Annex L

Shadow Flicker and Blade Glint Report

DNV·GL

JUPITER WIND FARM

Shadow Flicker and Blade Glint Assessment for the Proposed Jupiter Wind Farm

Environmental Resources Management Australia Pty Ltd

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EXECUTIVE SUMMARY

DNV GL has been commissioned by Environmental Resources Management Australia Pty Ltd ("ERM" or "the Customer") to independently assess the expected annual shadow flicker duration 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.

Shadow flicker involves the modulation of light levels resulting from the periodic passage of a rotating wind turbine generator (WTG) blade between the sun and an observer. The duration of shadow flicker experienced at a specific location can be determined using a purely geometric analysis which takes into account the relative position of the sun throughout the year, the WTGs at the site, local topography and the viewer. This method has been used to determine the shadow flicker duration at sensitive locations neighbouring the proposed Project.

However, this analysis method tends to be conservative and typically results in over-estimation of the number of hours of shadow flicker experienced at a dwelling [1]. As such, an attempt has been made to quantify the likely reduction in shadow flicker duration due to WTG orientation and cloud cover, and therefore produce a prediction of the actual shadow flicker duration likely to be experienced at a dwelling.

The Customer has commissioned DNV GL to assess the shadow flicker based upon a layout provided for the Project consisting of 88 WTGs [2]. A number of WTG models are under consideration for the Project, and for the shadow flicker analysis the Customer has requested [3] that DNV GL model a WTG configuration with a hub height of 110 m and a blade diameter of 126 m with the maximum blade tip height of 173 m. The Customer has also provided the locations of dwellings in the vicinity of the Project [4] and elevation contours for the Project Area (PA) [5]. These have been used to determine the theoretical duration of shadow flicker caused by the Project at each dwelling.

The Secretary's Environmental Assessment Requirements (SEARs) [6] for the Project, indicate that shadow flicker impacts must be assessed. The Draft New South Wales (NSW) Planning Guidelines (Draft NSW Guidelines) [7] recommend a shadow flicker limit of 30 hours per year. However, the Draft NSW Planning Guidelines do not contain or recommend a methodology for assessing shadow flicker durations. Planning guidelines in a number of other jurisdictions [8] [9] refer to the Environment Protection and Heritage Council (EPHC) Draft National Wind Farm Development Guidelines [10] for guidance on the methodology for assessing shadow flicker durations. As such, this assessment was based on the methodology recommended in the Draft National Wind Farm Development Guidelines. Calculations were carried out assuming dwellings had either one or two stories with window heights of either 2 m or 6 m, respectively. The relevant shadow flicker duration at a dwelling was taken as the maximum duration occurring within 50 m of the dwelling, in accordance with the Draft National Wind Farm Development Guidelines. DNV GL considers this to be good practice, as this recommendation has been made to account for minor modelling inaccuracies, uncertainty in the turbine and dwelling locations, and the potential for shadow flicker to vary considerably over the area occupied by a dwelling. However, it is noted that there is no explicit requirement to consider shadow flicker durations within 50 m of a dwelling under the SEARs and Draft NSW Guidelines.

In addition, the EPHC Draft National Wind Farm Development Guidelines [10] recommend a limit on the theoretical shadow flicker duration of 30 hours per year, and a limit on the actual shadow flicker duration of 10 hours per year.

The results indicate that, of the dwellings identified by the Customer for study, there are locations within 50 m of 23 dwellings that are predicted to experience some shadow flicker. Thirteen of these locations are predicted to experience a theoretical shadow flicker duration in excess of the recommended limit of

30 hours per year within 50 m of the dwelling location. The information provided by the Customer [4] describes 11 of these dwellings as involved landholders, and two as non-involved landholders. It is noted that the recommended limits are exceeded by up to 110 hours at some of the involved landowner dwellings.

When considering the actual shadow flicker duration, which takes into account the reduction in shadow flicker due to WTG orientation and cloud cover, 11 dwellings are expected to experience shadow flicker durations in excess of the recommended limit of 10 hours per year within 50 m of the dwelling location. Nine of these dwellings are described as involved landholders, and two as non-involved landholders. The prediction of the actual shadow flicker duration does not take into account any reduction due to low or high wind speed (when the WTGs would not be operating), vegetation or other shielding effects around each dwelling in calculating the number of shadow flicker hours. Therefore, the values presented may still be regarded as conservative.

It is noted that the exceedances experienced by non-involved landholders are typically small, with the limits exceeded by at most 13%, and that the exceedances occur within 50 m of the dwelling, rather than at the dwelling itself. Although DNV GL considers it good practice to assess shadow flicker durations within 50 m of a dwelling, it is noted that under the SEARs and Draft NSW Guidelines, there is no explicit requirement to do so. When the shadow flicker durations at dwellings are considered (rather than the durations within 50 m of dwellings) it is noted that only eight dwellings exceed the theoretical shadow flicker duration limit of 30 hours, and that all of these dwellings are involved landholders.

The effects of shadow flicker may be reduced through a number of mitigation measures, such as, the installation of screening structures or planting of trees to block shadows cast by the WTGs, the use of WTG control strategies which shut down selected WTGs when shadow flicker is likely to occur, or the relocation of WTGs.

It should be noted that the results presented here have been generated based on the WTG dimensions described above. If the WTG eventually selected for the Project has dimensions smaller than those considered here, but still within the WTG envelope, then shadow flicker durations in the vicinity of the Project site are likely to be lower than those predicted here.

Blade glint involves the reflection of light from a WTG blade, and can be seen by an observer as a periodic flash of light coming from the WTG. Blade glint is not generally a problem for modern WTGs provided non-reflective coatings are used for the surface of the blades.

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*.

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 [2]. 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. The Customer has also provided 1 m vertical resolution elevation contours for the PA [5].

A map showing the PA, proposed WTGs, and residential dwellings is presented in *Figure 3*. The coordinates of the proposed WTG locations are given in *Table 2*.

DNV GL has modelled the shadow flicker using the WTG configuration as outlined by the Customer [3] with a hub height of 110 m and rotor diameter of 126 m, and a maximum tip height of 173 m. These WTG dimensions represent the maximum physical dimensions of WTG models under consideration for the Project, and results generated based on these dimensions will be conservative for WTG configurations with dimensions that remain inside this maximum WTG envelope, by satisfying all of the following criteria:

- a rotor diameter of 126 m or less;
- a maximum blade chord[1] of 4.75 m or less;
- an upper blade tip height of 173 m or less; and
- a lower tip height of 47 m or higher.

1.2 Dwelling locations

The locations of dwellings in the vicinity of the proposed Project have been provided by the Customer [4]. All dwellings within 2 km of the Project have been considered in this analysis, and details of the dwellings 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.

[1] The maximum blade chord is the thickest part of the blade.

2 ASSESSMENT REQUIREMENTS

2.1 Secretary's Environmental Assessment Requirements (SEARs)

The Secretary's Environmental Assessment Requirements for the Jupiter Wind Farm (SEARs) [6] state the following with regard to shadow flicker:

> *"The EIS must address the following specific matters for both the wind farm and associated infrastructure: … the EIS must … assess the impact of shadow "flicker" [and] "blade glint" … from the wind farm."*

2.2 Planning guidelines

The Draft NSW Planning Guidelines for Wind Farms (Draft NSW Guidelines) [7] currently state:

> *"The impact of 'shadow flicker' from wind turbines on neighbours'* dwelling *within 2 km of a proposed wind turbine should be assessed. The shadow flicker experienced at any dwelling should not exceed 30 hours per year as a result of the operation of the wind farm. Specialist modelling software should be used to model shadow flicker impacts prior to the finalisation of the turbine layout."*

Although the Draft NSW Guidelines specify a shadow flicker limit (30 hours per year), neither the SEARs nor the Draft NSW Guidelines specify a methodology for assessing shadow flicker impacts. Guidelines for wind farm development in other jurisdictions (including Victoria [8] and Queensland [9]) refer to the Environment Protection and Heritage Council (EPHC) Draft National Wind Farm Development Guidelines (Draft National Guidelines) [10] with regard to the methodology for assessing shadow flicker. DNV GL has utilised this methodology to conduct shadow flicker assessments across Australia, and has utilised it to assess the shadow flicker impact for the Project.

The Draft National Guidelines recommend that the modelled theoretical shadow flicker duration at a dwelling should not exceed 30 hours per year, and that the actual or measured shadow flicker duration should not exceed 10 hours per year. The guidelines also recommend that the shadow flicker duration at a dwelling should be assessed by calculating the maximum shadow flicker occurring within 50 m of the centre of a dwelling. Consideration of the shadow flicker occurring within 50 m of a dwelling is intended to account for minor modelling inaccuracies, uncertainty in the turbine and dwelling locations, and the potential for shadow flicker to vary considerably over the area occupied by a single dwelling. However, it is noted that there is no explicit requirement to assess shadow flicker durations within 50 m of a dwelling under the SEARs and Draft NSW Guidelines.

These limits are assumed to apply to a single dwelling, and it is noted that there is no requirement under either the SEARs, Draft NSW Guidelines or Draft National Guidelines to assess shadow flicker durations at locations other than in the vicinity of dwellings.

The Draft National Guidelines provide background information, a proposed methodology and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm.

The impact of shadow flicker is typically only significant up to a distance of approximately 10 rotor diameters from a WTG [1] or approximately 800 to 1300 m for modern WTGs (which typically have rotor diameters of 80 to 130 m). Beyond this distance limit, the shadow is diffused such that the variation in light levels is not likely to be sufficient to cause annoyance. This issue is discussed in the Draft National Guidelines where it is stated that:

"Shadow flicker can theoretically extend many kilometres from a wind turbine. However the intensity of the shadows decreases with distance. While acknowledging that different individuals have different levels of sensitivity and may be annoyed by different levels of shadow intensity, these guidelines limit assessment to moderate levels of intensity (i.e., well above the minimum theoretically detectable threshold) commensurate with the nature of the impact and the environment in which it is experienced."

The Draft National Guidelines therefore suggest a distance equivalent to 265 maximum blade chords as an appropriate limit, which corresponds to approximately 800 to 1325 m for modern WTGs (which typically have maximum blade chord lengths of 3 to 5 m). The distance limit used in this assessment is discussed in *Section 3.2*.

The Draft National Guidelines also provide guidance on blade glint and state that:

"The sun's light may be reflected from the surface of wind turbine blades. Blade Glint has the potential to annoy people. All major wind turbine manufacturers currently finish their blades with a low reflectivity treatment. This prevents a potentially annoying reflective glint from the surface of the blades and the possibility of a strobing reflection when the turbine blades are spinning. Therefore the risk of blade glint from a new development is considered to be very low."

The Draft National Guidelines also provide commentary on the negligible risk of distraction of vehicle drivers, and state the following:

"There is a negligible risk associated with distraction of vehicle drivers who experience shadow flicker, for the following reasons:

- *Shadow flicker is little different for a vehicle in motion than the effect of shadows from trees on the side of the road or high passing vehicles, neither of which represent a significant risk in terms of road transport.*
- *In spite of extensive searches, no references to motor vehicle accidents caused by this phenomenon have been found.*

It is noted, however, that until wind farms become widespread in Australia they will represent a novelty that could cause distraction for drivers (regardless of shadow flicker). Consideration should be given to development of viewing areas for wind farms close to high volume roads."

3 SHADOW FLICKER AND BLADE GLINT ASSESSMENT

3.1 Shadow flicker overview

Shadow flicker may occur under certain combinations of geographical position and time of day, when the sun passes behind the rotating blades of a WTG and casts a moving shadow over neighbouring areas. When viewed from a stationary position the moving shadows cause periodic flickering of the light from the sun, giving rise to the phenomenon of 'shadow flicker'.

The effect is most noticeable inside buildings, where the flicker appears through a window opening. The likelihood and duration of the effect depends upon a number of factors, including:

- direction of the property relative to the WTG;
- distance from the WTG (the further the observer is from the WTG, the less pronounced the effect will be);
- wind direction (the shape of the shadow will be determined by the position of the sun relative to the WTG rotor which will be oriented to face the wind);
- WTG height and rotor diameter;
- time of year and day (the position of the sun in the sky); and
- weather conditions (cloud cover reduces the occurrence of shadow flicker).

3.2 Theoretical modelled shadow flicker duration

The theoretical number of hours of shadow flicker experienced annually at a given location can be calculated using a geometrical model which incorporates the sun path, topographic variation over the PA and WTG details such as rotor diameter and hub height.

The WTGs have been modelled assuming they are spherical objects, which is equivalent to assuming the WTGs are always oriented perpendicular to the sun-turbine vector. This assumption will mean the model calculates the maximum duration for which there is potential for shadow flicker to occur.

In line with the methodology proposed in the Draft National Guidelines, DNV GL has assessed the shadow flicker at the surveyed dwelling locations and has determined the highest shadow flicker duration within 50 m of the centre of each dwelling location.

Shadow flicker has been calculated at dwellings at heights of 2 m, to represent ground floor windows, and 6 m, to represent second floor windows. The shadow receptors are simulated as fixed points, representing the worst case scenario, as real windows would be facing a particular direction. The shadow flicker calculations for dwelling locations have been carried out with a temporal resolution of 1 minute; if shadow flicker is predicted to occur in any 1-minute period, the model records this as 1 minute of shadow flicker. The shadow flicker maps for this analysis (as shown in *Figure 4* and *Figure 5*) were generated using a temporal resolution of 5 min to reduce computational requirements to acceptable levels.

As part of the shadow flicker assessment, it is necessary to make an assumption regarding the maximum length of a shadow cast by a WTG that is likely to cause annoyance due to shadow flicker. The SEARs and Draft NSW Guidelines do not provide any guidance on this parameter. The UK wind industry considers that 10 rotor diameters is appropriate [11], while the Draft National Guidelines suggest a distance equivalent to 265 maximum blade chords as an appropriate limit. For this study, the Customer has nominated a WTG type which has a rotor diameter of 126 m. DNV GL has assumed a maximum shadow length equivalent to 10 rotor diameters, or 1260 m. Under the Draft National Guidelines, this will be conservative for any WTG with a maximum blade chord of less than 4.75 m.

The model also makes the following assumptions and simplifications:

- there are clear skies every day of the year;
- the WTGs are always rotating; and
- the blades of the WTGs are always perpendicular to the direction of the line of sight from the location of interest to the sun.

These simplifications mean that the theoretical results generated by the model are likely to overestimate the actual shadow flicker duration.

The settings used to execute the model can be seen in *Table 3*.

To illustrate typical results, an indicative shadow flicker map for a WTG located in a flat area is shown in *Figure 2*. The geometry of the shadow flicker map can be characterised as a butterfly shape, with the four protruding lobes corresponding to slowing of solar north-south travel around the summer and winter solstices for morning and evening. The lobes to the north of the indicative WTG location result from the summer solstice and conversely the lobes to the south result from the winter solstice. The lobes to the west result from morning sun while the lobes to the east result from evening sun. When the sun is low in the sky, the length of shadows cast by the WTG increases, increasing the area around the WTG affected by shadow flicker.

3.3 Factors affecting shadow flicker duration

Shadow flicker duration calculated in this manner overestimates the annual number of hours of shadow flicker experienced at a specified location for several reasons.

1. The WTG will not always be yawed such that its rotor is in the worst case orientation (i.e. perpendicular to the sun-turbine vector). Any other rotor orientation will reduce the area of the projected shadow, and hence the shadow flicker duration.

   The wind speed frequency distribution or wind rose at the Project site (as shown in *Figure 2*) can be used to determine probable WTG orientation, and to calculate the resulting reduction in shadow flicker duration.

2. The occurrence of cloud cover has the potential to significantly reduce the number of hours of shadow flicker.

   Cloud cover measurements recorded at nearby meteorological stations may be used to estimate probable levels of cloud cover, and to provide an indication of the resulting reduction in shadow flicker duration.

3. Aerosols (moisture, dust, smoke, etc.) in the atmosphere have the ability to influence shadows cast by a WTG.

   The length of the shadow cast by a WTG is dependent on the degree that direct sunlight is diffused, which is in turn dependent on the amount of dispersants (humidity, smoke and other aerosols) in the path between the light source (sun) and the receptor.

4. The modelling of the WTG rotor as a sphere rather than individual blades results in an overestimate of shadow flicker duration.

WTG blades are of non-uniform thickness with the thickest part of the blade (maximum chord) close to the hub and the thinnest part (minimum chord) at the tip. Diffusion of sunlight, as discussed above, results in a limit to the maximum distance that a shadow can be perceived. This maximum distance will also be dependent on the thickness of the WTG blade, and the human threshold for perception of light intensity variation. As such, a shadow cast by the blade tip will be shorter than the shadow cast by the thickest part of the blade.

5. The analysis does not consider that when the sun is positioned directly behind the WTG hub, there is no variation in light intensity at the receptor location and therefore no shadow flicker.
6. The presence of vegetation or other physical barriers around a shadow receptor location may shield the view of the WTG, and therefore reduce the incidence of shadow flicker.
7. Periods where the WTG is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce the annual shadow flicker duration.

3.4 Predicted actual shadow flicker duration

As discussed above in *Section 3.3*, there are a number of factors which may reduce the incidence of shadow flicker, such as cloud cover and variation in WTG orientation, that are not taken into account in the calculation of the theoretical shadow flicker duration. Exclusion of these factors means that the theoretical calculation is conservative. An attempt has been made to quantify the likely reduction in shadow flicker duration due to these effects, and therefore produce a prediction of the actual shadow flicker duration likely to be experienced at a dwelling.

Cloud cover is typically measured in 'oktas' or eighths of the sky covered with cloud. DNV GL has obtained data from three Bureau of Meteorology (BoM) stations, located approximately 33 to 45 km from the Project site [12] [13] [14], with twice daily approximations of the percentage of cloud cover visible across the sky. The results show that the average annual cloud cover values obtained from readings at 9 am and 3 pm, averaged over the three stations, are approximately 4.4 and 4.3 oktas respectively. This means that on an average day, 4.3/8 or approximately 54% of the sky in the vicinity of the Project is covered with clouds. Although it is not possible to definitively calculate the effect of cloud cover on shadow flicker duration, a reduction in the shadow flicker duration proportional to the amount of cloud cover is a reasonable assumption. An assessment of the likely reduction in shadow flicker duration due to cloud cover was conducted on a monthly basis, which indicated that a reduction of 52% to 58% is expected at the affected dwellings.

Similarly, WTG orientation can have an impact on the shadow flicker duration. The shadow flicker impact is greatest when the WTG rotor plane is approximately perpendicular to a line joining the sun and an observer, and a minimum when the rotor plane is approximately parallel to a line joining the sun and an observer. A wind direction frequency distribution previously derived by DNV GL from data collected by masts on-site has been used to estimate the reduction in shadow flicker duration due to rotor orientation. The measured wind rose is shown overlaid on the indicative shadow flicker map in *Figure 2*. An assessment of the likely reduction in shadow flicker duration due to variation in WTG orientation was conducted on an annual basis, which indicated that a reduction of 16% to 63% can be expected at the affected dwelling locations.

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in calculating the shadow flicker duration. Similarly, WTG shutdown has not been considered. It is therefore likely that the adjusted shadow flicker durations presented here can still be regarded as a conservative assessment.

3.5 Blade glint

Blade glint involves the regular reflection of sun off rotating WTG blades. Its occurrence depends on a combination of circumstances arising from the orientation of the nacelle, angle of the blade, and the angle of the sun. The reflectiveness of the surface of the blades is also important. As discussed, blade glint is not generally a problem for modern WTGs, provided the blades are coated with a non-reflective paint, and it is not considered further here.

4 RESULTS OF THE ANALYSIS

The theoretical shadow flicker durations at receptors within the vicinity of the proposed Project are presented in *Table 4*. The maximum predicted theoretical shadow flicker durations within 50 m of receptors are also presented in this table. The theoretical results are presented in the form of shadow flicker maps at 2 m and 6 m above ground in *Figure 4* and *Figure 5* respectively. Additionally, the theoretical results are presented in the form of shadow flicker duration contours in *Figure 6* and *Figure 7*.

These results indicate that 23 of the dwellings identified by the Customer for study are predicted to experience some shadow flicker within 50 m of the dwelling, based on the methodology recommended in the Draft National Guidelines. Thirteen dwellings are calculated to experience theoretical shadow flicker durations of greater than the NSW Guidelines recommended limit of 30 hours per year within 50 m of the dwelling. Eleven of these dwellings are described as involved landholders, and two as non-involved landholders. It is noted that the recommended limits are exceeded by up to 110 hours at some of the involved landowner dwellings.

An assessment of the level of conservatism associated with theoretical results has been conducted by calculating the possible reduction in shadow flicker duration due to WTG orientation (based on the wind rose measured at the Project site) and cloud cover. These adjusted results are presented as predicted actual shadow flicker durations in *Table 4*. Consideration of WTG orientation and cloud cover reduces the predicted shadow flicker duration by 60% to 84% at the dwellings considered.

After reductions due to WTG orientation and cloud cover are taken into account, 11 dwellings are predicted to be subject to an actual shadow flicker duration above the limit of 10 hours within 50 m of the dwelling location, as recommended in the Draft National Guidelines. Nine of these dwellings are described as involved landowners, and two as non-involved landholders.

It should be noted that the method prescribed by the Draft National Guidelines for assessing actual shadow flicker duration recommends that only reductions due to cloud cover, and not WTG orientation, be included. However, DNV GL considers that this additional reduction due to WTG orientation is appropriate, as the projected area of the WTG, and therefore the expected shadow flicker duration, is reduced when the WTG rotor is not perpendicular to the line joining the sun and dwelling.

It is noted that the exceedances experienced by non-involved landholders are typically small, with the limits exceeded by at most 13%, and that the exceedances occur within 50 m of the dwelling, rather than at the dwelling itself. Although DNV GL considers it good practice to assess shadow flicker durations within 50 m of a dwelling, it is noted that under the SEARs and NSW Guidelines, there is no explicit requirement to do so. When the shadow flicker durations at dwellings are considered (rather than the durations within 50 m of dwellings) it is noted that only eight dwellings exceed the theoretical shadow flicker duration limit of 30 hours, and that all of these dwellings are involved landholders.

4.1 Mitigation options

If shadow flicker presents a problem, its effects can be reduced through a number of measures. These include the installation of screening structures or planting of trees to block shadows cast by the WTGs, the use of WTG control strategies which shut down selected WTGs when shadow flicker is likely to occur, or relocation of WTGs.

It should be noted that the results presented here have been generated based on the WTG configuration discussed in *Section 1.1*. If the WTG eventually selected for the Project has dimensions smaller than those considered here, but still within the hypothetical WTG envelope, then shadow flicker durations in the vicinity of the Project site are likely to be lower than those predicted here.

5 CONCLUSION

An analysis has been conducted to determine the annual duration of shadow flicker experienced at dwellings in the vicinity of the proposed Project, based on the methodology proposed in the Draft National Guidelines. The results of the assessment are presented in the form of shadow flicker maps, in *Figure 4* to *Figure 7*. The shadow flicker results for each dwelling location predicted to be affected by shadow flicker are also listed in *Table 4*.

The assessment of theoretical shadow flicker duration shows that 23 of the dwellings identified by the Customer are predicted to experience some level of theoretical shadow flicker within 50 m of the dwelling location. Thirteen of these dwellings are predicted to experience theoretical annual shadow flicker duration in excess of the 30 hour limit recommended in the Draft NSW Guidelines and the Draft National Guidelines within 50 m of a dwelling. Eleven of these dwellings are described as involved landowners, and two as non-involved landholders. It is noted that the recommended limits are exceeded by up to 110 hours at some of the involved landowner dwellings.

Approximation of the degree of conservatism associated with the theoretical results has been conducted by calculating the possible reduction in shadow flicker duration due to WTG orientation and cloud cover. The results of this analysis, also presented in *Table 4*, show that 11 dwellings are predicted to experience actual annual shadow flicker durations within 50 m of the dwelling location that are in excess of the limit of 10 hours recommended in the Draft National Guidelines. Nine of these dwellings are described as involved landowners, and two as non-involved landholders. The calculation of the predicted actual shadow flicker duration does not take into account any reduction due to low or high wind speed (when the WTGs would not be operating), vegetation or other shielding effects around each dwelling in calculating the number of shadow flicker hours. Therefore, the values presented may still be regarded as a conservative assessment.

It is noted that the exceedances experienced by non-involved landholders are typically small, with the limits exceeded by at most 13%, and that the exceedances occur within 50 m of the dwelling, rather than at the dwelling itself. Although DNV GL considers it good practice to assess shadow flicker durations within 50 m of a dwelling, it is noted that under the SEARs and Draft NSW Guidelines, there is no explicit requirement to do so. If only the shadow flicker durations at dwellings are considered (rather than the durations within 50 m of dwellings) it is noted that only eight dwellings exceed the theoretical shadow flicker duration limit of 30 hours, and that all of these dwellings are involved landholders.

If shadow flicker presents a problem, mitigation strategies to reduce the duration of shadow flicker experienced at a dwelling can include: the installation of screening structures or planting of trees to block shadows cast by the WTGs, the use of WTG control strategies which shut down selected WTGs when shadow flicker is likely to occur, or relocation of WTGs.

Blade glint is not likely to cause a problem for observers in the vicinity of the Project provided non-reflective coatings are used on the blades of the WTGs.

6 REFERENCES

[1] H.-D. Freund, F. H. Kiel, “Influences of the opaqueness of the atmosphere, the extension of the sun and the rotor blade profile on the shadow impact of wind turbines”, DEWI Magazine No. 20, February 2002, pp43-51.

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

[3] Email from ERM to DNV GL, 2 July 2015.

[4] “JWF_Dwellings_20160513.xlsx”, download from file delivery service, access provided by ERM to DNV GL, 17 May 2015.

[5] “Jupiter_1mcontours.zip”, download from file delivery service, access provided by EYPC to DNV GL, 8 May 2014.

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

[7] “Draft NSW Planning Guidelines, Wind Farms”, NSW Department of Planning and Infrastructure, December 2011.

[8] “Policy and planning guidelines for development of wind energy facilities in Victoria”, Sustainable Energy Authority Victoria, July 2012.

[9] “Wind farm state code, Planning guideline – draft for consultation”, Queensland Department of State Development, Infrastructure and Planning, April 2014.

[10] “National Wind Farm Development Guidelines – Public Consultation Draft”, Environment Protection and Heritage Council (EPHC), July 2010.

[11] “Planning for Renewable Energy – A Companion Guide to PPS22”, Office of the Deputy Prime Minister, UK, 2004.

[12] “Climate statistics for Australian locations – Canberra Airport Comparison”, Bureau of Meteorology, [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_070014.shtml. [Accessed 3 December 2014].

[13] “Climate statistics for Australian locations – Goulburn TAFE”, Bureau of Meteorology [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_070263.shtml. [Accessed 3 December 2014].

[14] “Climate statistics for Australian locations – Nerriga Composite”, Bureau of Meteorology [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_069049.shtml. [Accessed 3 December 2014].

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Dwelling ID	Easting[1] [m]	Northing[1] [m]	Dwelling status	Nearest WTG	Distance from nearest WTG [m]
J103A	742505	6107961	Involved Landholder	22	1181
J103B	742583	6107895	Involved Landholder	73	1153
J119	742009	6092676	Involved Landholder	19	634
J12A	743409	6103064	Involved Landholder	68	1011
J12B	743588	6103119	Involved Landholder	68	824
J140	743132	6101006	Involved Landholder	9	1106
J151	740388	6090540	Involved Landholder	35	710
J163	745543	6100089	Involved Landholder	85	929
J165	743165	6102466	Involved Landholder	67	1020
J44	744067	6106726	Involved Landholder	75	606
J53	744982	6106579	Involved Landholder	4	751
J79	742678	6099519	Involved Landholder	17	563
J89	742923	6106135	Involved Landholder	44	605
J96A	742667	6105528	Involved Landholder	87	1086
J96B	742750	6105322	Involved Landholder	87	1129
J105	738940	6092132	-	36	1392
J115	738440	6092661	-	36	1914
J120	738906	6091824	-	36	1495
J126B	741615	6111462	-	25	1927
J130	741215	6110328	-	16	1972
J134	741536	6110624	-	25	1715
J135	741319	6110706	-	25	1941
J138	742295	6107519	-	73	1182
J141	746551	6103871	-	20	1286
J142	746010	6104388	-	20	1577
J144	746494	6104799	-	32	1160
J145	745726	6105138	-	32	1263
J146	746184	6104994	-	32	1078
J147	746447	6104325	-	20	1633
J148	746014	6104219	-	20	1411
J152	746501	6110413	-	78	1702
J153	746929	6110488	-	76	1927
J16	743867	6104375	-	68	1098
J162_TB[2]	748557	6101408	-	14	1169
J174A	748193	6102321	-	54	1186
J174B	748387	6102234	-	54	1363
J178	742061	6099366	-	17	1178
J181	742108	6102518	-	67	1996

[1] Coordinate system: UTM zone 55, WGS84 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]	Dwelling status	Nearest WTG	Distance from nearest WTG [km]
J184	741451	6100095	-	17	1900
J194	740800	6087598	-	47	1492
J197	738848	6090268	-	35	1130
J116A	742069	6102101	-	67	1943
J116B	742116	6101885	-	67	1883
J20	742740	6102263	-	67	1317
J208	745869	6099526	-	85	1079
J216	744854	6099403	-	60	1079
J217	745680	6099319	-	85	1353
J224	738743	6092769	-	36	1645
J226	745401	6099419	-	85	1444
J227	741806	6089667	-	29	1508
J230A	747497	6110096	-	76	1886
J230B	747576	6110176	-	76	1998
J234A	747774	6103681	-	82	1711
J234B	747601	6103861	-	82	1735
J235	745302	6099055	-	60	1633
J237	741499	6091426	-	19	1080
J241	739229	6091823	-	36	1194
J247	745265	6098403	-	60	1993
J255	741085	6090116	-	35	1149
J257	741556	6110433	-	25	1684
J269	746899	6097757	-	45	1435
J3	745692	6110374	-	81	1351
J392	742308	6107841	-	73	1327
J393	738904	6091486	-	36	1637
J40	744089	6104771	-	87	1336
J422_TB[2]	741808	6098273	-	17	1846
J424	741606	6098909	-	17	1715
J425	741737	6098901	-	17	1594
J5	742375	6102772	-	67	1854
J60	744900	6111980	-	42	1927
J70	739472	6091650	-	36	1072
J75A	742333	6104756	-	87	1817
J75B	742283	6104697	-	87	1894
J76A	745945	6110174	-	78	1226
J76b	745980	6110265	-	78	1323
J85	742574	6102275	-	67	1479
J87	742702	6105043	-	87	1353
J88	738838	6092449	-	36	1490

[1] Coordinate system: UTM zone 55, WGS84 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]	WTG ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
1	744406	6109438	724	45	747883	6098802	681
2	744346	6102432	724	46	746955	6100823	701
3	747323	6100126	699	47	739725	6088632	744
4	745727	6106483	680	48	744924	6108865	695
5	743945	6109545	713	49	743832	6109942	707
6	746442	6106428	690	50	743529	6109312	710
7	744212	6109049	718	51	745152	6108446	699
8	745556	6102445	684	52	746223	6108273	671
9	744118	6101506	704	53	744009	6107522	680
10	744847	6101969	708	54	747035	6102064	663
11	744355	6102014	712	55	745786	6101474	675
12	744134	6108304	701	56	747726	6100214	675
13	744765	6108412	708	57	747190	6100490	726
14	748237	6100284	680	58	746645	6101051	679
15	740388	6092679	767	59	745180	6102300	692
16	743099	6109744	712	60	743855	6099811	686
17	743236	6099443	677	61	740751	6092804	745
18	741121	6092899	743	62	739380	6088927	739
19	741400	6092501	734	63	739751	6089012	732
20	745805	6102824	691	64	739842	6089457	721
21	744416	6109825	730	65	740659	6092128	726
22	743337	6108799	700	66	744347	6100627	702
23	743494	6109695	739	67	743999	6101878	701
24	744430	6102811	720	68	744364	6103396	713
25	743240	6110426	736	69	745147	6101171	687
26	747802	6099561	670	70	745874	6101867	673
27	744071	6107931	698	71	745340	6101530	684
28	745255	6102680	701	72	746284	6102215	670
29	740402	6089116	750	73	743389	6107071	683
30	748085	6099883	666	74	743994	6108684	708
31	744857	6101587	697	75	744014	6106122	700
32	746701	6105940	680	76	746242	6108688	680
33	743359	6110062	737	77	743615	6110341	707
34	743780	6109027	724	78	745515	6109026	685
35	739943	6089987	720	79	743151	6109226	705
36	740321	6092305	748	80	743755	6108268	692
37	744772	6100957	695	81	744871	6109301	698
38	745332	6101919	694	82	746574	6102462	666
39	748502	6099956	671	83	746635	6102051	656
40	744282	6101002	725	84	746268	6101014	670
41	744510	6108708	714	85	746390	6100471	688
42	744240	6110170	727	86	747039	6099715	687
43	745649	6108613	690	87	743632	6106026	709
44	743477	6106380	725	88	740884	6092435	736

[1] Coordinate system: UTM zone 55, WGS84 datum

Table 2: Proposed WTG layout for the Project

Model setting	Value
Maximum shadow length	1260 m
Year of calculation	2027
Minimum elevation of the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere (Disc for WTG orientation reduction calculation)
Sun modelled as	Disc
Offset between rotor and tower	None
Receptor height (single storey)	2 m
Receptor height (double storey)	6 m
Locations used for determining maximum shadow flicker within 50 m of each dwelling[1]	25 m grid centred on dwelling location

[1] In addition to the 25 m resolution grid points, points were added every 45° on a 50 m radius circle centred on the dwelling location.

Table 3: Shadow flicker model settings for theoretical shadow flicker calculation

Dwelling ID	Easting[1] [m]	Northing[1] [m]	Dwelling status	Contributing WTGs	Theoretical annual				Predicted actual annual[3]			
					At dwelling[2] [hr/yr]		Max within 50 m of dwelling[2] [hr/yr]		At dwelling[2] [hr/yr]		Max within 50 m of dwelling[2] [hr/yr]	
					SF at 2 m	SF at 6 m	SF at 2 m	SF at 6 m	SF at 2 m	SF at 6 m	SF at 2m	SF at 6 m
J103A	742505	6107961	Involved	80	0.0	0.0	10.7	10.4	0.0	0.0	3.7	3.5
J103B	742583	6107895	Involved	80	11.9	11.4	13.2	12.8	3.9	3.8	4.4	4.3
J119	742009	6092676	Involved	18, 19, 61, 88	**100.8**	**100.7**	**120.2**	**119.1**	**36.5**	**36.1**	**44.5**	**44.5**
J12A	743409	6103064	Involved	24, 68	**37.3**	**37.0**	**42.1**	**41.7**	**12.6**	**12.6**	**14.1**	**14.1**
J12B	743588	6103119	Involved	24, 68	**71.1**	**70.3**	**80.2**	**80.6**	**24.5**	**24.1**	**28.9**	**29**
J138	742295	6107519	-	73	20.6	19.5	28.9	27.8	7.4	7.1	**10.8**	**10.5**
J140	743132	6101006	Involved	9, 40, 66	**36.8**	**37.0**	**62.5**	**62.2**	**11.1**	**11.2**	**18.3**	**18.4**
J163	745543	6100089	Involved	85	26.8	26.6	**36.1**	**36.6**	7.9	7.8	9.5	9.4
J165	743165	6102466	Involved	2, 11	11.6	11.6	**39.2**	**38.1**	4.1	4.1	**14.1**	**13.5**
J174A	748193	6102321	-	54	14.9	14.4	17.2	16.9	4.6	4.5	5.2	5.1
J178	742061	6099366	-	17	9.5	9.0	10.8	10.4	3.4	3.2	3.9	3.8
J197	738848	6090268	-	35	14.9	14.4	16.9	16.4	5.3	5.1	5.9	5.7
J208	745869	6099526	-	86	10.0	9.6	11.1	10.7	3.6	3.4	3.9	3.8
J216	744854	6099403	-	60	14.8	14.4	17.1	16.8	5.9	5.8	6.8	6.6
J237	741499	6091426	-	65	18.7	17.8	**30.9**	**30.2**	6.1	5.7	**10.9**	**10.5**
J241	739229	6091823	-	36	16.8	16.9	20.0	20.4	5.1	5.1	5.7	5.7
J255	741085	6090116	-	35	12.7	12.1	14.0	13.5	4.2	4.1	4.6	4.4
J44	744067.1	6106726	Involved	73	**36.3**	**37.1**	**47.5**	**48.7**	**14.0**	**14.3**	**17.5**	**18.0**
J53	744982	6106579	Involved	4, 75	**39.6**	**40.7**	**55.9**	**56.8**	**12.3**	**12.8**	**19.5**	**19.8**
J70	739472	6091650	-	36, 65	12.4	11.2	**33.8**	**31.9**	2.2	1.8	8.7	8.3
J79	742677.8	6099519	Involved	17, 60	**66.3**	**66.4**	**91.0**	**89.0**	**22.8**	**22.7**	**31.0**	**30.5**
J89	742923	6106135	Involved	44, 75, 87	**96.0**	**96.2**	**113.9**	**114.4**	**31.3**	**31.3**	**36.3**	**36.4**
J96A	742667	6105528	Involved	87	24.6	23.7	**30.1**	29.3	6.2	6.0	7.8	7.6
		Limits		**n/a**	**30**		**30**		**10**		**10**	

[1] Coordinate system: UTM zone 55, WGS84 datum
[2] Dwellings with zero hours shadow flicker have been omitted from this table, and values above the recommended limits are highlighted in **bold text**
[3] Considering likely reductions in shadow flicker duration due to cloud cover and WTG orientation

Table 4: Theoretical and predicted actual annual shadow flicker durations

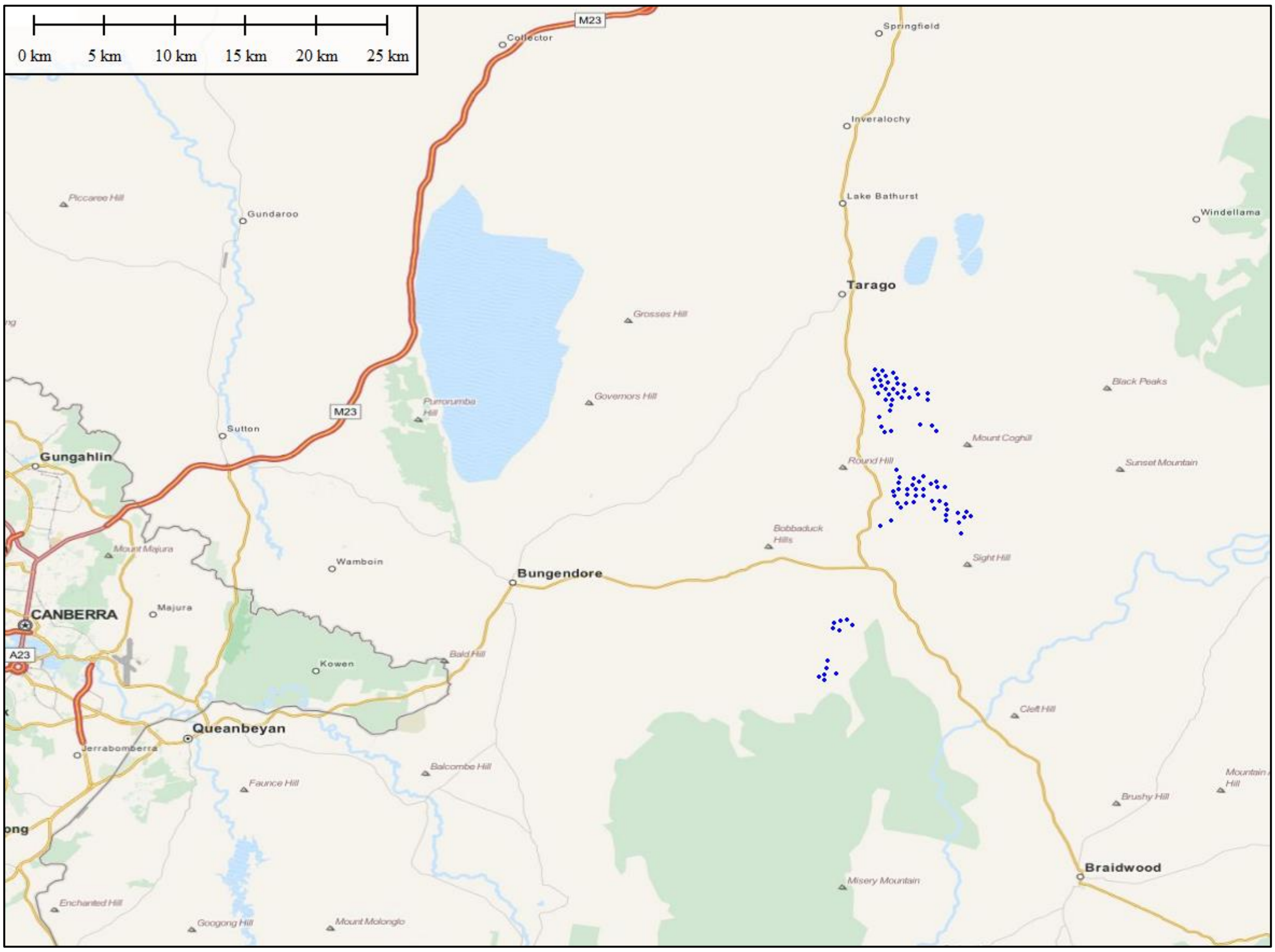


Figure 1: Location of the proposed Project

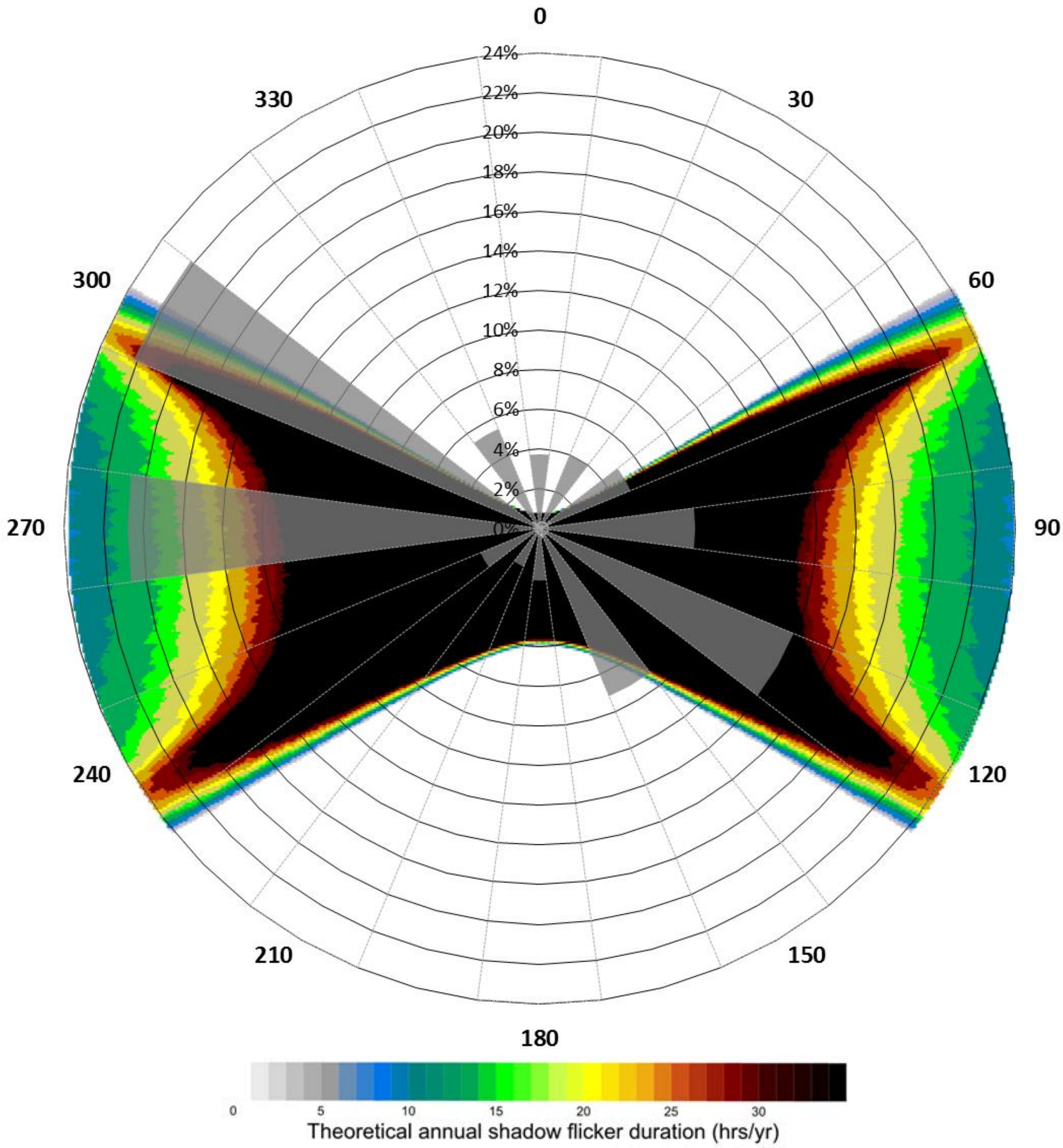
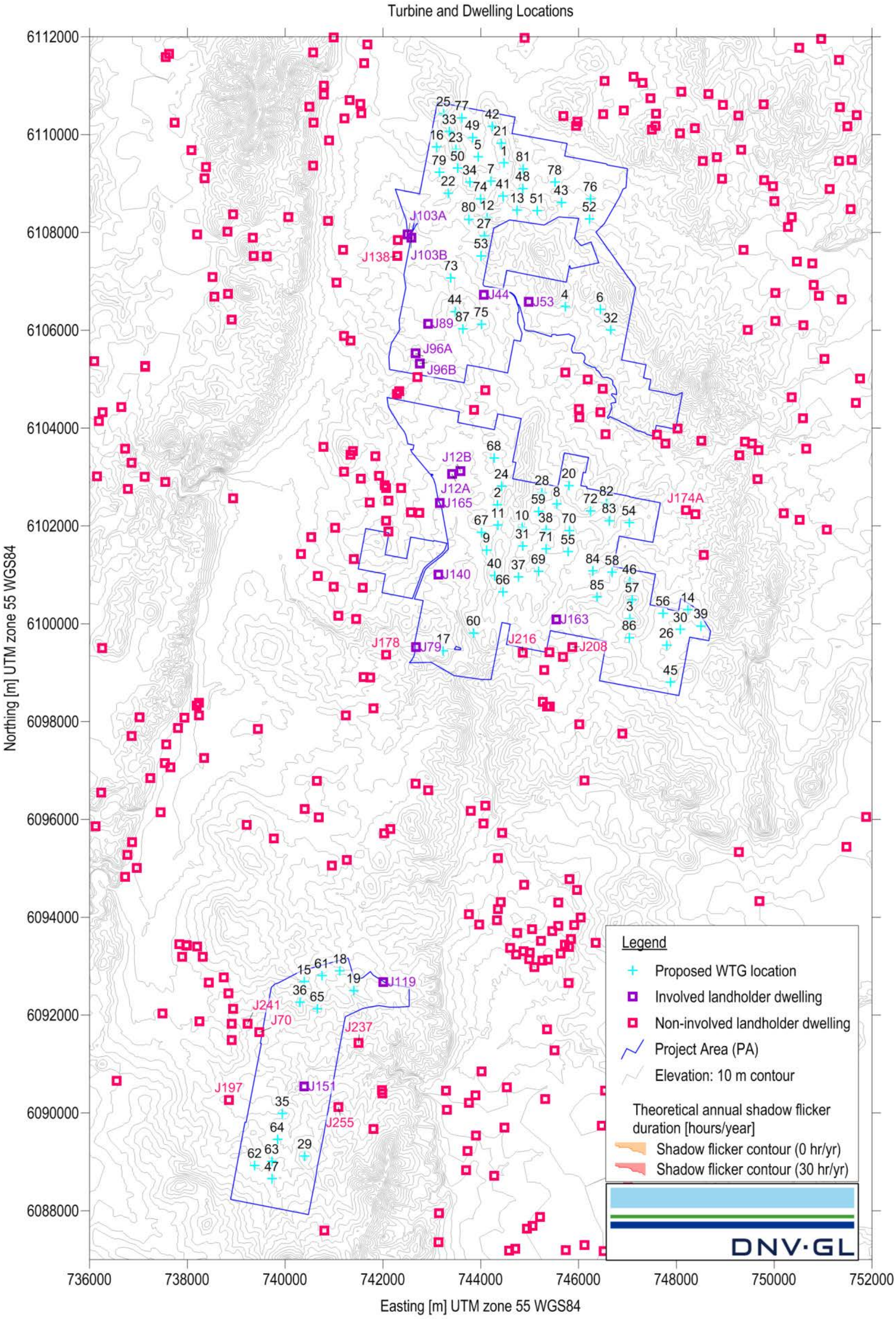
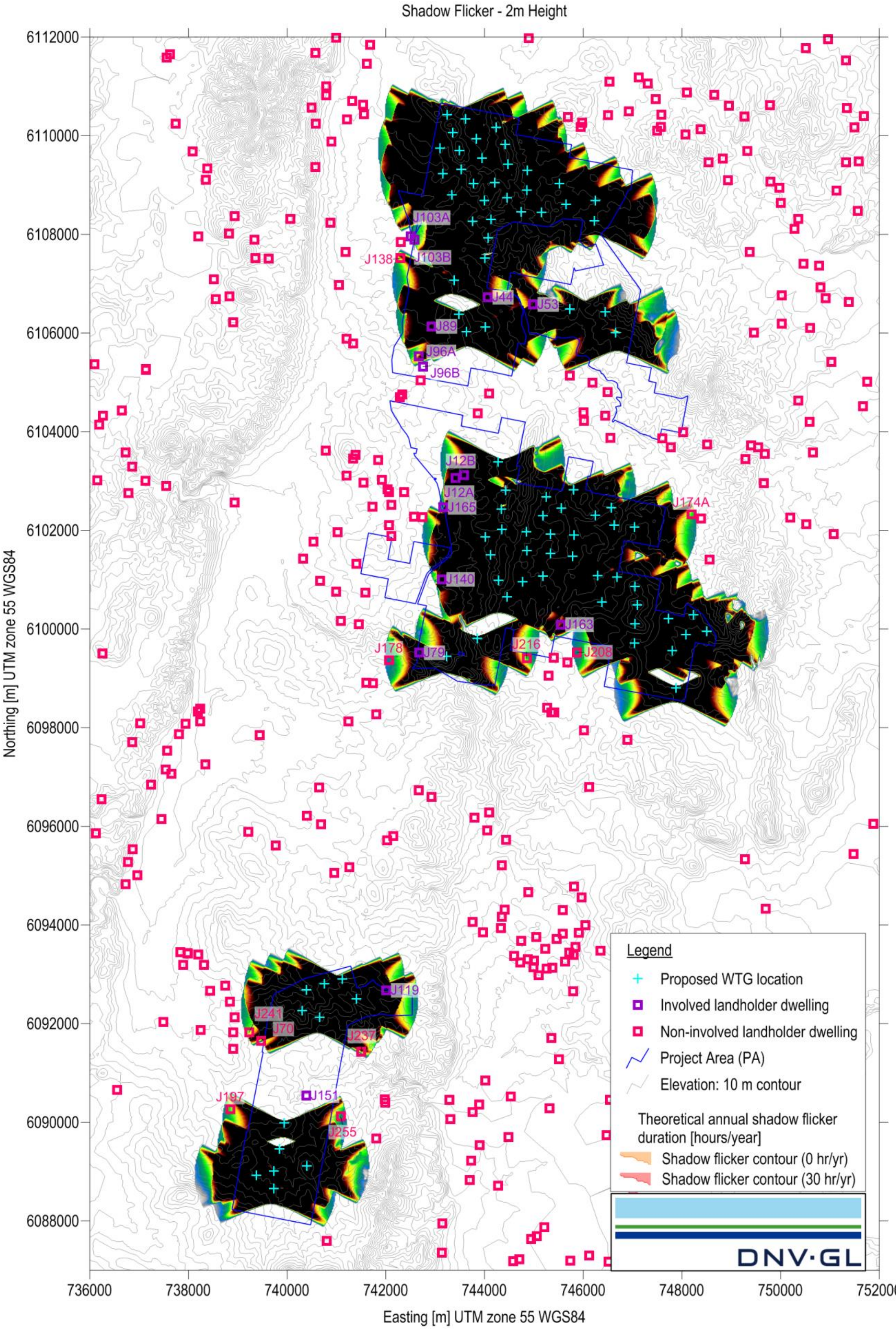


Figure 2: Indicative shadow flicker map and wind direction frequency distribution



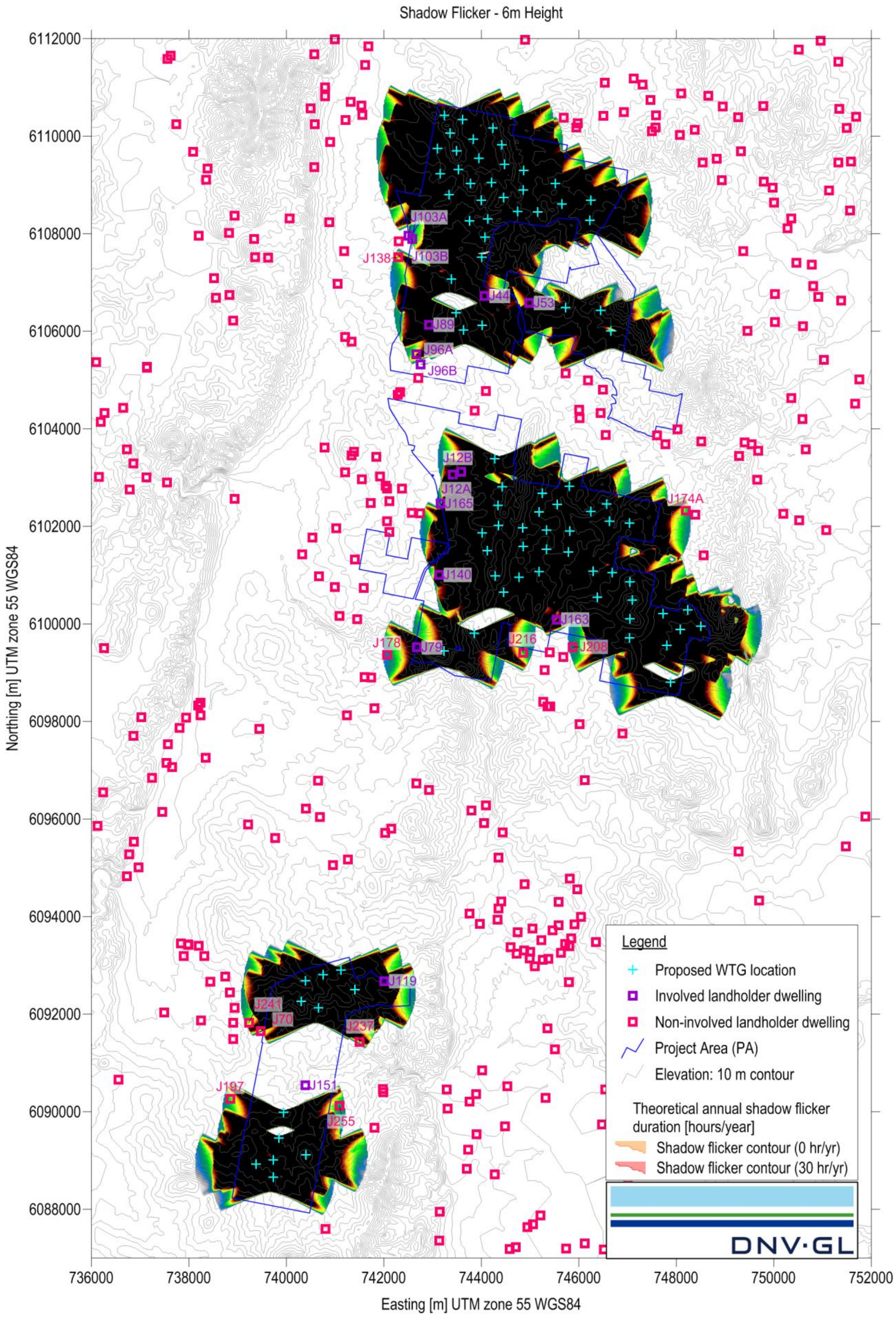
Note: The shadow flicker calculation follows the methodology prescribed by the "EPHC - National Wind Farm Development Guidelines - Draft (July 2010)"

Figure 3: Map of the proposed Project with WTG and dwelling locations.



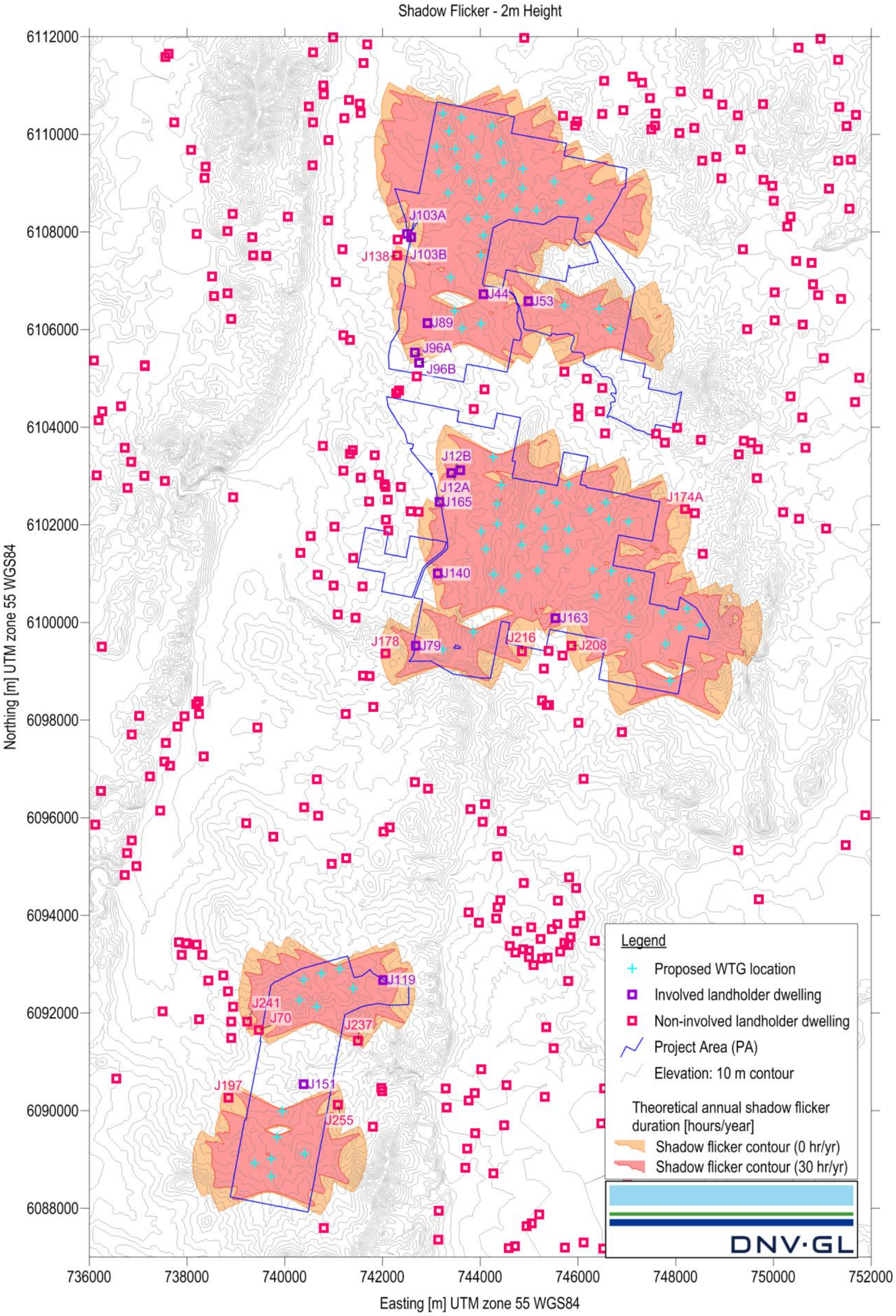
Note: The shadow flicker calculation follows the methodology prescribed by the "EPHC - National Wind Farm Development Guidelines - Draft (July 2010)"

Figure 4: Map of the proposed Project with WTGs, dwelling locations and theoretical annual shadow flicker duration at 2 m above ground level



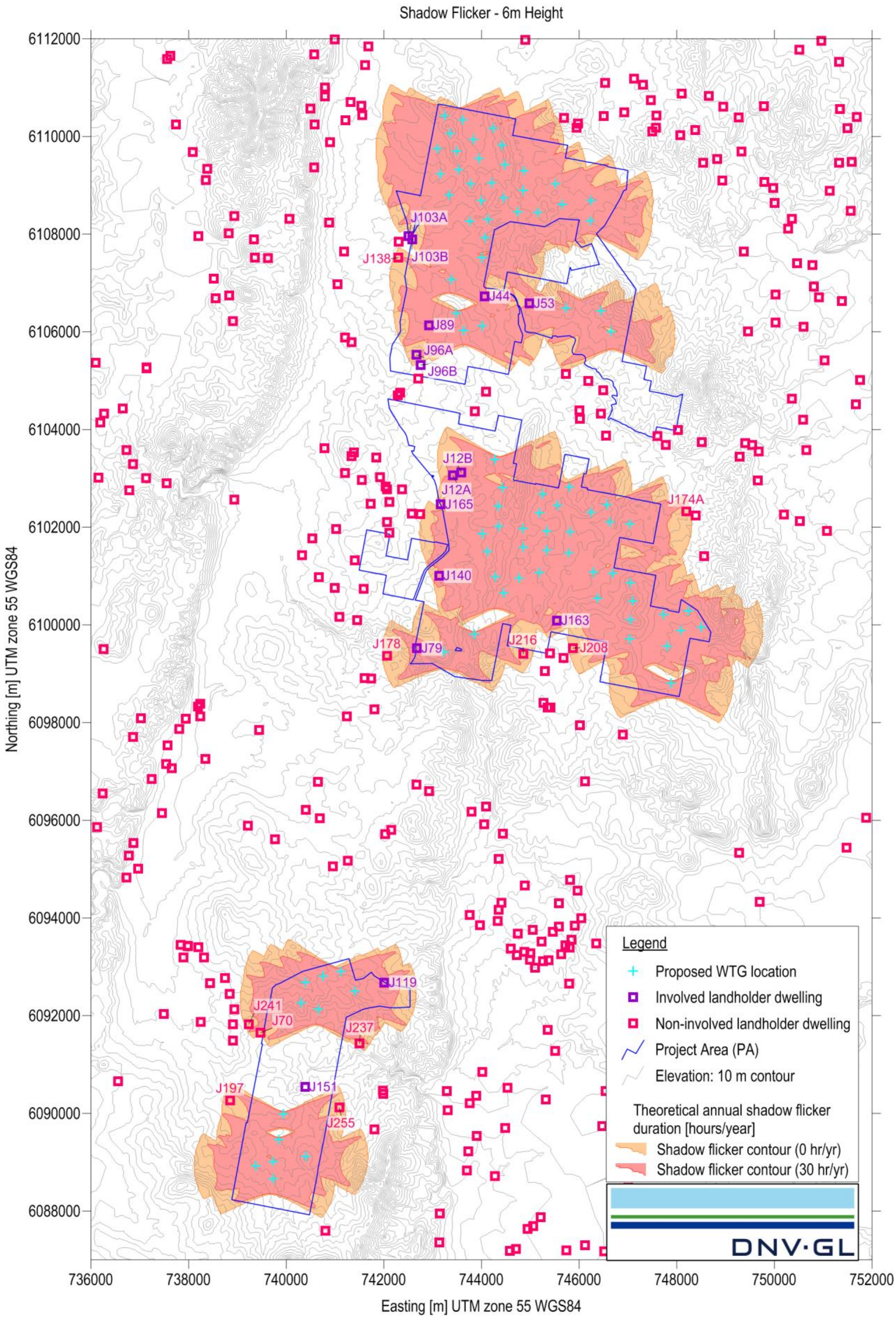
Note: The shadow flicker calculation follows the methodology prescribed by the "EPHC - National Wind Farm Development Guidelines - Draft (July 2010)"

Figure 5: Map of the proposed Project with WTGs, dwelling locations and theoretical annual shadow flicker duration at 6 m above ground level



Note: The shadow flicker calculation follows the methodology prescribed by the "EPHC - National Wind Farm Development Guidelines - Draft (July 2010)"

Figure 6: Map of the proposed Project with WTGs, dwelling locations and theoretical annual shadow flicker duration limits at 2 m above ground level



Note: The shadow flicker calculation follows the methodology prescribed by the "EPHC - National Wind Farm Development Guidelines - Draft (July 2010)"

Figure 7: Map of the proposed Project with WTGs, dwelling locations and theoretical annual shadow flicker duration limits at 6 m above ground level

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.