Annex M

Blade Throw Risk Report

JUPITER WIND FARM PROJECT

Blade Throw Risk

Environmental Resources Management Australia Pty Ltd

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Customer:	Environmental Resources Management Australia Pty Ltd, Lumley House, Level 15, 309 Kent St, NSW 2000	
Contact person:	Nathan Lynch	
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DNV GL - Energy
Renewables Advisory
Suite 25, level 8
401 Docklands Drive
Docklands, VIC, 3008
Australia
Tel: +61 3 9600 1993
[Enterprise No]

Task and objective:
Consider blade throw risk in the vicinity of the proposed Jupiter Wind Farm.

Prepared by:	Verified by:	Approved by:
M Purcell Engineer	T Gilbert Principal Engineer	G Slack Area Manager, Pacific
M Quan Engineer	M Purcell Engineer	T Gilbert Principal Engineer
N Brammer Engineer		

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EXECUTIVE SUMMARY

DNV GL has been commissioned by Environmental Resources Management Australia Pty Ltd ("ERM" or "the Customer") to consider blade throw risks in the vicinity of the proposed Jupiter Wind Farm ("the Project"), on behalf of EPYC Pty. Ltd. ("EPYC" or "the Proponent") who is developing the Project. The results of the work are reported here.

Blade throw describes the rare phenomenon of a structural failure in a wind turbine generator (WTG) blade during operation resulting in the potential for parts of the blade to be ejected into the surrounding area.

The Secretary's Environmental Assessment Requirements (SEARs) [1] and the Draft New South Wales (NSW) Planning Guidelines for wind farms published by NSW Government Planning and Infrastructure [2] require that the risk of blade throw at a wind farm be considered and appropriately mitigated.

The risk of blade throw and the mitigation measures relevant to the Project are discussed in this technical note. The risk of damage to life or property through a blade throw event at the Project can be considered to be very low.

1 PROJECT SITE

1.1 Site description

The proposed development involves the construction and operation of the Jupiter Wind Farm ("the Project") within the Southern Tablelands Region of New South Wales (NSW). The Project Area (PA) covers an area of approximately 4,999 hectares (ha) spanning across the Goulburn Mulwaree and former Palerang Local Government Areas (LGAs), and is situated approximately 5 kilometres (km) southeast of the township of Tarago and approximately 18 km east of Bungendore. The Project locality is shown in *Figure 1.*

1.2 Project description

The Project will involve construction of up to 88 wind turbine generators (WTGs) within two distinct precincts. The northern precinct will consist of up to 75 WTGs, and the southern precinct up to 13 WTGs, with a maximum height of 173 m above ground level (AGL).

The Customer has provided a proposed layout for the Project [3]. The WTGs are proposed to be located on top of low lying hills present across the Project site with base elevations ranging from approximately 656 m to 767 m above sea level.

A map showing the PA, proposed WTGs, and residential dwellings is presented in *Figure 2*. The coordinates of the proposed WTG locations and the distance from each WTG to the nearest dwelling are given in *Table 2*.

1.3 Dwelling locations

A list of dwellings neighbouring the Project was supplied to DNV GL by the Customer [4]. The supplied list of dwellings also includes four unbuilt dwelling locations for which development approval has been granted.

The coordinates of dwellings within 2 km of the proposed WTG locations, involved landholder status, and distance from each dwelling to the nearest WTG are presented in *Table 1*.

DNV GL has assumed that all listed dwellings are potential inhabited residential locations. It should be noted that DNV GL has not carried out a detailed and comprehensive survey of dwelling locations in the area and is relying on information provided by the Customer.

2 ASSESSMENT REQUIREMENTS

2.1 Secretary's Environmental Assessment Requirements (SEARs)

The Secretary's Environmental Assessment Requirements for the Jupiter Wind Farm (SEARs) [1] 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."*

2.2 Planning guidelines

The Draft NSW Planning Guidelines for Wind Farms (Draft NSW Guidelines) [2] currently state:

> *"The risk of 'blade throw' – involving a wind turbine's blades breaking or being ejected during operation – should be considered. Relevant considerations may include (but are not limited to):*

- *whether the proposed turbines are certified against relevant standards such as* IEC 61400-23 Wind turbine generator systems – Part 23: Full-scale structural testing of rotor blades *or other equivalent standards - evidence of any such certification should be provided;*
- *overspeed protection mechanisms including 'fail safe' mechanisms (e.g. back up (battery) power in the event of a power failure);*
- *operational management and maintenance procedures including any regular maintenance inspections;*
- *provisions for blade replacement in the event a blade fault is identified (e.g. during a periodic inspection);*
- *the separation distance between turbines, neighbouring dwellings and property boundaries;*
- *the probability of blade throw occurring."*

3 BLADE THROW RISK

Although occurrences of blade throw are considered rare, the consequences of a blade throw event may be serious and it is important to gain a full understanding of the risks associated with the phenomenon. Understanding the behaviour of blade throw may help to inform policies regarding safe separation distances between WTGs and dwellings, as well as safe operational procedures within a wind farm. Much research has been performed within the wind industry to establish the likelihood of a blade throw event occurring and the subsequent risk of damage to property or life.

3.1 Likelihood of a blade throw event

In order to quantify the likelihood of a blade throw event, researchers have examined historical data sets of accidents and incidents on wind farms. Comprehensive and detailed data sets are not typically available [5][6], however researchers developing wind farm planning guidelines for the Dutch government examined databases in Germany, Denmark and the Netherlands and were able to establish incident rates based on the equivalent of 43,000 turbine years of operation [7]. The likelihood of loss of an entire blade was found to be 8.4×10^{-4} incidents per turbine WTG per year and the risk of loss of a blade tip was found to be 1.2×10^{-4} incidents per turbine per year. Another study calculated the likelihood of blade failure based on historical records to be in the order of 10^{-3} to 10^{-4} failures per turbine per year [6].

Although a number of the studies referred to here have based their conclusions on data sets which contain blade throw event data for older WTGs, it is expected that these probabilities will represent a conservative estimate for a modern WTG. This is because the data sets used are likely to contain information for WTGs that may not have been certified to modern standards, and are unlikely to have the sophisticated control and safety systems of a modern WTG.

3.2 Maximum blade throw distance

To examine the likely distribution of projectiles in a blade throw event, researchers typically perform aerodynamic modelling considering the projectile motion of a range of blade fragment sizes for various WTG models and wind speed conditions.

Rogers et al. [8] performed a Monte Carlo analysis based on blade throw dynamic modelling for different fragment sizes and environmental conditions, using 0.66 MW, 1.5 MW and 3.0 MW WTG models. A theoretical maximum throw distance of 590 m was found to occur for a 20% blade fragment for the 1.5 MW WTG model. This study also demonstrated that WTG throw distance is related mostly to the release velocity of a fragment, rather than the WTG height or blade radius. This suggests that the typical increase in hub height and rotor diameter seen in modern WTG designs will not necessarily relate to a greater potential blade throw distance.

A maximum throw distance of 400 m for a blade was modelled by Braam & Rademakers [7] considering overspeed conditions (defined as two times the rated rotor speed) and a 2 MW WTG. Cotton [5] used a simplified point-mass projectile model and a worst-case scenario of a 1 in 50 year extreme wind speed event and low air-drag conditions. Maximum (99^{th} percentile) throw distances of 198 m and 1462 m were predicted for a full blade and 10% fragment respectively for a 3.0 MW WTG. Based on information from the Caithness Windfarm Information Forum which included 37 reported instances of blade throw, Cotton [5] established that most blade throw events resulted in fragments being propelled to within 600 m of the WTG location, with only one reported incident of a blade fragment reaching 1000 m.

These studies all demonstrate maximum blade throw distances of between approximately 200 m and 1500 m, with the throw distance inversely proportional to the size of the object, and more extreme scenarios (e.g., high wind or overspeed conditions) resulting in larger throw distances. The studies also indicate that blade throw distances are not particularly sensitive to WTG dimensions or capacity, meaning that the findings are expected to be relevant for modern WTGs.

3.3 Likelihood of a blade or fragment being thrown a specified distance

The maximum throw distances presented in *Section 3.2* represent low probability events in themselves, and in order to determine the overall likelihood of a blade or fragment being thrown this distance, the probability must be combined with the likelihood of a blade throw event occurring (as discussed in *Section 3.1*). In the case of the results presented by Cotton, the maximum blade throw distances correspond to a 1-in-50 year wind event (likelihood of 2×10^{-2}), and a 1-in-100 or 99th percentile throw distance (likelihood of 1×10^{-2}), which when combined with the likelihood of a blade throw event occurring (10^{-3} or 10^{-4}) result in very low likelihoods of blades or fragments being thrown to the maximum distances described here.

Braam & Rademakers [7] calculated contours around a WTG representing the likelihood of an individual being hit by a WTG fragment. For a 2 MW WTG, a risk contour of 10^{-6} incidents/turbine/year was established at a distance of 144 m from the WTG. Another study calculated the overall risk of direct impact from a blade throw event at a distance of 160 m from WTG locations as being smaller than 10^{-9} incidents/turbine/year [6].

These likelihoods can be considered to be extremely small, and are significantly smaller than the likelihood of accidents occurring during many everyday activities such as road travel or working in the agricultural industry (both approximately 10^{-4} incidents/year) [6].

3.4 Risk rating

The risk associated with a particular event or activity is defined as the combination of the likelihood of the event occurring, and the potential consequence. With an understanding of the likelihood of occurrence of a blade throw event at specified distances from WTG locations, along with consideration of the possible consequences of a blade throw event, it is possible to establish the associated risks to life and property.

Although the consequences of a blade throw event could be significant (e.g., damage to human life or property) the very small likelihood of a blade or fragment being thrown a significant distance means 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, 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.

4 MITIGATION

Although the likelihood of a blade throw event causing damage to human life or property can be considered extremely small, a number of mitigating factors or recommendations are presented here to provide additional confidence that blade throw represents a very low risk:

- It is understood that a number of potential WTG models are currently under consideration for use at the Project. It is recommended that the selected WTG model is certified to the appropriate international standards including:
  - *IEC 61400-1 Wind turbines – Part 1: Design requirements*;
  - *IEC 61400-23 Wind turbine generator systems – Part 23: Full-scale structural testing of rotor blades;* and
  - *IEC 62305-1/3/4 Protection against lightning*.

  Compliance with these standards will mean that the WTG is designed with protection systems that are capable of maintaining the WTG in a safe condition in response to a range of faults or unusual conditions (e.g., high wind speed, high rotational speed, excessive vibration).
- It is 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.
- Distances between WTGs and dwellings are presented in *Table 1* and *Table 2*. It can be noted that the minimum distance between a WTG and a non-involved landholder dwelling is 1.07 km, while the minimum distance between a WTG and an involved landholder dwelling is 0.56 km. While there are a number of dwellings within the 'maximum throw distance' discussed in *Section 3.2*, the discussion in *Section 3.3* demonstrates that the likelihood of a blade or fragment damaging life or property at these distances is extremely small and the risk lower than levels typically deemed acceptable by society.

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

The SEARs for the Jupiter Wind Farm and Draft NSW Planning Guidelines require that the risk of a blade throw event is considered and appropriately mitigated. An understanding of the likelihood, dynamics and risks associated with blade throw has been attained within the wind industry through a broad range of research and investigation of blade throw incidents. From this, it is generally accepted that risk associated with blade throw is very low, and that likelihood of damage to human life or property from a blade throw event is very small, and well within levels typically deemed acceptable by society.

While there are a number of neighbouring dwellings located within the maximum blade throw distance established in relevant literature, the blade throw risk at the Project is considered very low and can be mitigated through use of a WTG designed and built to appropriate certification standards, an operation and maintenance program designed to ensure asset integrity, and large separation distances between WTGs and the majority of residential dwellings.

6 REFERENCES

[1] "Secretary's Environmental Assessment Requirements", SEARs for Jupiter Wind Farm - Application Number SSD 13_6277, NSW Department of Planning and Infrastructure, 2 March 2016.

[2] "Draft NSW Planning Guidelines, Wind Farms", NSW Department of Planning and Infrastructure, December 2011.

[3] "JWF_WTG_V5_20150522.shp", download from file delivery service, access provided by ERM to DNV GL, 29 June 2015.

[4] "JWF_Dwellings_MGA55_20160513.xlsx", provided by email from ERM to DNV GL, 17 May 2016.

[5] R. Cotton, "Numerical Modelling of Wind Turbine Blade Throw", Health & Safety Laboratory, Bristol, 2007.

[6] "Study and development of a methodology for the estimation of the risk and harm to persons from wind turbines ", Health and Safety Executive UK, MMI Engineering Ltd, Warrington UK, 2013.

[7] H. Braam, L. W. M. M. Rademakers, "Guidelines on the environmental risk of wind turbines in the Netherlands", presentation Global Wind Energy Conference, Paris, France, 2002.

[8] J. Rogers, N. Slegers, M. Costello, "A method for defining wind turbine setback standards", *Wind Energy*, John Wiley & Sons, Ltd., 2011.

[9] "0034-7616_V10 - General Specifications V 126 3_3 MW IEC 3A 50 Hz.pdf", download from file delivery service, access provided by ERM to DNV GL, 29 May 2015.

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Dwelling ID	Easting[1] [m]	Northing[1] [m]	Status	Distance to nearest WTG [m]
J103A	742505	6107961	Involved Landholder	1181
J103B	742583	6107895	Involved Landholder	1153
J119	742009	6092676	Involved Landholder	634
J12A	743409	6103064	Involved Landholder	1011
J12B	743588	6103119	Involved Landholder	824
J140	743131.7	6101006	Involved Landholder	1106
J151	740388	6090540	Involved Landholder	710
J163	745543	6100089	Involved Landholder	929
J165	743165	6102466	Involved Landholder	1020
J44	744067.1	6106726	Involved Landholder	606
J53	744981.7	6106579	Involved Landholder	751
J79	742677.8	6099519	Involved Landholder	563
J89	742923.4	6106135	Involved Landholder	605
J96A	742667	6105528	Involved Landholder	1086
J96B	742750	6105322	Involved Landholder	1129
J105	738940	6092132	-	1392
J115	738440	6092661	-	1914
J120	738906	6091824	-	1495
J126B	741615	6111462	-	1927
J130	741215.3	6110328	-	1972
J134	741536	6110624	-	1715
J135	741319	6110706	-	1941
J138	742295	6107519	-	1182
J141	746551	6103871	-	1286
J142	746010	6104388	-	1577
J144	746494	6104799	-	1160
J145	745725.7	6105138	-	1263
J146	746184	6104994	-	1078
J147	746447	6104325	-	1633
J148	746014	6104219	-	1411
J152	746501	6110413	-	1702
J153	746929	6110488	-	1927
J16	743867	6104375	-	1098
J162_TB[2]	748557	6101408	-	1169
J174A	748193	6102321	-	1186
J174B	748387	6102234	-	1363
J178	742061	6099366	-	1178
J181	742108	6102518	-	1996
J184	741451	6100095	-	1900

[1] Coordinate system: MGA zone 55, GDA94 datum
[2] Dwelling not yet built

Table 1: Dwelling locations within 2 km of WTGs at the proposed Project

Dwelling ID	Easting[1] [m]	Northing[1] [m]	Status	Distance to nearest WTG [m]
J194	740800	6087598	-	1492
J197	738848	6090268	-	1130
J116A	742069	6102101	-	1943
J116B	742116	6101885	-	1883
J20	742740	6102263	-	1317
J208	745869	6099526	-	1079
J216	744854	6099403	-	1079
J217	745680	6099319	-	1353
J224	738743	6092769	-	1645
J226	745401	6099419	-	1444
J227	741806	6089667	-	1508
J230A	747497	6110096	-	1886
J230B	747576	6110176	-	1998
J234A	747774	6103681	-	1711
J234B	747601	6103861	-	1735
J235	745302	6099055	-	1633
J237	741499	6091426	-	1080
J241	739229	6091823	-	1194
J247	745265	6098403	-	1993
J255	741085	6090116	-	1149
J257	741556	6110433	-	1684
J269	746899	6097757	-	1435
J3	745692	6110374	-	1351
J392	742308	6107841	-	1327
J393	738904	6091486	-	1637
J40	744089	6104771	-	1336
J422_TB[2]	741808	6098273	-	1846
J424	741606	6098909	-	1715
J425	741737	6098901	-	1594
J5	742375	6102772	-	1854
J60	744900	6111980	-	1927
J70	739472	6091650	-	1072
J75A	742333	6104756	-	1817
J75B	742283	6104697	-	1894
J76	745945	6110174	-	1226
J76b	745980	6110265	-	1323
J85	742574	6102275	-	1479
J87	742702	6105043	-	1353
J88	738838	6092449	-	1490

[1] Coordinate system: MGA zone 55, GDA94 datum
[2] Dwelling not yet built

Table 1: Dwelling locations within 2 km of WTGs at the proposed Project - concluded

WTG ID	Easting[1] [m]	Northing[1] [m]	Base Elevation [m]	Nearest Dwelling	Distance to Nearest Dwelling [m]
1	744406	6109438	724	J3	1591
2	744346	6102432	724	J12B	1023
3	747323	6100126	699	J208	1573
4	745727	6106483	680	J53	751
5	743945	6109545	713	J3	1934
6	746442	6106428	690	J146	1457
7	744212	6109049	718	J3	1986
8	745556	6102445	684	J141	1739
9	744118	6101506	704	J140	1106
10	744847	6101969	708	J12B	1705
11	744355	6102014	712	J165	1273
12	744134	6108304	701	J44	1579
13	744765	6108412	708	J44	1825
14	748237	6100284	680	J162_TB[2]	1169
15	740388	6092679	767	J70	1378
16	743099	6109744	712	J257	1690
17	743236	6099443	677	J79	563
18	741121	6092899	743	J119	916
19	741400	6092501	734	J119	634
20	745805	6102824	691	J141	1286
21	744416	6109825	730	J3	1389
22	743337	6108799	700	J103B	1177
23	743494	6109695	739	J103A	1996
24	744430	6102811	720	J12B	897
25	743240	6110426	736	J257	1684
26	747802	6099561	670	J208	1933
27	744071	6107931	698	J44	1205
28	745255	6102680	701	J148	1716
29	740402	6089116	750	J255	1211
30	748085	6099883	666	J162_TB[2]	1596
31	744857	6101587	697	J163	1648
32	746701	6105940	680	J146	1078
33	743359	6110062	737	J257	1841
34	743780	6109027	724	J103B	1647
35	739943	6089987	720	J151	710
36	740321	6092305	748	J70	1072
37	744772	6100957	695	J163	1161
38	745332	6101919	694	J163	1842
39	748502	6099956	671	J162[2]	1453
40	744282	6101002	725	J140	1150
41	744510	6108708	714	J44	2031
42	744240	6110170	727	J3	1466
43	745649	6108613	690	J76A	1589
44	743477	6106380	725	J89	605

[1] Coordinate system: MGA zone 55, GDA94 datum
[2] Dwelling not yet built

Table 2: Proposed WTG layout for the Project site - continued

WTG ID	Easting[1] [m]	Northing[1] [m]	Base Elevation [m]	Nearest Dwelling	Distance to Nearest Dwelling [m]
45	747883	6098802	681	J269	1435
46	746955	6100823	701	J163	1591
47	739725	6088632	744	J194	1492
48	744924	6108865	695	J76A	1660
49	743832	6109942	707	J3	1910
50	743529	6109312	710	J103A	1695
51	745152	6108446	699	J53	1875
52	746223	6108273	671	J76A	1921
53	744009	6107522	680	J44	798
54	747035	6102064	663	J174A	1186
55	745786	6101474	675	J163	1406
56	747726	6100214	675	J162_TB[2]	1455
57	747190	6100490	726	J208	1635
58	746645	6101051	679	J163	1463
59	745180	6102300	692	J12B	1790
60	743855	6099811	686	J216	1079
61	740751	6092804	745	J119	1264
62	739380	6088927	739	J197	1443
63	739751	6089012	732	J197	1547
64	739842	6089457	721	J151	1213
65	740659	6092128	726	J237	1095
66	744347	6100627	702	J140	1273
67	743999	6101878	701	J165	1020
68	744364	6103396	713	J12B	824
69	745147	6101171	687	J163	1152
70	745874	6101867	673	J163	1809
71	745340	6101530	684	J163	1455
72	746284	6102215	670	J141	1677
73	743389	6107071	683	J44	761
74	743994	6108684	708	J103B	1617
75	744014	6106122	700	J44	606
76	746242	6108688	680	J76A	1515
77	743615	6110341	707	J257	2061
78	745515	6109026	685	J76A	1226
79	743151	6109226	705	J103A	1420
80	743755	6108268	692	J103B	1230
81	744871	6109301	698	J3	1351
82	746574	6102462	666	J141	1409
83	746635	6102051	656	J174A	1581
84	746268	6101014	670	J163	1175
85	746390	6100471	688	J163	929
86	747039	6099715	687	J208	1185
87	743632	6106026	709	J89	717
88	740884	6092435	736	J119	1151

[1] Coordinate system: MGA zone 55, GDA94 datum
[2] Dwelling not yet built

Table 2: Proposed WTG layout for the Project site - concluded

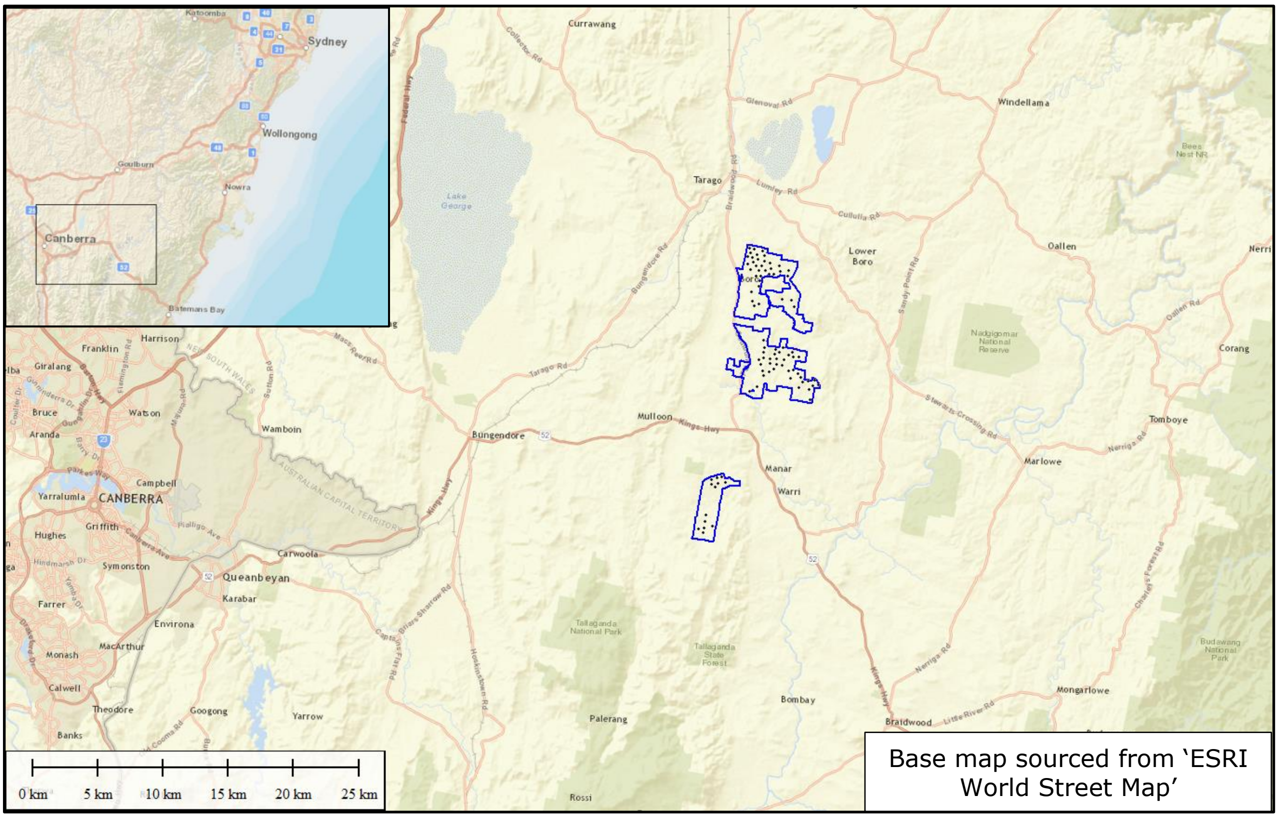

Figure 1: Location of the proposed Project

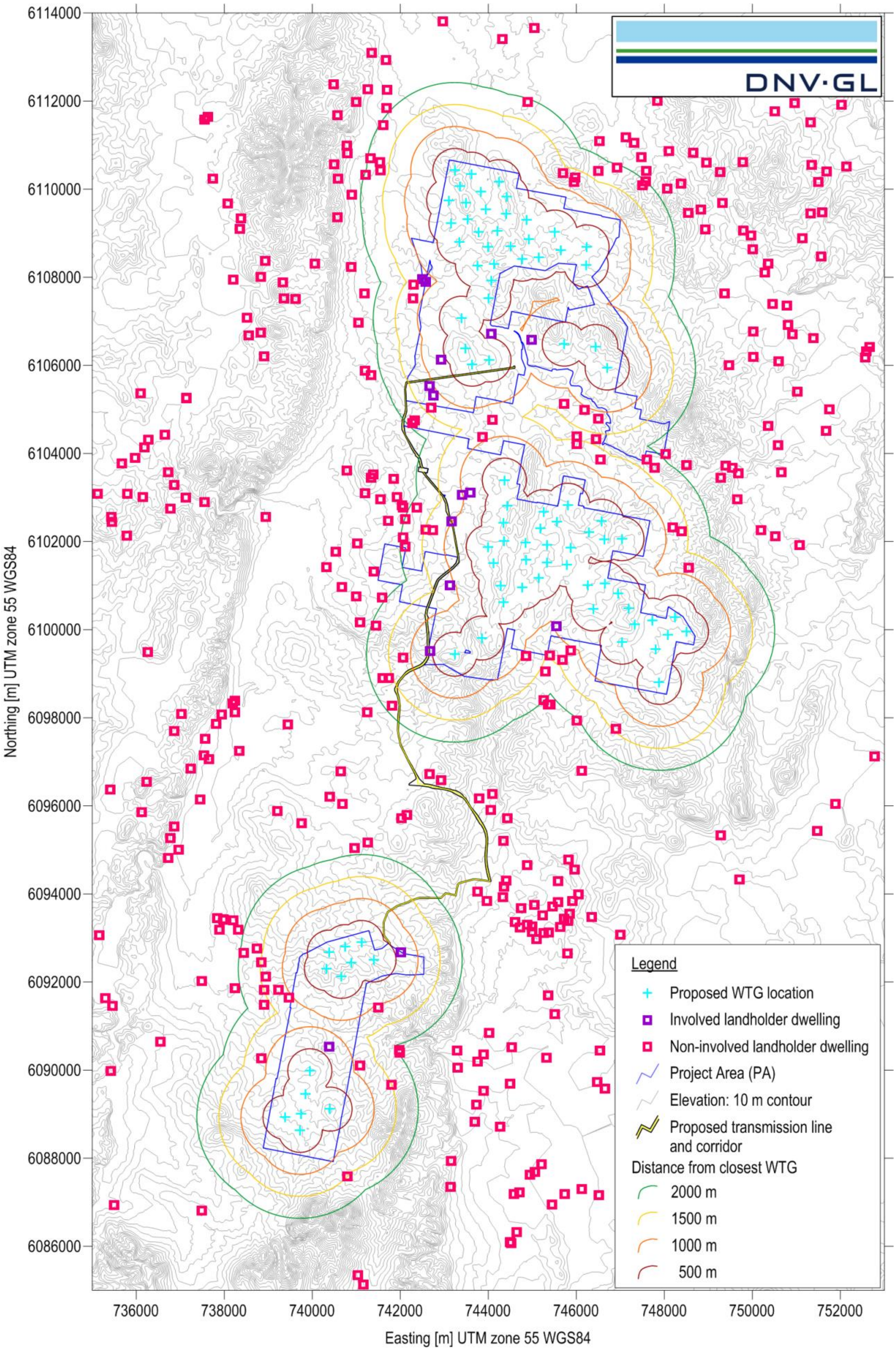

Figure 2: Map of the proposed Project showing PA and distances from WTG to dwellings.

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