.62% | 0.52% | 0.54% | 0.34% | 0.02% |
| **225m** | 0.00% | 0.07% | 0.46% | 0.65% | 0.55% | 0.56% | 0.51% | 0.45% | 0.49% | 0.35% | 0.05% | 0.00% |
| **275m** | 0.00% | 0.00% | 0.02% | 0.22% | 0.40% | 0.37% | 0.41% | 0.34% | 0.16% | 0.02% | 0.00% | 0.00% |
| **-275m** | 0.00% | 0.00% | 0.00% | 0.12% | 0.27% | 0.31% | 0.37% | 0.44% | 0.19% | 0.02% | 0.00% | 0.00% |

## Figure 11 Zonal Probability of BT-w Strike



The above calculations were repeated for a theoretical BT-f event.

- The zonal probability values for a BT-f event are given in **Table 6**.
- In this instance, they provide the probabilities for a BT-f impact occurring within a 150 m x 150 m square area.
    - A larger grid size is used because of the difference in potential maximum throw distance for BT-f events (305 m) versus BT-w events (855 m).
    - Note that the increased grid size needs to be taken into account when calculating the probability of a sensitive receptor (eg a motorist) being within that grid area at the same time as BT-f impact.

**Table 6 Zonal Probabilities of BT-f Blade Fragment Throw Strike**

| Grid Square Mid-Point | -825m | -675m | -525m | -375m | -225m | -75m | 75m | 225m | 375m | 525m | 675m | 825m |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -825m | 0.00% | 0.00% | 0.00% | 0.04% | 0.16% | 0.30% | 0.25% | 0.30% | 0.10% | 0.00% | 0.00% | 0.00% |
| -675m | 0.00% | 0.00% | 0.13% | 0.25% | 0.33% | 0.44% | 0.52% | 0.49% | 0.49% | 0.26% | 0.00% | 0.00% |
| -525m | 0.00% | 0.13% | 0.37% | 0.49% | 0.55% | 0.50% | 0.75% | 0.89% | 0.63% | 0.56% | 0.28% | 0.00% |
| -375m | 0.08% | 0.46% | 0.54% | 0.64% | 0.66% | 0.80% | 1.08% | 1.04% | 0.90% | 0.80% | 0.62% | 0.10% |
| -225m | 0.21% | 0.69% | 0.61% | 0.91% | 0.97% | 1.23% | 1.84% | 1.66% | 1.09% | 0.89% | 0.75% | 0.29% |
| -75m | 0.37% | 0.69% | 0.79% | 1.08% | 1.74% | 3.90% | 5.01% | 2.10% | 1.35% | 0.91% | 0.72% | 0.41% |
| 75m | 0.42% | 0.75% | 0.93% | 1.14% | 2.32% | 5.53% | 5.18% | 1.60% | 1.09% | 0.67% | 0.55% | 0.36% |
| 225m | 0.28% | 0.72% | 0.90% | 1.12% | 1.60% | 1.92% | 1.78% | 1.33% | 0.94% | 0.66% | 0.56% | 0.25% |
| 375m | 0.11% | 0.61% | 0.89% | 0.88% | 1.02% | 1.10% | 1.12% | 0.88% | 0.91% | 0.72% | 0.51% | 0.07% |
| 525m | 0.00% | 0.24% | 0.50% | 0.69% | 0.68% | 0.79% | 0.81% | 0.79% | 0.71% | 0.56% | 0.26% | 0.00% |
| 675m | 0.00% | 0.00% | 0.29% | 0.57% | 0.64% | 0.73% | 0.72% | 0.71% | 0.39% | 0.35% | 0.00% | 0.00% |
| 825m | 0.00% | 0.00% | 0.00% | 0.12% | 0.23% | 0.27% | 0.37% | 0.25% | 0.06% | 0.00% | 0.00% | 0.00% |

# 5.0 Blade Throw Failure Statistics

**Section 4** illustrated the potential impacts on the ground surrounding a WTG, via strike zone probabilities, if a BT-w or BT-f failure event occurs.

A key input for the risk analysis in this BTRA is therefore how often a BT-w or BT-f failure event may occur.

This probability is determined using experiences of global and National blade failure statistics.

## 5.1 Global Experience

### 5.1.1 Blade Failure Rate (ALL failure mechanisms)

Blade failures cover many scenarios, including blade buckling, blade folding, cracking, delamination, flaking, etc.

Only a relatively small portion of these blade failure scenarios lead to a blade throw incident.

The references cited below suggest probabilities for the full suite of blade failure categories. These references draw on WTG failure records kept by a number of national regulatory bodies including:

- Denmark — Windstats (WSDK)
- Europe — Project RELIAWIND.
- Finland — VTT (Valtion Teknillinen Tutkimuskeskus) Technical Research Centre.
- Germany — LandWirtschaftsKammer (LWK).
  Wissenschaftliches Mess- und Evaluierungsprogramm (WMEP).
  Windstats (WSD)
- Sweden — Vindstat reliability database
- US — National Renewable Energy Laboratory (NREL).

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Ref:

- P. Tavner, *"How are we going to make offshore wind farms more reliable?"*, in SUPERGEN Wind 2011 General Assembly, 2011.

Annual Blade Failure Rate:

- 0.10% / turbine

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Ref:

- A. Stenberg & H. Holttinen, *"Analysing failure statistics of wind turbines in Finland"*, VTT, 2010.

Annual Blade Failure Rate:

- 0.04% / turbine

Ref:

- W.K.G. Palmer, *“Wind Turbine Public Safety Risk, Direct and Indirect Health Impacts”*, Journal of Energy Conservation, 2018.

Annual Blade Failure Rate:

- 0.04% to 0.4%/ turbine

Ref:

- J.D. Sørensen, *"Probabilistic design of wind turbine blades"*, 2010.
- J.D. Sørensen, *"Reliability Of Wind Turbines and Wave Energy Devices"*, 2013.

Annual Blade Failure Rate:

- 0.01% to 0.1% / turbine

Ref:

- Dutch, *"Wind Turbine Risk Zoning Handbook"*, 2014.

Annual Blade Failure Rate:

- 0.084% / turbine

### 5.1.2 Blade Failure Rate Involving Blade Throw

The above references involve all blade failure mechanisms, many/most of which do NOT involve a detachment of a whole blade or blade fragment.

The above assessments show that complete blade detachment would comprise less than 10% of the above failure scenarios.

- The rate of blade detachment estimated from the above and consistent with global BTRA studies is 0.008%.
- This would correspond to a return period of approximately 12,500 years (per turbine).

## 5.2 Australian Experience

As far as is known via internet searches, Australia has experienced the following relevant blade failure incidents, although not all involved blade detachment:

- Windy Hill Wind Farm (QLD) – blade throw involving blade fragments
- Bald Hills Wind Farm (VIC) – blade throw involving blade fragment
- Wonthaggi Wind Farm (VIC) – blade still connected, but fragments thrown
- Lal Lal Wind Farm (VIC) – a whole blade fell to the ground, incident occurred during a lightning strike
- Dundonnell Wind Farm (VIC) – blade fell to ground during commissioning
- Berry Bank Wind Farm (VIC) – hub and blades all collapsed to ground
- MacIntyre Wind Farm (QLD) – blade break, but still connected
- Flyers Creek Wind Farm (NSW) – blade buckle, but still connected

### Renew Economy Wind Farm Atlas

The above resources states that Australia currently has:

- Almost 100 operational grid-scale wind farms (10MW or above);
- An average 35 WTG/facility (has been increasing over time).
- An average in-service WTG age of approximately 7-8 years.

On the basis of the above known failures, a conservative estimate of the inferred failure rates are:

- BT-f: 0.01% - return period of once per 10,000 years
- BT-w: 0.0067% - return period of once per 15,000 years

The Australian statistics are consistent with the global statistics for blade detachment (return period of 12,500 years), noting that they (conservatively) include the case of simple blade drop as opposed to blade throw.

#### Regarding Return Period:

- As previously noted, return period refers to the average time interval between occurrences of a given event. Using the above failure rates:
  - The average time interval between BT-f events (for a single WTG) would be 10,000 years.
  - The average time interval between BT-w events (for a single WTG) would be 15,000 years.
- Return period is also the inverse of the annual probability of exceedance of that event. Again, using the above failure rates:
  - A BT-f event would have a 0.01% chance of occurring in any one year.
  - A BT-w event would have a 0.0067% chance of occurring in any one year.

# 6.0 Risk Calculations

## 6.1 Overall Risk Calculation

The risk assessment for blade throw (either BT-w or BT-f) involves the following probability calculation:

*Prob(Receptor Impact) =* *P1w = Prob(**BT-w** event occurs)*
*x P2w = Prob(blade drops at a specific location)*
*x P3 = Prob(receptor is at the specific location at time of drop)*

*+*

*P1f = Prob(**BT-f** event occurs)*
*x P2f = Prob(fragment drops at a specific location)*
*x P3 = Prob(receptor is at specific location at time of drop)*

## 6.2 Risk Component Probabilities

### 6.2.1 P1: Probability of a BT-w or BT-f Event

SLR has adopted the following Australian-based failure rates for a BT-w or BT-f event (refer **Section 5.2**):

- BT-f: P1f = 0.01% Return period = 10,000 years
- BT-w: P1w = 0.0067% Return period = 15,000 years

Note that these are consistent with the global statistics for BTRA studies.

### 6.2.2 P2: Probability of Zonal Impact

The probability that a blade or fragment drops at a specific location is given by **Table 5** (BT-w) for P2w and **Table 6** (BT-f) for P2f.

Note that the impact area of the blade or blade fragment also plays a role in the risk calculation where a specific zone square dimension is used:

- For a whole-of-blade incident, a blade throw event could impact anywhere within a 50 m x 50 m square zone.
- For a blade fragment incident, involving say a large fragment 15 m in length, the impact would occur within a 15m x 15m area within that zone, ie 1% of the overall 150m x 150m zone area.

### 6.2.3 P3: Probability of Receptor Co-Located (in Time and Space) with a BT-w or BT-f Event

The remaining inputs into the risk calculation involve estimating the likelihood that a receptor (eg dwelling, agricultural worker within a field, motorist traversing the site, etc) happens to be located within the specific zone of impact at the same time that a BT-w or BT-f event occurs.

### Dwelling Risk

| | |
|---|---|
| Risk Assumption: | dwelling is occupied 16 hours per day (67% of the time)<br>dwelling is located within a 50m x 50m area |
| BT-w risk: | P3 = 100% for a 50m x 50m zone x 0.67 = 0.67 |
| BT-f risk: | P3 = 1% for a 150m x 150m zone x 0.67 = 0.0067<br>( assumes 15m long fragment ) |

### Vehicle Risk

The risk is proportional to the number of vehicles using the roadway, the vehicle speed and the size of the grid square used in the analysis.

**Major Road**

Risk Assumption: Major Road (ie B260, Loddon Valley Highway)
Occupancy = 2,365 vehicles per day
Typical travel speed = 70 kph
Time taken to traverse 50 m = 2.5 seconds
Time taken to traverse 150 m = 7.5 seconds

Hence, the co-location risk (ie concurrent blade impact and vehicle presence):

BT-w: P3 = 1 x 2,365 x 2.5 / ( 24x3,600) = 0.068 (50mx50m square)
BT-f: P3 = 0.1 x 2,365 x 7.5 / ( 24x3,600) = 0.0205 (150mx150m square)

**Minor Road**

Risk Assumption: Minor Road (assume worst-case for a sealed local road)
Occupancy = 726 vehicles per day
Typical travel speed = 30 kph
Time taken to traverse 50 m = 6 seconds
Time taken to traverse 150 m = 18 seconds

Hence, the co-location risk (ie concurrent blade impact and vehicle presence):

BT-w: P3 = 1 x 726 x 6 / ( 24x3,600) = 0.050 (50mx50m square)
BT-f: P3 = 0.1 x 726 x 18 / ( 24x3,600) = 0.015 (150mx150m square)

### Motorist / Rail Operator

Risk Assumption: Yungera Rail Line: 4 trains per day
average speed 70 kph (slower speed close to Macorna train station)
typical travel speed = 70 kph
time taken to traverse 50 m = 2.5 seconds
time taken to traverse 150 m = 7.5 seconds

Hence, the co-location risk (ie concurrent blade impact and vehicle presence):

BT-w: P3 = 4 x 2.5 / ( 24x3,600) = 0.000116 (50mx50m square)
BT-f: P3 = 4 x 7.5 / ( 24x3,600) = 0.00035 (150mx150m square)

### Agricultural Worker Risk

A majority of the WTGs are located either adjacent to or within working farm agricultural acreage. It is therefore possible that agricultural workers may be located in relatively close proximity to specific WTGs.

The following assumptions have been made:

- 1 agricultural worker within any 50m x 50m zone at any one time (re BT-w).
- Up to 3 agricultural workers within any 150m x 150m zone at any one time (re BT-f).
- Worker presence = 2 days per month / 10 hours per day.
- Worker presence zone = 15m x 15m square (same area as potential blade fragment).

For BT-w events:

- Co-location probability = 12 x 2 x 10 ÷ 8,760 x 1 = 0.028

For BT-f events:

- Co-location probability = 3 x 12 x 2 x 10 ÷ 8,760 x 0.01 = 0.00082

The above receptor co-location probabilities are summarised in **Table 7**.

Note that these probabilities are not “intrinsic” probabilities but are directly related to the grid size used in this study:

- The BT-w co-location probabilities relate to the chance that the relevant receptor is located within a 50m x 50m grid square.
- The BT-w co-location probabilities relate to the chance that the relevant receptor is located within a 150m x 150m grid square.

This allows the co-location probabilities to be combined with the zonal risk probabilities in **Table 5** (BT-w) and **Table 6** (BT-f).

**Table 7 Receptor Co-Location Probabilities**

| Receptor | Co-Location Probability for BT-w | Co-Location Probability for BT-f |
|---|---|---|
| Dwelling | 0.67 | 0.0067 |
| Motorist – MAJOR Road | 0.068 | 0.0205 |
| Motorist – Minor Road | 0.050 | 0.015 |
| Rail | 0.000116 | 0.00035 |
| Agricultural Worker | 0.028 | 0.00082 |

# 7.0 Risk Assessment

## 7.1 Criteria

The risk criteria adopted in the BTRA take into account the following:

- The risk criteria should be probabilistic in nature, which allows the risk to account for both the consequences (effects) and likelihood (probability) of a hazardous event.
- Virtually all activities have an associated level of risk. It is not possible to totally eliminate the risk unless the activity itself is eliminated. Risk criteria are therefore based on the concept of a residual risk, the acceptability of which should be established in relation to various land uses and the sensitivity of the receptors involved.
- Individuals will generally tolerate a given level of risk for a wide range of activities, eg driving, hiking, bungee jumping, etc, as long as the individual understands that reasonable safety measures have been undertaken to mitigate those risks.
- When a risk is to be imposed on an individual or a group of people (eg by locating a hazardous facility in a nearby area), the acceptability of that risk in the decision-making process is that it should be low relative to other known and tolerated risks.

The risk criteria used in this study are based on the potential for injury or a fatality resulting from a blade throw event. No distinction is drawn between injury and fatality. Any BT-w or BT-f event is assumed to have the potential to result in a fatality.

The acceptable level of risk is as follows (source: NSW HIPAP 4 *Risk Criteria for Land Use Safety Planning*, 2011):

| | | |
|---|---|---|
| • Dwellings | $1 \times 10^{-6}$ | (risk to the dwelling) |
| • Agricultural Worker | $1 \times 10^{-6}$ | (risk to the individual) |
| • Road/Rail | $1 \times 10^{-6}$ | (risk to an individual) |

### Context of the above

The above risk level is commonly adopted throughout Australia and can be compared to the following representative societal risks:

| Fatality resulting from: | Risk: | Source: |
|---|---|---|
| • Smoking | $5,000 \times 10^{-6}$ | NSW HIPAP 4 |
| • Agricultural field work | $150 \times 10^{-6}$ | Safe Work Australia |
| • Road Travel | $145 \times 10^{-6}$ | NSW HIPAP 4 |
| • Accidents in the Home | $110 \times 10^{-6}$ | NSW HIPAP 4 |
| • Swimming | $50 \times 10^{-6}$ | NSW HIPAP 4 |
| • Train Travel | $30 \times 10^{-6}$ | NSW HIPAP 4 |
| • Air Travel | $10 \times 10^{-6}$ | NSW HIPAP 4 |

## 7.2 Dwelling Risk

The data from **Table 3** (Separation Distance from each assessed dwelling to the nearest WTG) has been combined with the data in **Tables 5 and 6** and the probability of occurrence of a BT-w or BT-f event to determine risk levels for all dwellings.

**BT-w Event:**

- In relation to BT-w events, dwellings further than **305 m** from any nearest WTG are automatically excluded from the analysis.
- It is noted that the closest dwelling to a WTG is H080 (500 m from WTG028).

**Risk Level – BT-w Event:**

- All dwellings: NIL

**BT-f Event:**

- In relation to BT-f events, dwellings further than **855 m** from any nearest WTG are automatically excluded from the analysis.

In **Table 2**, it was noted that the closest dwelling to any WTG is H080, and that it is understood that this dwelling has been abandoned.

The next nearest dwelling is more than 1,000 m from any WTG.

On this basis, the BT-f Event Risk Level would be NIL for all dwellings.

Nevertheless, a calculation has been made for this dwelling, should it be occupied at some future date. H080 is located 500 m from WTG028.

**Risk Level – BT-f Event**

- H080: = 0.000067 ( probability of a BT-f event )
  x 0.014 ( zonal risk from **Table 6** )
  x 0.0067 ( co-location dwelling is within the 150m x 150m square )
  = $6 \times 10^{-9}$

**Combined BT-w and (worst-case) BT-f Risk**

Based on the above:

> The Dwelling Risk Level is (well) below the target (acceptable) risk of $1 \times 10^{-6}$

## 7.3 Road / Rail Risk

The data from **Table 4** (Separation Distance from each WTG to the nearest roadway or rail line) has been combined with the data in **Tables 5 and 6** and the probability of occurrence of a BT-w or BT-f event to determine risk levels for all surrounding roads and rail line.

As noted above:

- In relation to BT-w events, any road or rail line further than **305 m** from any nearest WTG is automatically excluded from the analysis.
- In relation to BT-f events, any road or rail line further than **855 m** from any nearest WTG is automatically excluded from the analysis.

There are many roads which are within the potential BT-f impact zones of WTGs within the Project Area. The Yungera Rail Line also lies within the potential BT-f impact zone for a number of WTGs within the Project Area.

Only minor roads lie within the potential BT-w impact zones of any WTG within the Project Area.

### 7.3.1 Major Roads (B260) – 2,365 vehicles per day travelling at 70 kph

The nearest WTGs are WTG067, WTG089 and WTG103 – which are 305 m, 310 m and 305 m from the nearest point of the Loddon Valley Highway (B260).

For B260, the risk levels are:

- BT-w: = NIL ( highway is located ≥305 m from any WTG )
- BT-f: = 0.000067 ( probability of a BT-f event )
  x 0.003 ( zonal risk from **Table 6** )
  x 0.0205 ( co-location risk within any 150m x 150m square )
  = 4 x $10^{-9}$

> The Road Traffic Risk Level is well below the target (acceptable) risk of 1 x $10^{-6}$ for the major road potentially impacted by the Project.

### 7.3.2 Minor Roads – 100 vehicles per day travelling at 30 kph

#### BT-w Risk

- Worst-case scenario: Minor roads which are less than 150 m from nearest WTG
  risk = 0.0001 ( risk of a BT-w event )
  x 0.03 ( refer **Table 5** )
  x 0.051 ( co-location risk within any 50m x 50m square )
  = 1.5 x $10^{-7}$

#### BT-f Risk

- Worst-case scenario: Minor roads which are less than 150 m from nearest WTG
  risk = 0.000067 ( risk of a BT-f event )
  x 0.05 ( refer **Table 5** )
  x 0.015 ( co-location risk within any 150m x 150m square ) =
  = 5.1 x $10^{-8}$

#### Combined BT-w and BT-f Risk

- Worst-case scenario for minor roads less than 150 m from the nearest WTG
- Risk = 2 x $10^{-7}$

> The Road Traffic Risk Level is below the target (acceptable) risk of 1 x $10^{-6}$ for all minor roads potentially impacted by the Project.

### 7.3.3 Yungera Rail Line – 4 train movements per day travelling at 70 kph

**BT-w Risk**

The nearest WTGs are WTG077 and WTG026, located at 310 m and 370 m from the nearest point of the rail line.

- Risk Level – BT-w Event: NIL

**BT-f Risk**

- Nearest WTGs

| | | |
|---|---|---|
| risk = | 0.000067 | ( risk of a BT-f event ) |
| | x 0.02 | ( refer **Table 6** ) |
| | x 0.00035 | ( co-location risk within any 150m x 150m square ) |
| | = $4.7 \times 10^{-10}$ | |

> The Rail Traffic Risk Level is below the target (acceptable) risk of $1 \times 10^{-6}$ for the Yungera Rail Line.

## 7.4 Agricultural Workers

Agricultural workers would not normally be located closer than 50 m from any WTG. However, it is understood that, for very short periods of time, landowners and their workers may utilize the access tracks alongside turbines.

On this basis, the co-location risk provide in Table 7 (which gives the likelihood of a worker being located in any area within the Project Area, ie not necessarily close to a WTG)has been conservatively combined with the highest percentage figures from **Tables 5 and 6** to determine agricultural worker risk.

For agricultural workers, the worst-case scenario risk would be:

| | | |
|---|---|---|
| • BT-w = | 0.0001 | ( risk of a BT-w event ) |
| | x 0.053 | ( refer **Table 5** ) |
| | x 0.028 | ( co-location risk within any 50m x 50m square ) |
| | = $1.5 \times 10^{-7}$ | |
| • BT-f = | 0.000067 | ( risk of a BT-f event ) |
| | x 0.055 | ( refer **Table 6** ) |
| | x 0.00082 | ( co-location risk within any 150m x 150m square ) |
| | = $3.3 \times 10^{-8}$ | |

**Combined BT-w and BT-f Risk**

Based on the above, the worst-case scenario is:

- 50 m to 150 m: = $1.83 \times 10^{-7}$

> The Agricultural Worker Risk Level is below the target (acceptable) risk of $1 \times 10^{-6}$

# 8.0 Summary and Conclusion

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Macorna SPV – Atmos MWV Pty Ltd as trustee for the Atmos MHV Trust (the Client) to carry out a Blade Throw Risk Assessment for the proposed Macorna Wind Farm.

The assessment has reviewed the risks associated with both:

- A BT-w (Blade Throw – Whole of Blade) event; and
- A BT-f (Blade Throw – Fragment of Blade) event.

The assessment has determined potential risks in relation to the nearest sensitive receptors to the Project, comprising dwellings, carriageways (road and rail) and agricultural workers.

### Criteria

The acceptable risk limits used in this study are as follows (refer **Section 7.1** for background to the adopted risk criteria):

- Dwellings $1 \times 10^{-6}$ (risk to the dwelling)
- Agricultural Worker $1 \times 10^{-6}$ (risk to the individual)
- Road/Rail $1 \times 10^{-6}$ (risk to an individual)

### Outcomes of the Assessment

**Dwellings (worst-case risk for dwelling closest to any WTG)**

- Worst-case Risk Level: $6 \times 10^{-9}$

**Road Traffic – Major Roads (Loddon Valley Highway)**

- Worst-case Risk Level: $1 \times 10^{-9}$

**Road Traffic – Minor Roads (worst-case risk for closest minor roads to any WTG)**

- Worst-case Risk Level: $7.6 \times 10^{-8}$

**Yungera Rail Line (worst-case risk for nearest WTGs)**

- Worst-case Risk Level: $4.7 \times 10^{-10}$

**Agricultural Workers**

- Worst-case Risk Level: $1.7 \times 10^{-7}$

All Risk Levels are below the target (acceptable) risk of $1 \times 10^{-6}$
( 1 event per 1,000,000 years )

## Conclusion

On the basis of the above, the BTRA has concluded that no mitigation will be required (eg re-positioning of any WTGs) to address the potential impact of a blade throw event from the Project.

# 9.0 References

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