APPENDIX K BLADE THROW REPORT

Wind Energy Partners Pty LTD

Developed by Clean Energy Partners Pty Limited

Blade Throw Risk Assessment

Hills of Gold Wind Farm

15 October 2020

Project No.: 0550690

The business of sustainability

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15 October 2020

Blade Throw Risk Assessment

Hills of Gold Wind Farm

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CONTENTS

EXECUTIVE SUMMARY

Environmental Resources Management Australia Pty Ltd (ERM) has been commissioned by Wind Energy Partners (WEP) to consider blade throw risks in the vicinity of the proposed Hills of Gold Wind Farm.

Blade throw describes the rare phenomenon of a structural failure in a turbine blade during operation resulting in the ejection of projectiles into the surrounding area.

The Secretary's Environmental Assessment Requirements (SEARs) and the NSW Governments Wind Energy Guideline (2016) require that the risk of blade throw at a wind farm be considered and appropriately mitigated.

This document finds that the risk of damage to life or property through a blade throw event at the Hills of Gold Wind Farm can be considered to be negligible.

1. INTRODUCTION

1.1 Overview

Wind Energy Partners Pty Ltd (WEP or the Proponent) is seeking approval to construct and operate the Hills of Gold Wind Farm, located on the ridge line between Hanging Rock and Crawney Pass in the Northern Tablelands region of New South Wales (NSW) (the Project). A locality plan is provided in Figure 1-1. The Project will supply renewable energy directly into the national electricity grid through a proposed connection into the TransGrid Liddell to Tamworth transmission line.

The proposed development involves the construction and operation of:

- A maximum of 70 turbines, an approximate 420 megawatts (MW) install capacity and maximum height of 230 metres (to blade tip); and
- Ancillary infrastructure including internal access tracks, laydown areas, road upgrades, two concrete batching facilities, laydown areas, underground and overhead electricity cabling, substation, battery energy storage system (BESS) and a switching station and grid connection to the existing 330kV Liddell to Tamworth transmission line.

1.2 Locality Description and Context

The Project is located approximately 5km south of Hanging Rock, 8km southeast of Nundle and 60 km southeast of Tamworth. The proposed development is located within the Tamworth Regional, Upper Hunter and Liverpool Plains local government areas. The general locality includes Ben Halls Gap Nature Reserve / National Park, Crawney Pass National Park, Ben Halls Gap State Forest, Hanging Rock State Forest and Nundle State Forest.

Hanging Rock and Nundle are towns which begun as pastoral runs and transformed into gold mining villages. Today, the main industries are agriculture and tourism. Hanging Rock lookout provides scenic views of the Nundle Valley. The majority of dwellings in proximity to the proposed wind farm are lifestyle blocks located on Morrisons Gap Road and to a lesser extent Barry Road.

Land on which the Project is proposed to be located is owned by 14 freehold landholdings and includes Crown Land paper roads and one Crown land allotment (the Project Area). The proposed development corridor within the Project Area is predominately agricultural land with a high percentage of overstorey native vegetation adjacent to the development corridor and within steeper terrain. The Project Area has a history of grazing cattle with the native understorey converted to exotic pastures in many locations. The landownership that constitute the Project Area includes a number of rural dwellings in close proximity to the development corridor with each landowner holding a lease or agreement with WEP to host the development ('associated dwellings').

1.3 Assessment Requirements

1.3.1 Secretary's Environmental Assessment Requirements (SEARS)

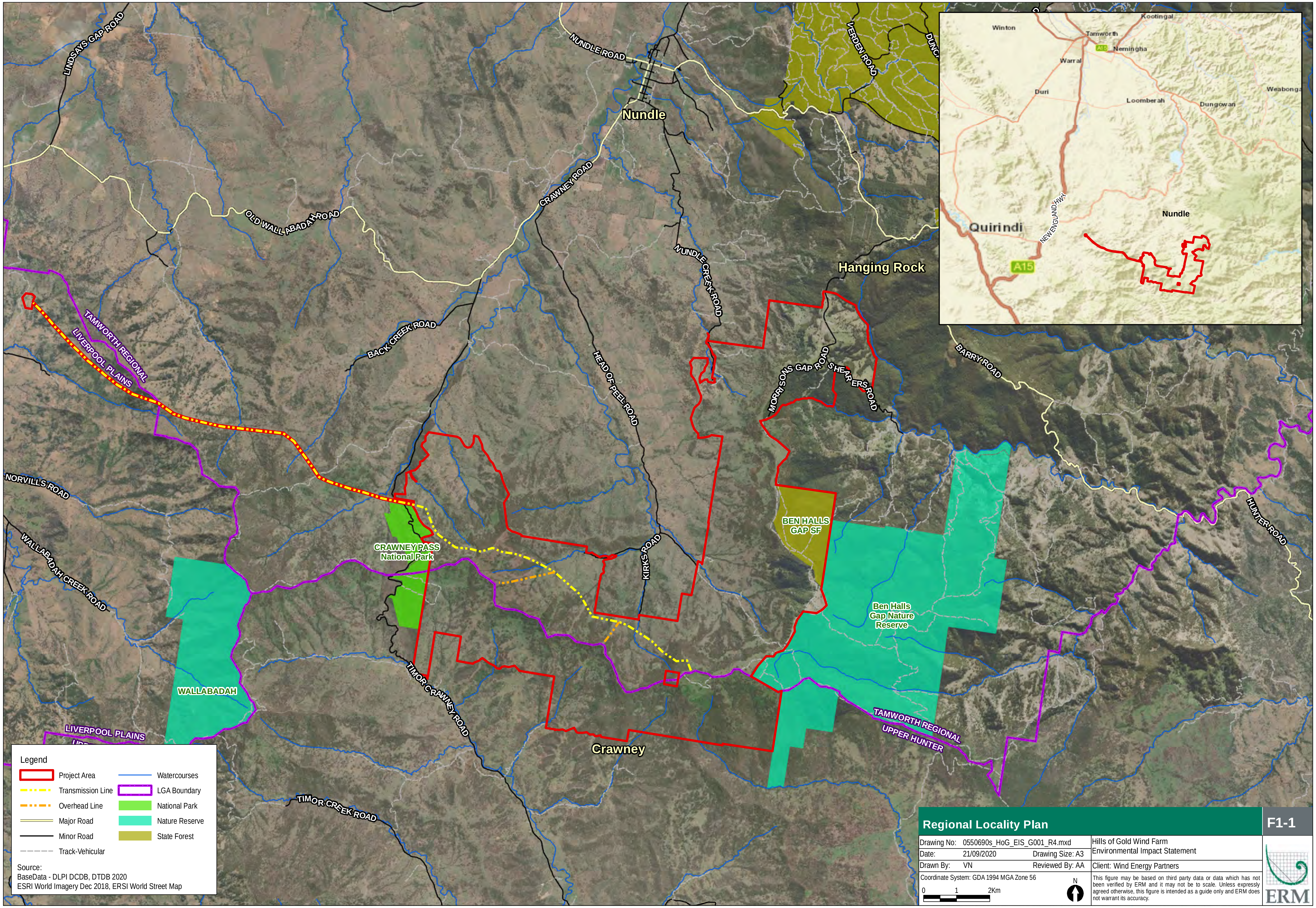
The Secretary's Environmental Assessment Requirements for the Hills of Gold Wind Farm (SEARS) state the following with regard to blade throw:

> *"Hazards/Risks – The EIS must include an assessment of the following: … Blade throw: assess blade throw risks."*

1.3.2 The NSW Governments Wind Energy Guideline

The NSW Governments Wind Energy Guideline (2016) currently states that the issues which are specifically relevant for wind energy development and will be considered in the environmental assessment of an application, include:

> *"blade throw: consider blade throw risk".*



Regional Locality Plan

F1-1

Drawing No: 0550690s_HoG_EIS_G001_R4.mxd	Hills of Gold Wind Farm Environmental Impact Statement
Date: 21/09/2020 Drawing Size: A3	
Drawn By: VN Reviewed By: AA	Client: Wind Energy Partners
Coordinate System: GDA 1994 MGA Zone 56 0 1 2Km N	This figure may be based on third party data or data which has not been verified by ERM and it may not be to scale. Unless expressly agreed otherwise, this figure is intended as a guide only and ERM does not warrant its accuracy.

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2. PROJECT DESCRIPTION

The Project involves the construction, operation and commissioning of a wind farm with up to 70 wind turbine generators (WTG), together with associated and ancillary infrastructure.

The Project consists of the following key components:

- up to 70 WTGs, each with:
  - a maximum height of 230 m AGL (to the blade tip) with a generating capacity of approximately 6MW;
  - a 4-7 part tubular steel tower holding the nacelle;
  - three blades mounted to a rotor hub and the gearbox and generator assembly housed in the nacelle; and
  - adjacent hardstands for use as crane pads and assembly / laydown areas;
- decommissioning of three current monitoring masts and installation of up to five additional monitoring masts for power testing. The five monitoring masts will be located close to a WTG location and will have same WTG hub height. The exact number and location will be defined at the detailed design stage;
- a central electrical substation, including transformers, insulators, switchyard and other ancillary equipment;
- an operations and maintenance facility;
- a battery energy storage system (BESS) of 100/400 MWh;
- an internal private access road network (up to a combined total length of approximately 48 km) connecting the WTGs and other Project infrastructure to the public road network;
- aboveground and underground 33 kV electrical reticulation and fibre optic cabling connecting the WTGs to the onsite substation (following site access tracks where possible);
- a 330 kV overhead transmission line to connect the onsite substation to the existing 330kV TransGrid Liddell to Tamworth overhead transmission line network, located approximately 13.5 km west of the WTG Project Area. A switching station will be constructed to connect the Project to the 330 kV TransGrid Liddell to Tamworth line; and
- upgrades to local roads and waterway crossings, as required for the delivery, installation and maintenance of WTG components and other associated materials and structures.

The following temporary elements will be required during construction of the Project:

- temporary site buildings and facilities for construction contractors / equipment, including site offices, car parking and amenities for the construction workforce;
- two temporary concrete batching plants to supply concrete for WTG footings and substation construction works;
- earthworks for access roads, WTG platforms and foundations, including blasting;
- potentially rock crushing facilities for the generation of suitable aggregates for concrete batching or sized rock for access road and hardstand construction;
- up to seven hardstand laydown areas for the temporary storage of construction materials, plant, and equipment construction;
- external water supply and aggregates / materials for concrete batching and construction activities; and
- the transport, storage and handling of fuels, oils and other hazardous materials for construction and operation of wind farm infrastructure.

The proposed Project layout including the WTGs, access roads and supporting infrastructure as well as nearby dwellings are shown in Figure 2-1.

3. BLADE THROW RISK ASSESSMENT

A blade throw incident can occur when an entire wind turbine blade becomes separated from its hub at the metal to metal root joint. A possible cause which could lead to this event, is the instantaneous failure of the bearing or hub flange fastening system (MMI Engineering Ltd, 2013). In this instance, it is possible a blade could be thrown from the hub if the control system fails to detect an abnormality (e.g. vibration, imbalance, under power). However the progression of this failure is generally slow enough that the control system will detect an abnormality and the machine will fault and shut down, preventing a blade throw event (MMI Engineering Ltd, 2013).

Preventing structural failures such as fatigue resistance of wind turbine subassemblies can, in addition, prevent the possibility of a blade throw event (MMI Engineering Ltd, 2013). A diagram of wind turbine subassemblies and components is depicted in Figure 3-1. Data has indicated that subassembly failure frequencies are reducing with time, which has been correlated to improvements in design and manufacturing (Ribrant & Bertling, 2007). The causes for wind turbine blade failures may also include extreme environmental conditions, incorrect design for ultimate or fatigue loads, extremely low strength of the materials, failure of turbine control system, and human error (Carbone & Afferrante, 2013; Rastayesh, et al., 2019).

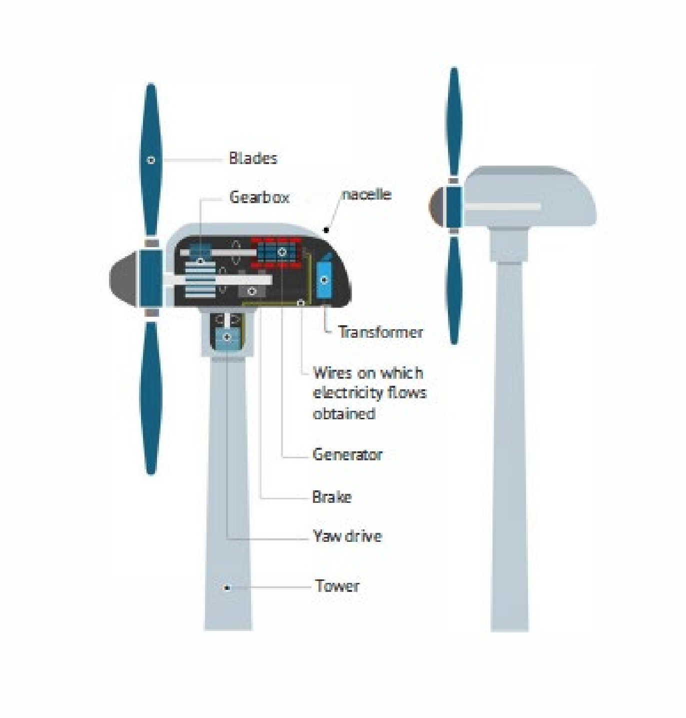
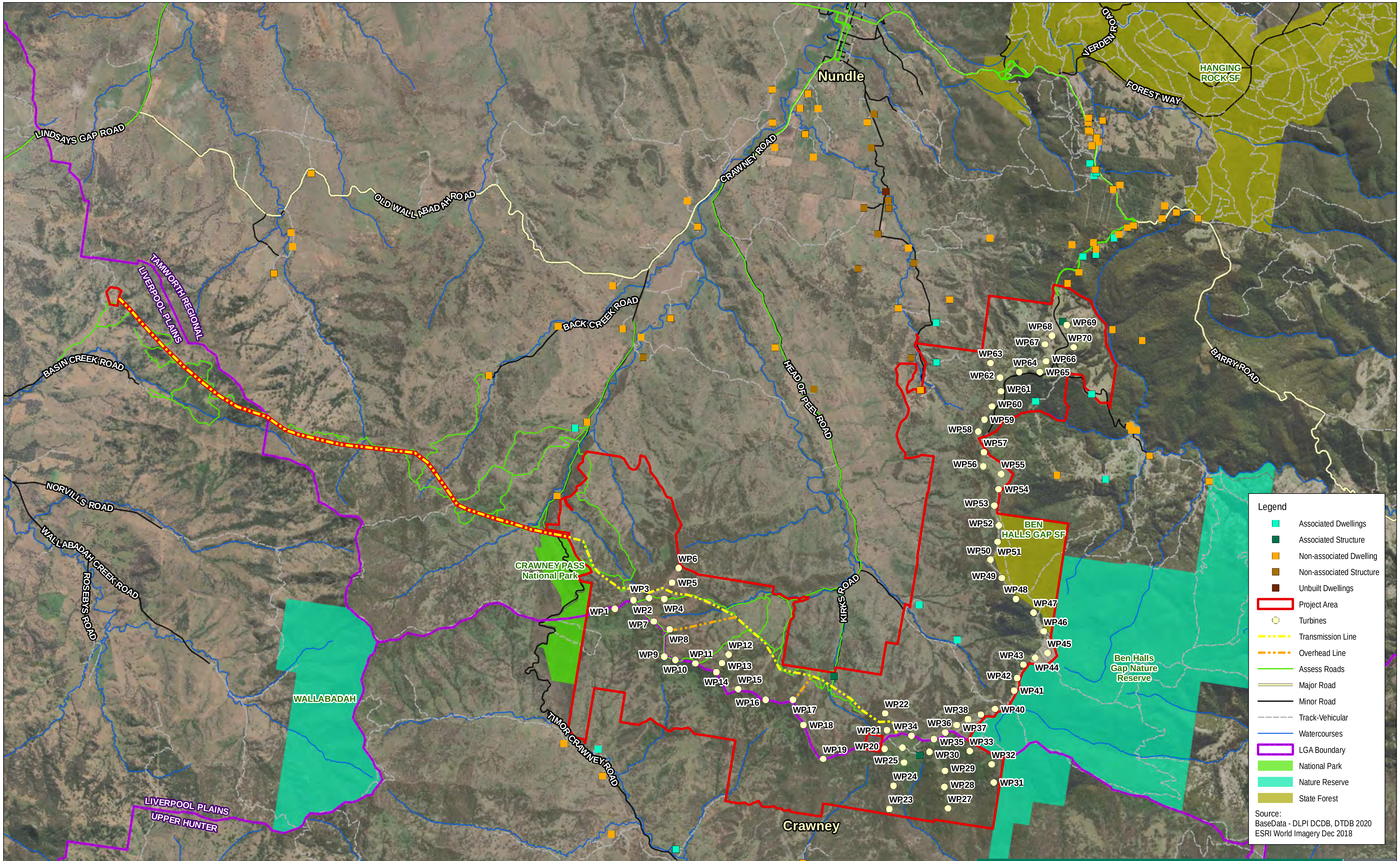


Figure 3-1 Wind Turbine Components

3.1 Likelihood and distance of a blade throw event

In order to quantify the likelihood of a blade throw event, researchers have examined historical data sets of incidents on wind farms. Comprehensive and detailed blade throw data sets are not typically available to the public. Where databases have been compiled, the data is typically held in confidence by manufacturers or industrial bodies (Larwood & Simms, 2018; MMI Engineering Ltd, 2013). The limited data available includes a database of over 200 severe wind turbine incidents which occurred in Germany and Denmark from 1980 until 2001. Using this database, researchers (Braam & Rademakers, 2002) were able to establish rates of incidents as depicted in Table 3-1 below. Documented blade failures and blade throw distances were also reported. The maximum throw distance for an entire blade and blade fragment were 150 metres and 500 metres respectively.



Project Overview **F2-1**

Drawing No: 0550690s_HoG_EIS_G002_R6.mxd		Hills of Gold Wind Farm Environmental Impact Statement
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Drawn By: VN	Reviewed By: AA	Client: Wind Energy Partners

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Table 3-1 Blade throw probabilities – frequencies of occurrences

Scenario	Recommended Value (1 / year)
Collapse of an entire tower from base	$3.2 \cdot 10^{-4}$
Loss of an entire blade	$8.4 \cdot 10^{-4}$
Loss of a blade tip	$2.6 \cdot 10^{-4}$

Source: Braam & Rademakers 2002

A public testimonial from a managing engineer at wind turbine manufacturer Vestas further contributes to the blade failure rate data (Larwood, et al., 2005). In the testimony for the Kittitas Valley Wind Power Project in Washington State, the managing engineer declared that there had been only one blade failure in ten-thousand units for twelve years. The failure occurred in 1992 on a V39-500kW turbine and a blade was thrown 50-75 metres. It has been estimated that if an average of six years of total operation for the entire fleet is assumed, the failure rate would be $1.6 \cdot 10^{-5}$ blade failures per turbine per year (Larwood, et al., 2005).

Using an extensive database compiled by Caithness Windfarm Information Forum (CWIF) entitled *Wind Turbine Accident and Incident Compilation (last updated 30 June 2020)* (http://www.caithnesswindfarms.co.uk/fullaccidents.pdf) and through using web search engines, it was identified that 4 incidents of blade throw are estimated to have occurred at the following Australian wind farms:

- Bald Hills Wind Farm, VIC (2020);
- Lal Lal Wind Farm, VIC (2019);
- Wonthaggi Wind Farm, VIC (2012); and
- Windy Hill Wind Farm, QLD (2005).

Very limited information is publically available on these occurrences, however in all occurrences no damage to human life or property were reported.

3.2 Blade Fragment Throw

Blade fragment throw has also been estimated through use of a dynamic model of blade failure and Monte Carlo simulation techniques examined using three models of wind turbines (Rogers, et al., 2011). The study found that the critical factor in determining the maximum distance fragments are likely to travel, is the release velocity of the blade fragment. This leads to a conclusion that standards for wind turbine setback distances should not be based on turbine height or radius, but instead, will be far more effective when based upon the mass centre velocity of the minimum sized blade fragment (Rogers, et al., 2011). Models based on release velocity, wind turbine dimensions, and acceptable risk, also found that theoretical lateral throw distance of a fragment was up to 526 metres for a 3.0MW wind turbine (Rogers, et al., 2011). A supporting study has shown that smaller blade fragments consistently fly farther than larger fragments because of higher initial release velocity (Sledgers, et al., 2009).

Another study conducted a trajectory analysis using Newton's and Euler's equations of motion and rotation and found that while at tip speeds of about 70m/s (normal operating conditions), pieces of blade (with weights in the range of approximately 7-16 ton) would be thrown out less than 700 metres for the entire range of wind turbines (Sarlak & Sorensen, 2016).

A more recent study on blade fragment throw used turbine height as a metric for establishing safe setback distances. They found that for a six turbine wind generator site the probability for a fragment impacting a road was between $1 \cdot 10^{-5}$ and $1 \cdot 10^{-6}$ when the road was twice the turbine height away from the site. The risk of fragment impact for a dwelling was below $1 \cdot 10^{-6}$ when the dwellings were placed 3.5 times the turbine height away from the site (Larwood & Simms, 2018).

The studies discussed in this section together place the maximum blade fragment throw distance between about 500 – 800 metres under normal operating conditions.

3.3 Risk Statement

The studies discussed in this risk assessment all assign a very small likelihood of a blade or fragment being thrown a significant distance. Therefore, this risk assessment finds that that the risk associated with a blade throw event can be considered very low. However, it is acknowledged that in the event of a blade throw, the consequence could be significant (e.g. damage to human life or property).

4. MITIGATION MEASURES

At present there is no Australian or New Zealand standard for the design of large wind turbines (rotor swept area above 200m^2). In the absence of these, the International Electrotechnical Commission (IEC) Standards are accepted as the default for the design of wind turbines.

The IEC is a global organisation that prepares and publishes international standards for all electrical, electronic and related technologies. Its membership consists of more than sixty participating countries, including all the world's major trading nations and a growing number of industrialising countries.

The following IEC Standards will be used for the design and construction of the Project which will reinforce the confidence that blade throw will represent a very low risk:

- **IEC WT 01:2001 System for Conformity Testing and Certification of Wind Turbines — Rules and procedures:** Defines a certification system for wind turbines (IEC WT). It specifies rules for procedures and management to carry out conformity evaluation of WTs, with respect to specific standards and other technical requirements, relating to safety, reliability, performance, testing and interaction with electrical power networks.
- **IEC 61400-1:2005 Wind turbines Part 1: Design requirements:** Specifies essential design requirements to ensure the engineering integrity of wind turbines. Provides an appropriate level of protection against damage from all hazards during the planned lifetime. Is concerned with all subsystems of wind turbines such as control and protection mechanisms, internal electrical systems, mechanical systems and support structures.
- **IEC 61400-12-1:2005 Wind turbines Part 12-1: Power performance measurements of electricity-producing wind turbines:** Specifies a procedure for measuring the power performance characteristics of a single wind turbine and applies to the testing of wind turbines of all types and sizes connected to the electrical power network.
- **IEC 61400-23 Wind turbine generator systems – Part 23: Full-scale structural testing of rotor blades:** Defines the requirements for full-scale structural testing of wind turbine blades and for the interpretation and evaluation of achieved test results. Static load tests and fatigue tests are considered in this standard.
- **IEC 62305-1/3/4 Protection against lightning:** Together, these parts describe how to design a Lightning Protection System (LPS) and requirements to prevent injury to people and structure by means of a LPS, and the protection of electrical and electronic systems.
- **IEC 61400-4:2012 Wind turbines — Part 4: Design requirements for wind turbine gearboxes:** Provides guidance on the analysis of the wind turbine loads in relation to the design of the gear and gearbox elements.

It is also recommended that a high quality, comprehensive and robust operations and maintenance program is implemented to ensure that WTG faults are prevented or detected and rectified quickly, minimising the risk of occurrence of a serious or dangerous problem. The industry is constantly developing measures to limit the cost of blade damages, such as sensors to identify blade weaknesses and enable early maintenance and management measures which will also assist in mitigating blade throw risks.

Finally, a vital mitigation measure is to ensure that dwellings are located a safe distance from wind turbine generators (WTGs). As discussed in Section 0, studies place the maximum blade fragment throw distance between about 500 – 800 metres under normal operating conditions.

All dwellings are located outside the radii of a potential worst-case blade throw distance from an event, which the discussion of research in Section 3 confirms has a very low risk of occurrence, with the exception of one dwelling which is located within the upper limit of the maximum blade fragment throw distance of around 800m (dwelling AD_5, being 765 m from WTG 65). Whilst this dwelling is located downwind of the turbine, the turbine would be predominantly orientated such that the blades would be heading away from the dwelling if there was any failure. Distances between WTGs and dwellings are presented in Appendix A, with the WTG layout and dwellings detailed in Figure 2-1.

Given these factors, the risk of damage to life or property through a blade throw event at the Project can be considered very low.

5. CONCLUSIONS

This assessment has demonstrated the very small likelihood of a blade or fragment being thrown a significant distance. This assessment therefore establishes that the risk associated with a blade throw event can be considered very low. Although the predictions for blade throw likelihoods and maximum throw distances vary, studies place the maximum blade fragment throw distance between about 500 – 800 metres under normal operating conditions, and there is general agreement throughout the literature that the likelihood of damage to human life or property from a blade throw incident is extremely small and well within risk levels typically deemed acceptable by society.

6. REFERENCES

Braam, H. & Rademakers, L., 2002. *Guidelines on the environmental risk of wind turbines in the Netherlands,* The Netherlands: ECN.

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Rogers, J., Slegers, N. & Costello, M., 2011. A method for defining wind turbine setback standards. *Wind Energy.*

Sarlak, H. & Sorensen, J., 2016. Analysis of throw distances of detached objects from horizontal-axis wind turbines. *Wind Energy,* Volume 19, pp. 151-166.

Sledgers, N. et al., 2009. Modelling the risk of a failed wind turbine blade impacting a power transmission line. *Wind Engineering,* Volume 33, pp. 587-606.

APPENDIX A DISTANCE BETTWEEN WTGS AND DWELLINGS

Table 6-1 – Distance between WTGs and Dwellings

WTG No.	Easting (m)*	Northing (m)*	Nearest Dwelling ID	Nearest Dwelling Type	Distance to nearest dwelling (m)
WP1	316190.846	6502649.423	NAD_21	Non-associated Dwelling	3,235.95
WP2	316660.033	6502869.954	NAD_21	Non-associated Dwelling	3,294.01
WP3	317061.845	6502922.861	NAD_21	Non-associated Dwelling	3,506.16
WP4	317449.239	6502903.104	NAD_21	Non-associated Dwelling	3,789.73
WP5	317646.578	6503320.59	NAD_21	Non-associated Dwelling	3,668.60
WP6	317817.553	6503696.303	NAD_21	Non-associated Dwelling	3,601.26
WP7	317184.441	6502322.26	AD_7	Associated Dwelling	3,550.99
WP8	317588.545	6502126.598	AD_7	Associated Dwelling	3,562.02
WP9	317453.026	6501426.236	AD_7	Associated Dwelling	2,901.49
WP10	317732.464	6501347.185	AD_7	Associated Dwelling	3,012.58
WP11	318250.898	6501255.867	AD_7	Associated Dwelling	3,313.65
WP12	319102.057	6501480.181	AD_7	Associated Dwelling	4,119.95
WP13	318924.1	6501258.676	AD_7	Associated Dwelling	3,846.76
WP14	318777.791	6501032.549	AD_7	Associated Dwelling	3,599.21
WP15	319341.128	6500599.035	AD_7	Associated Dwelling	3,892.99
WP16	320042.268	6500328.808	NAD_1	Non-associated Dwelling	4,278.11
WP17	320736.01	6500326.421	AD_3	Associated Dwelling	4,047.83
WP18	321007.066	6499684.836	NAD_1	Non-associated Dwelling	3,527.33
WP19	321513.273	6498815.938	NAD_1	Non-associated Dwelling	2,708.96
WP20	323082.517	6499076.731	AD_8	Associated Dwelling	3,350.46
WP21	323138.002	6499550.962	AD_8	Associated Dwelling	2,933.86
WP22	323095.633	6499977.322	AD_8	Associated Dwelling	2,641.30
WP23	323198.929	6497537.828	NAD_1	Non-associated Dwelling	2,602.73

WTG No.	Easting (m)*	Northing (m)*	Nearest Dwelling ID	Nearest Dwelling Type	Distance to nearest dwelling (m)
WP24	323308.03	6498134.149	NAD_1	Non-associated Dwelling	3,044.57
WP25	323580.758	6498725.926	AD_8	Associated Dwelling	3,418.90
WP26	323545.962	6499107.037	AD_8	Associated Dwelling	3,089.09
WP27	324703.502	6497555.803	NAD_1	Non-associated Dwelling	3,965.83
WP28	324612.564	6498100.249	AD_8	Associated Dwelling	3,773.81
WP29	324632.3	6498514.803	AD_8	Associated Dwelling	3,359.19
WP30	324229.061	6498998.423	AD_8	Associated Dwelling	2,949.84
WP31	325872.662	6498217.873	AD_8	Associated Dwelling	3,756.42
WP32	325818.826	6498681.887	AD_8	Associated Dwelling	3,293.99
WP33	325257.989	6499019.076	AD_8	Associated Dwelling	2,856.68
WP34	323773.148	6499406.095	AD_8	Associated Dwelling	2,720.28
WP35	324341.665	6499321.566	AD_8	Associated Dwelling	2,609.17
WP36	324635.236	6499495.047	AD_8	Associated Dwelling	2,384.73
WP37	324927.945	6499682.672	AD_8	Associated Dwelling	2,176.45
WP38	325216.988	6499831.368	AD_8	Associated Dwelling	2,045.25
WP39	325542.572	6499948.689	AD_8	Associated Dwelling	2,000.36
WP40	325908.197	6500088.913	AD_8	Associated Dwelling	2,013.19
WP41	326393.749	6500561.993	AD_8	Associated Dwelling	1,941.39
WP42	326467.498	6500880.587	AD_8	Associated Dwelling	1,806.25
WP43	326624.181	6501222.002	AD_8	Associated Dwelling	1,792.02
WP44	326929.625	6501399.61	AD_8	Associated Dwelling	2,033.01
WP45	327248.683	6501519.799	AD_8	Associated Dwelling	2,324.37
WP46	327153.191	6502076.909	AD_8	Associated Dwelling	2,214.73
WP47	326890.069	6502553.69	AD_8	Associated Dwelling	2,061.44

WTG No.	Easting (m)*	Northing (m)*	Nearest Dwelling ID	Nearest Dwelling Type	Distance to nearest dwelling (m)
WP48	326439.481	6502905.657	AD_8	Associated Dwelling	1,821.10
WP49	326079.134	6503433.761	AD_8	Associated Dwelling	1,938.19
WP50	325789.146	6503901.545	AD_3	Associated Dwelling	2,146.13
WP51	325975.227	6504359.619	NAD_67	Non-associated Dwelling	2,275.16
WP52	326001.772	6504778.277	NAD_67	Non-associated Dwelling	1,961.58
WP53	325887.628	6505288.792	NAD_67	Non-associated Dwelling	1,775.08
WP54	325995.059	6505707.101	NAD_67	Non-associated Dwelling	1,532.39
WP55	326064	6506091.801	NAD_67	Non-associated Dwelling	1,422.44
WP56	325597.428	6506290.322	NAD_67	Non-associated Dwelling	1,902.58
WP57	325618.03	6506644.815	AD_5	Associated Dwelling	1,856.71
WP58	325468.553	6507176.882	AD_5	Associated Dwelling	1,663.51
WP59	325632.774	6507482.547	AD_5	Associated Dwelling	1,390.69
WP60	325827.066	6507813.573	AD_5	Associated Dwelling	1,125.26
WP61	326056.198	6508201.729	AD_5	Associated Dwelling	925.29
WP62	326035.871	6508550.506	AD_5	Associated Dwelling	1,092.85
WP63	325787.51	6508927.482	AD_6	Associated Dwelling	1,377.87
WP64	326518.5	6508699.386	AD_5	Associated Dwelling	867.63
WP65	327050.469	6508701.461	AD_5	Associated Dwelling	765.10
WP66	327215.065	6508969.014	AD_5	Associated Dwelling	1,060.34
WP67	327184.579	6509402.788	AD_5	Associated Dwelling	1,478.66
WP68	327366.554	6509622.758	NAD_11	Non-associated Dwelling	1,399.71
WP69	327737.176	6509901.339	NAD_11	Non-associated Dwelling	1,064.75
WP70	327921.575	6509330.633	NAD_8	Non-associated Dwelling	1,081.38

NB: Distance between WTG and dwellings were calculated by a GIS specialist using the 'spatial join function' of the ArcGIS Mapping Tool. The distance calculation does account for terrain.

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