MORETON HILL WIND FARM

Shadow Flicker Assessment and Blade Glint Assessment

MHWF Nominees Pty Ltd as The Trustee for MHWF Trust

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EXECUTIVE SUMMARY

DNV has been commissioned by MHWF Nominees Pty Ltd as The Trustee for MHWF Trust ("the Customer") to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Moreton Hill Wind Farm ("the Project") in southwest Victoria. The results of this assessment are described in this document.

Background and methodology

DNV has assessed the expected annual shadow flicker durations for the Project in accordance with the Guidelines for Development of Wind Energy Facilities in Victoria [1] (Victorian Planning Guidelines). For the purposes of this assessment, DNV has also considered the guidance and recommendations given in the Draft National Wind Farm Development Guidelines [2] (Draft National Guidelines), and standard industry practices. The methodology used in this study has been informed by these guidelines and various standard industry practices.

The Victorian Planning Guidelines recommend a shadow flicker limit of 30 hours per year in the area immediately surrounding a dwelling. In addition, the Draft National Guidelines [2] recommend limits of 30 hours per year on the theoretical shadow flicker duration, and 10 hours per year on the actual shadow flicker duration.

A Project layout consisting of 62 wind turbines with a proposed rotor diameter of up to of 172 m and hub height of 166 m, resulting in an upper tip height of 252 m, has been modelled. Forty-nine dwellings in the area surrounding the Project have been considered for this assessment. Twenty of these dwellings are host dwellings.

The theoretical shadow flicker durations at dwellings in the vicinity of the Project have been determined using a purely geometric analysis. The actual shadow flicker duration likely to be experienced at each dwelling has also been predicted by estimating the possible reduction in shadow flicker due to turbine orientation and cloud cover.

Assessment results

The results of the shadow flicker assessment are summarised in Table 4.

Based on this assessment, a number of dwellings are expected to experience some shadow flicker above a moderate level of intensity, which is assumed here to occur up to a distance of around 10 rotor diameters from the wind farm.

A total of 26 dwellings are predicted to experience some shadow flicker above a moderate level of intensity, of which 17 are host dwellings and 9 are neighbour dwellings.

Out of the 17 host dwellings predicted to experience some shadow flicker above a moderate level of intensity, 14 are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling. When considering the likely reduction in shadow flicker duration due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of nine host dwellings remain above the recommended limit of 10 hours per year. DNV notes that the modelled theoretical shadow flicker durations within 50 m of some of these dwellings are very high, with modelled theoretical shadow flicker durations within 50 m of dwelling 111 exceeding 100 hours per year. However, the Customer has advised DNV that this particular dwelling is derelict and will be demolished as part of the development of the Project.

Out of the nine neighbouring dwellings predicted to experience some shadow flicker above a moderate level of intensity, none are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling.

The calculation of the predicted actual shadow flicker duration does not take into account other potential reductions due to low wind speed, vegetation, or other shielding effects around each house.

The Customer has advised that they are committed to reaching commercial agreements with host landowners recognising impacts from the wind farm, and to meeting an actual shadow flicker limit of 30 hours or less per year for host dwellings. However, DNV notes that this is 3 times the limit recommended by the Draft National Guidelines [2] for predicted actual shadow flicker durations. Based on the predicted actual annual maximum shadow flicker durations within 50 m of host dwellings, it is considered likely that this objective will be met, although it is noted that there is some uncertainty associated with the predicted actual shadow flicker durations.

The effects of blade glint have not been quantified in this study as the Victorian Planning Guidelines [1] and the National Wind Farm Development Guidelines – Draft [2] do not provide any quantification methodology. The guidelines, however, recommend that the Customer ensures that the turbine blades used have a surface finish with a low reflectivity to avoid occurrences of blade glint.

1 INTRODUCTION

MHWF Nominees Pty Ltd as The Trustee for MHWF Trust ("the Customer") has commissioned DNV to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Moreton Hill Wind Farm ("the Project") in southwest Victoria. The results of this work are reported here. This document has been prepared in accordance with the Consulting Agreement between MHWF Nominees Pty Ltd as the Trustee for MHWF Trust and DNV Australia Pty Ltd, dated 28 April 2023, and is subject to the terms and conditions in that agreement.

This assessment evaluates the shadow flicker durations in the vicinity of the Project for the current proposed turbine layout [3] and configuration in general accordance with the Policy and Planning Guidelines for Development of Wind Energy Facilities in Victoria (Victorian Planning Guidelines) prepared by the Victorian Department of Environment, Land, Water and Planning in November 2021 [1]. For the purpose of this assessment, DNV has also considered the guidance and recommendations given in the Draft National Wind Farm Development Guidelines (Draft National Guidelines) prepared by the Environment Protection and Heritage Council (EPHC) in July 2010 [2], as well as standard industry practices [4, 5, 6].

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The site

The proposed Moreton Hill Wind Farm ("the Project") is located in southwest Victoria, approximately 5 km east of Skipton, 2 km south of Pittong, and 40 km southwest of Ballarat. An overview of the Project location is presented in Figure 2.

The terrain within and surrounding the Project site is relatively flat, consisting mostly of farmland. A digital elevation model (DEM) extending approximately 8 km from the site was acquired from publicly available data [7].

2.2 The project

2.2.1 Proposed wind farm layout

The Project is composed of 62 wind turbines [3]. A map of the site with the proposed turbine layout is shown in Figure 3, and the coordinates of the proposed turbine locations are given in Table 1.

DNV has modelled the shadow flicker based on a hypothetical turbine model with a rotor diameter of 172 m and a hub height of 166 m, such that the upper tip height of the turbine is 252 m [3]. The maximum blade chord length for this hypothetical turbine, defined as the dimension through the thickest part of the blade, is 4.3 m [8].

2.2.2 Shadow receptor locations

A list of 175 receptors surrounding the proposed Moreton Hill Wind Farm was provided to DNV by the Customer [9], of which 169 have been identified by the Customer as dwellings, and the remaining 6 as either a CFA depot, community hall, shed or possible future dwelling. Forty-nine dwellings have been identified as having the potential to experience shadow flicker, and these have been considered in this assessment. The coordinates of these 49 dwellings are presented in Table 2.

Out of the 49 dwellings identified:

- twenty are host dwellings.
- twenty-nine are neighbouring dwellings.

The remaining 126 dwellings are at locations that are considered unlikely to be impacted by shadow flicker, as discussed further in Sections 3.1 and 4.1.

It should be noted that the scope of the current work has not included a comprehensive survey of sensitive land uses and building locations in the area, and so DNV is relying on the information provided by the Customer.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

In relation to shadow flicker, the Victorian Planning Guidelines [1] currently state that:

> *"The shadow flicker experienced immediately surrounding the area of a dwelling (garden fenced area) must not exceed 30 hours per year as a result of the operation of the wind energy facility."*

The Victorian Planning Guidelines also include the following example permit condition:

> *"Shadow flicker from the wind energy facility must not exceed 30 hours per annum at any pre-existing dwelling (insert date), unless an agreement has been entered into with the relevant landowner waiving this requirement. The agreement must be in a form that applies to the land comprising a pre-existing dwelling for the life of the wind energy facility, to the satisfaction of the responsible authority, and must be provided to the responsible authority upon request."*

Although the Victorian Planning Guidelines state that *"[t]he seasonal duration of [shadow flicker] can be calculated from the geometry of the machine and the latitude of the site [and] modelled in advance"*, they do not provide detailed methodologies for these calculations.

Given that the Victorian Planning Guidelines do not provide a methodology for modelling shadow flicker impacts, DNV considers that the Draft National Guidelines [2] are also relevant.

The Draft National Guidelines recommend that the modelled theoretical shadow flicker duration 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 be assessed by calculating the maximum shadow flicker occurring within 50 m of the centre of a dwelling.

As details of the 'garden fenced area' for a dwelling are not readily available, DNV assumes that the evaluation of the maximum shadow flicker duration within 50 m of a dwelling (as required by the Draft National Guidelines) is similar to assessing shadow flicker durations within the 'garden fenced area'. In most cases this approach is expected to be adequate, however it is acknowledged that, in rural areas, the 'garden fenced area' may extend beyond 50 m from a dwelling.

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

The Draft National Guidelines also 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 around 10 rotor diameters from a turbine [5, 6] or approximately 1200 m to 1900 m for modern wind turbines (which typically have rotor diameters of 120 m to 190 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 times the maximum blade chord as an appropriate limit, which corresponds to approximately 1000 m to 1600 m for modern wind turbines (which typically have maximum blade chord lengths of 4 m to 6 m).

For the purposes of this assessment, DNV has considered the guidance and recommendations given in the Victorian Planning Guidelines, the Draft National Guidelines, and standard industry practices in relation to shadow flicker.

3.2 Blade glint

Blade glint involves the regular reflection of the sun off rotating turbine 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. Blade glint is not generally a problem for modern wind turbines [1, 2].

Methodology for the quantification of blade glint impacts as well as a regulatory limit were not provided by any of the Victorian Planning Guidelines [1] or the Draft National Guidelines [2]. A common resolution from the Victorian Planning Guidelines and the Draft National Guidelines suggest that the Customer ensures the blades of the wind turbines have a finish with low reflectivity. Specific text extracts from these documents are provided below.

In relation to blade glint, guidance from the Victorian Planning Guidelines [1] states that:

"Blades should be finished with a surface treatment of low reflectivity to ensure that glint is minimised."

In relation to blade glint, guidance from the Draft National Guidelines [2] states that:

"Blade glint can be produced when the sun's light is reflected from the surface of wind turbine blades. Blade glint has potential to annoy people.

All major wind turbine blade 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.

Proponents should ensure that blades from their supplier are of low reflectivity."

4 ASSESSMENT METHODOLOGY

4.1 Shadow flicker

4.1.1 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 wind turbine 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:

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

Example photographs of wind turbines and associated shadows which have the potential to cause flicker are shown in Figure 1 below.

Figure 1 Examples of wind turbine shadows

4.1.2 Theoretical modelled 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 site area, and wind turbine details such as rotor diameter and hub height.

The wind turbines have been modelled assuming they are spherical objects, which is equivalent to assuming that the rotors of the turbines are disks that 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, up to a specified distance limit.

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

Shadow flicker has been calculated at dwellings at heights of 2 m, to represent ground floor windows as the Customer indicated that all dwelling identified in the vicinity of the project were single storey buildings. The shadow receptors are simulated as fixed points, representing the worst-case scenario, as real windows at the receptor may be facing a particular direction less affected by shadows cast from the turbines. The shadow flicker calculations for dwelling locations have been carried out with a temporal resolution of 1 minute. The shadow flicker map was generated using a temporal resolution of 5 minutes and a spatial resolution of 10 m 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 wind turbine that is likely to cause annoyance due to shadow flicker (the zone of influence of shadows). The UK wind industry and planning guidelines in the UK suggest that a distance of 10 rotor diameters (10D) may be appropriate [5, 6], while the Draft National Guidelines suggest a distance equivalent to 265 times the maximum blade chord (265C) as an appropriate distance.

The determination of the distance of 265C for the zone of influence of shadows suggested by the Draft National Guidelines is provided in Appendix E.7 of [2], and explains that the distance of 10D for the zone of influence of shadows was actually the basis for the derivation of the distance of 265C at the time of publication of the Draft National Guidelines.

DNV notes that the recommendation of a distance of 265C can only be found in the Draft National Guidelines and the Queensland State Government planning guidance State Code 23 [10], and that standard practice in the European wind industry is to still consider a distance of 10D for the zone of influence of shadows [4, 11]. In at least one instance, DNV has also observed evidence of shadow flicker at or beyond 10D from wind turbines. Although the level of annoyance caused by shadow flicker can be subjective, this demonstrates the potential for its effects to extend to at least a distance of 10D, regardless of the durations of these shadow flicker occurrences. This is supported by the following reports [6, 11]. As such, DNV typically considers the greater of the 10D and 265C distances for shadow flicker assessments.

For the current assessment, DNV has applied a maximum shadow length of 10D, which corresponds to a distance limit of 1720 m. Beyond this distance limit, it is assumed that any shadow flicker experienced will be below a “moderate level of intensity” and unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by shadow flicker intensities below the moderate level of intensity assumed by this distance limit. To account for this possibility, and although not suggested by the Draft National Guidelines [2], DNV has also assessed the shadow flicker for an increased distance limit of 15 times the rotor diameter (15D), or 2580 m, to include the potential for occurrences of shadow flicker below a moderate level of intensity.

In this report shadow flicker of a moderate level of intensity or above is assumed to occur up to a distance of approximately 10D from the wind farm. Conversely, shadow flicker below a moderate level of intensity is assumed to occur beyond a distance of 10D and up to a distance of approximately 15D from the wind farm.

The model also makes the following assumptions and simplifications:

- there are clear skies every day of the year
- the plane of rotation of the blades of the turbines is always perpendicular to the direction of the line of sight from the location of interest to the sun
- the turbine blades are always rotating, inherently assuming continuous wind flow across the site.

The first two of these items are addressed in the calculation of the predicted actual shadow flicker duration as described in Section 4.1.4. The third item is not considered but is unlikely to have a significant impact on the results. The settings used to execute the model can be seen in Table 3.

To illustrate typical results, an indicative shadow flicker map for a turbine located in a flat area is shown in Figure 4. 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 turbine location result from the summer months and conversely the lobes to the south result from the winter months. 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 turbine increases, increasing the area around the turbine affected by shadow flicker.

4.1.3 Factors affecting 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, including:

1. The wind turbine will not always be oriented such that its rotor is in the worst-case position (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 site can be used to determine probable turbine 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 wind turbine. The length of the shadow cast by a wind turbine 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 receiver.

4. The modelling of the wind turbine rotor as a sphere rather than individual blades results in an overestimation of the shadow flicker duration. Turbine 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 turbine 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 wind turbine hub, there is no variation in light intensity at the receiver 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 wind turbine, and therefore reduce the incidence of shadow flicker.
7. Periods where the wind turbine is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce the annual shadow flicker duration.

4.1.4 Predicted actual duration

As discussed in Section 4.1.3, there are a number of factors which may reduce the incidence of shadow flicker that are not taken into account in the calculation of the theoretical shadow flicker duration. An attempt has been made to quantify the likely reduction in shadow flicker duration due to cloud cover and, therefore, produce a prediction of the actual shadow flicker duration likely to be experienced at a receptor.

Cloud cover is typically measured in ‘oktas’, effectively eighths of the sky covered with cloud. DNV has obtained data from the following Bureau of Meteorology (BoM) stations:

- Lismore (Post Office) (089018), located approximately 25 km southeast of the centre of the site [12]
- Durdidwarrah (087021), located approximately 67 km east of the centre of the site [13]
- Ararat Prison (089085), located approximately 68 km northwest of the centre of the site [14]
- Ballarat Aerodrome (089002), located approximately 39 km northeast of the centre of the site [15].

The number of oktas of cloud cover visible across the sky at these stations is recorded twice daily, at 9 am and 3 pm, and the observations are provided as monthly averages. After averaging the 9 am and 3 pm observations for the stations considered, the results indicate that the average monthly cloud cover in the region ranges between 48% and 64%, and the average annual cloud cover is approximately 59%. This means that on an average day, 59% of the sky in the vicinity of the wind farm 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.

Similarly, turbine orientation can have an impact on the shadow flicker duration. The shadow flicker duration is greatest when the turbine 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 derived from data collected by an on-site LiDAR device has been provided by the Customer [16] and 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 4. An assessment of the likely reduction in shadow flicker duration due to variation in turbine orientation was conducted on an annual basis.

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 turbine orientation, be included. However, DNV considers that the additional reduction due to turbine orientation is appropriate as the projected area of the turbine, and therefore the expected shadow flicker duration, is reduced when the turbine rotor is not perpendicular to the line joining the sun and dwelling. Due to limitations in the availability of suitable cloud cover data, the methodology used in this assessment also deviates somewhat from the method recommended by the Draft National Guidelines for assessing the reduction in shadow flicker due to cloud cover. However, considering the available cloud cover data, the approach described above is deemed to provide a reasonable estimate of the likely impact of cloud cover on the shadow flicker duration.

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in calculating the shadow flicker duration. Similarly, turbine shutdown has not been considered.

4.2 Blade glint

Blade glint involves the regular reflection of sun off rotating turbine 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. Blade glint is not generally a problem for modern wind turbines.

In order for blade glint not to be an issue for the wind farm, it is recommended that the turbine blades are coated with a non-reflective paint.

As discussed in Section 3.2, neither the Victorian Planning Guidelines [1] or the Draft National Guidelines [2] provide a methodology for the quantification of blade glint impacts.

5 ASSESSMENT RESULTS

5.1 Shadow flicker

Shadow flicker assessments were carried out at all provided dwelling locations, or ‘receptors’, as outlined in Table 2.

The theoretical and predicted actual shadow flicker durations at all dwellings identified to be affected by shadow flicker based on modelling parameters discussed in Section 4.1 are presented in Table 4. The maximum predicted shadow flicker durations within 50 m of these receptors are also presented in this table. Furthermore, the results are shown in the form of shadow flicker maps in Figure 5 and Figure 6.The shadow flicker values presented in these maps represent the modelled shadow flicker results at 2 m above ground level, corresponding to the ground level of a dwelling. Based on information provided by the Customer [17], it is understood that there are no two-storey dwellings in the vicinity of the project and, as such results at 6 m above ground are not discussed in this document.

Based on DNV’s modelling, a number of dwellings are predicted to experience some shadow flicker of at least a moderate level of intensity, which is expected to occur up to a distance of around 10 rotor diameters from the wind farm. A total of 26 dwellings are predicted to experience some shadow flicker above a moderate level of intensity, 17 of which are host dwellings and 9 of which are neighbour dwellings.

Out of the 17 host dwellings, 14 are predicted to experience theoretical shadow flicker durations within 50 m of the dwelling that exceed the limit recommended by the current guidelines. When considering the likely reduction due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of nine host dwellings remain above the recommended limit of 10 hours per year. DNV notes that the modelled theoretical shadow flicker durations at some of these dwellings are very high, with modelled theoretical shadow flicker durations within 50 m of dwelling 111 exceeding 100 hours per year. However, the Customer has advised DNV that this particular dwelling is derelict and will be demolished as part of the development of the Project.

Out of the nine neighbour dwellings predicted to experience some shadow flicker above a moderate level of intensity, none are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be below a moderate level of intensity and thus unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by shadow flicker below a moderate level of intensity that may occur beyond this distance limit. To account for this possibility, and although not part of the methodology outlined in the Draft National Guidelines, DNV has also assessed the shadow flicker impacts for the Project using an extended distance for the zone of influence of shadows intended to capture the occurrences of low intensity shadow flicker. For the purpose of this assessment, to account for low intensity shadow flicker, the distance limit has been increased by 50% (to 15D), and the results of this additional assessment are illustrated in the map presented in Figure 5. These results indicate the possibility for low intensity shadow flicker to occur within 50 m of an additional nine dwellings. These dwellings are noted in Table 4.

The Customer has advised that commercial arrangements will be entered into with host landowners recognising impacts from the wind farm and they are committed to:

- conducting further assessment of screening around dwellings to further refine the predictions
- working with host landowners to develop specific measures to limit shadow flicker.

DNV understands that the Customer is committed to meeting an actual shadow flicker limit of 30 hours or less per year for host dwellings. However, DNV notes that this is 3 times the limit recommended by the Draft National Guidelines. Based on the predicted actual annual maximum shadow flicker durations within 50 m of host dwellings, it is considered likely that this objective will be met, although it is noted that there is some uncertainty associated with the predicted actual shadow flicker durations.

5.1.1 Mitigation options

If required, the effects of shadow flicker may be reduced through a number of mitigation options such as the removal or relocation of turbines, the use of smaller turbines, installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies (or shadow flicker protection systems) which shut down turbines when shadow flicker is likely to occur.

5.2 Blade glint

As discussed in Section 3.2, blade glint is not expected to be an issue for the Project provided a non-reflective finish is applied to the wind turbine blades.

6 CONCLUSIONS

A shadow flicker assessment was carried out at all provided dwelling locations in the vicinity of the Project. For this assessment, DNV has considered a layout consisting of 62 hypothetical turbines each with a rotor diameter of 172 m and a hub height of 166 m, resulting in a turbine upper tip height of 252 m. The results of the shadow flicker assessment based on this layout configuration are summarised in Table 4.

Based on the modelling conducted by DNV, 26 dwellings are predicted to experience some shadow flicker above a moderate level of intensity, 17 of which are host dwellings and 9 of which are neighbour dwellings.

Out of the 17 host dwellings, 14 are predicted to experience theoretical shadow flicker durations within 50 m of the dwelling that exceed the limit recommended by the current guidelines. When considering the predicted actual shadow flicker duration, which takes into account the reduction in shadow flicker due to cloud cover and rotor orientation, the predicted actual shadow flicker duration within 50 m of nine host dwellings are expected to remain above the limit recommended in the guidelines.

Out of the nine neighbour dwellings predicted to experience some shadow flicker above a moderate level of intensity, none are predicted to experience a theoretical shadow flicker duration within 50 m of the dwelling that exceeds the limit recommended by the current guidelines.

The Customer has advised that they are committed to reaching commercial agreements with host landowners recognising impacts from the wind farm, and to meeting an actual shadow flicker limit of 30 hours or less per year for host dwellings. However, DNV notes that this is 3 times the limit recommended by the Draft National Guidelines. Based on the predicted actual annual maximum shadow flicker durations within 50 m of a host dwelling, it is considered likely that this objective will be met, although it is noted that there is some uncertainty associated with the predicted actual shadow flicker durations.

It is recommended that the Customer ensures the turbine blades are coated with a non-reflective paint in order to avoid the occurrence of blade glint from the wind farm.

7 REFERENCES

[1] Department of Environment, Land, Water and Planning, “Development of Wind Energy Facilities in Victoria, Policy and Planning Guidelines,” November 2021.

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Table 1 Proposed turbine layout for the Project site [3]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation[2] [m]
T1	717599	5826548	315
T2	715995	5826389	339
T3	716634	5826338	328
T4	717179	5825891	318
T5	719764	5825867	341
T6	715824	5825609	324
T7	715349	5825580	351
T8	716184	5825101	317
T9	719984	5825006	313
T10	716738	5824683	317
T11	718692	5824502	298
T12	719228	5824415	293
T13	717297	5824368	296
T14	719566	5824176	300
T15	715993	5824088	312
T16	720194	5824020	317
T17	714872	5823925	389
T18	714193	5823798	370
T19	716521	5823458	298
T20	713555	5823398	328
T21	714528	5823255	328
T22	715197	5823101	331
T23	718747	5823072	292
T24	720212	5822987	363
T25	719629	5822913	306
T26	715730	5822793	326
T27	716313	5822383	314
T28	719082	5822204	282
T29	719661	5822049	286
T30	715881	5821873	313
T31	716203	5821056	287
T32	716491	5820278	287
T33	713108	5820100	307
T34	716037	5819810	295
T35	713668	5819661	317
T36	713166	5819053	313
T37	714258	5818973	324
T38	715865	5818943	301

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation[2] [m]
T39	716535	5818874	293
T40	717102	5818638	289
T41	713813	5818549	319
T42	715166	5818272	298
T43	714562	5818242	306
T44	716093	5818125	295
T45	715566	5817656	288
T46	714863	5817347	299
T47	715585	5816777	285
T48	713081	5816085	284
T49	712549	5815883	280
T50	711621	5815856	270
T51	716069	5815581	279
T52	716448	5815010	279
T53	715799	5814748	281
T54	720331	5814322	270
T55	719719	5814184	266
T56	716160	5813941	274
T57	718115	5813727	258
T58	718815	5813680	261
T59	720157	5813426	265
T60	719378	5813322	260
T61	720540	5812821	254
T62	719934	5812487	246

Note:

1. *Coordinate system: MGA zone 54, GDA94 datum. Coordinates were provided by the Customer in a different coordinate system and/or datum and have been converted using mapping software, which may result in small discrepancies depending on the software and transformation approach used.*
2. *Estimated from a digital elevation model obtained by DNV* [7].

Table 2 Location of receptors assessed for potential shadow flicker in this report [3]

Receptor ID	Landowner status	Easting[1] [m]	Northing[1] [m]	Distance to nearest turbine [m]	Nearest turbine ID
26	Neighbour	721109	5828006	2528	T5
27	Neighbour	714609	5827990	2118	T2
28	Neighbour	718075	5827982	1513	T1
35	Neighbour	721113	5827782	2344	T5
36	Neighbour	721548	5827774	2613	T5
39	Host	716610	5827714	1378	T3
40	Neighbour	714899	5827689	1701	T2
43	Neighbour	714772	5827575	1704	T2
45	Neighbour	715031	5827526	1491	T2
59	Neighbour	714477	5826841	1534	T7
63	Neighbour	722056	5826714	2445	T5
82	Neighbour	713853	5825374	1509	T7
84	Host	718181	5825050	750	T11
88	Host	721524	5824257	1352	T16
93	Neighbour	711160	5823837	2435	T20
95	Neighbour	711850	5822971	1757	T20
97	Host	717342	5822039	1085	T27
98	Host	721295	5821481	1730	T29
99	Neighbour	717890	5821071	1609	T32
100	Neighbour	721094	5820720	1954	T29
102	Host	717607	5820304	1117	T32
104	Host	717681	5819808	1279	T32
105	Host	717664	5819765	1261	T40
106	Host	717642	5819702	1195	T40
107	Host	714955	5819622	954	T37
108	Host	712809	5819356	469	T36
111	Host	716578	5819081	213	T39
113	Neighbour	718826	5818285	1760	T40
117	Host	717132	5817541	1096	T40
118	Host	713158	5817493	1241	T41
120	Neighbour	712214	5817342	1499	T49
122	Neighbour	710701	5817140	1581	T50
124	Neighbour	717123	5817033	1500	T44
128	Host	716848	5816241	1022	T51
129	Host	716881	5816166	1002	T51
131	Neighbour	714565	5815714	1472	T47
132	Neighbour	719318	5815636	1508	T55
135	Neighbour	721835	5814634	1537	T54
136	Neighbour	709667	5814571	2337	T50
137	Host	711719	5814528	1330	T50

Receptor ID	Landowner status	Easting[1] [m]	Northing[1] [m]	Distance to nearest turbine [m]	Nearest turbine ID
138	Neighbour	711682	5814344	1512	T50
139	Neighbour	711777	5814325	1537	T50
140	Neighbour	712363	5814231	1661	T49
141	Neighbour	714675	5813738	1498	T56
142	Host	721466	5813687	1269	T61
143	Host	717069	5813536	995	T56
170	Neighbour	722771	5824116	2578	T16
171	Neighbour	722724	5824038	2530	T16
175	Neighbour	709631	5814473	2422	T50

Note:

1. *Coordinate system: MGA zone 54, GDA94 datum. Coordinates were provided by the Customer in a different coordinate system and/or datum and have been converted using mapping software, which may result in small discrepancies depending on the software and transformation approach used.*

Table 3 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1720 m
Year of calculation	2035
Minimum elevation of the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere (disk for turbine orientation reduction calculation)
Sun modelled as	Disk
Offset between rotor and tower	None
Receptor height (single storey)	2 m
Locations used for determining maximum shadow flicker within 50 m of each dwelling	8 points evenly spaced (every 45°) on 25 m and 50 m radius circles centred on the provided house location

Table 4 Theoretical and predicted actual annual shadow flicker duration

House ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Theoretical annual[3] At dwelling [hr/yr]	Theoretical annual[3] Max within 50 m [hr/yr]	Predicted actual annual[3,4] At dwelling [hr/yr]	Predicted actual annual[3,4] Max within 50 m [hr/yr]
59	Neighbour	714477	5826841	T2	16.1	18.0	4.4	4.9
63[5]	Neighbour	722056	5826714	-	0.0	0.0	0.0	0.0
82	Neighbour	713853	5825374	T7	12.1	13.1	3.0	3.3
84	Host	718181	5825050	T4 T10	**51.7**	**61.4**	**12.6**	**15.4**
88	Host	721524	5824257	T9 T16	**33.9**	**37.2**	8.6	9.4
93[5]	Neighbour	711160	5823837	-	0.0	0.0	0.0	0.0
95	Neighbour	711850	5822971	T20	0.0	11.3	0.0	2.7
97	Host	717342	5822039	T23 T27 T28 T30	**41.2**	**65.0**	**10.3**	**15.9**
98	Host	721295	5821481	T29	0.0	3.7	0.0	0.9
99	Neighbour	717890	5821071	T31	10.7	11.5	2.7	2.9
100[5]	Neighbour	721094	5820720	-	0.0	0.0	0.0	0.0
102	Host	717607	5820304	T31 T32 T34	**61.6**	**70.6**	**15.3**	**17.7**
104	Host	717681	5819808	T32 T34	**32.2**	**34.6**	7.7	8.2
105	Host	717664	5819765	T32 T34	**33.3**	**35.9**	7.9	8.5
106	Host	717642	5819702	T32 T34	**35.6**	**38.9**	8.3	8.9
107	Host	714955	5819622	T32 T34 T35 T39	**51.3**	**74.4**	**12.6**	**19.2**
108	Host	712809	5819356	T35 T37	**55.0**	**60.8**	**13.7**	**15.2**
111	Host	716578	5819081	T38	**93.3**	**104.5**	**24.4**	**29.9**
113	Neighbour	718826	5818285	T40	0.0	10.7	0.0	2.6
117	Host	717132	5817541	T44 T45 T47	**42.1**	**62.1**	9.5	**15.1**

House ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Theoretical annual[3]		Predicted actual annual[3,4]	
					At dwelling [hr/yr]	Max within 50 m [hr/yr]	At dwelling [hr/yr]	Max within 50 m [hr/yr]
118	Host	713158	5817493	T43 T46	**31.5**	**39.7**	7.2	8.7
120[5]	Neighbour	712214	5817342	-	0.0	0.0	0.0	0.0
122[5]	Neighbour	710701	5817140	-	0.0	0.0	0.0	0.0
124	Neighbour	717123	5817033	T45 T47	26.7	28.7	6.8	7.3
128	Host	716848	5816241	T47	19.1	20.6	4.4	4.8
129	Host	716881	5816166	T47	18.8	20.8	4.3	4.6
131	Neighbour	714565	5815714	T48 T51	26.3	26.6	6.5	6.7
135	Neighbour	721835	5814634	T54	15.6	17.4	4.3	4.8
136[5]	Neighbour	709667	5814571	-	0.0	0.0	0.0	0.0
141	Neighbour	714675	5813738	T56	13.5	14.4	3.4	3.6
142	Host	721466	5813687	T54 T59	**47.3**	**52.7**	**11.4**	**12.6**
143	Host	717069	5813536	T56 T57 T58	**60.3**	**68.8**	**14.3**	**16.5**
170[5]	Neighbour	722771	5824116	-	0.0	0.0	0.0	0.0
171[5]	Neighbour	722724	5824038	-	0.0	0.0	0.0	0.0
175[5]	Neighbour	709631	5814473	-	0.0	0.0	0.0	0.0
Recommended duration limits					***30 hr/yr***		***10 hr/yr***	

Note:

1. *Dwellings identified in Table 2 for which there is no theoretical shadow flicker occurrence up to a distance limit of 15 times the rotor diameter have been omitted from this table.*
2. *Coordinate system: MGA zone 54, GDA94 datum.*
3. *Zone of influence of shadows assumed to extend to a distance of 10 times the rotor diameter following standard wind industry practice* [5, 6, 4].
4. *Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.*
5. *Dwelling is not predicted to experience any shadow flicker above a moderate level of intensity, but may experience some low-intensity shadow flicker.*

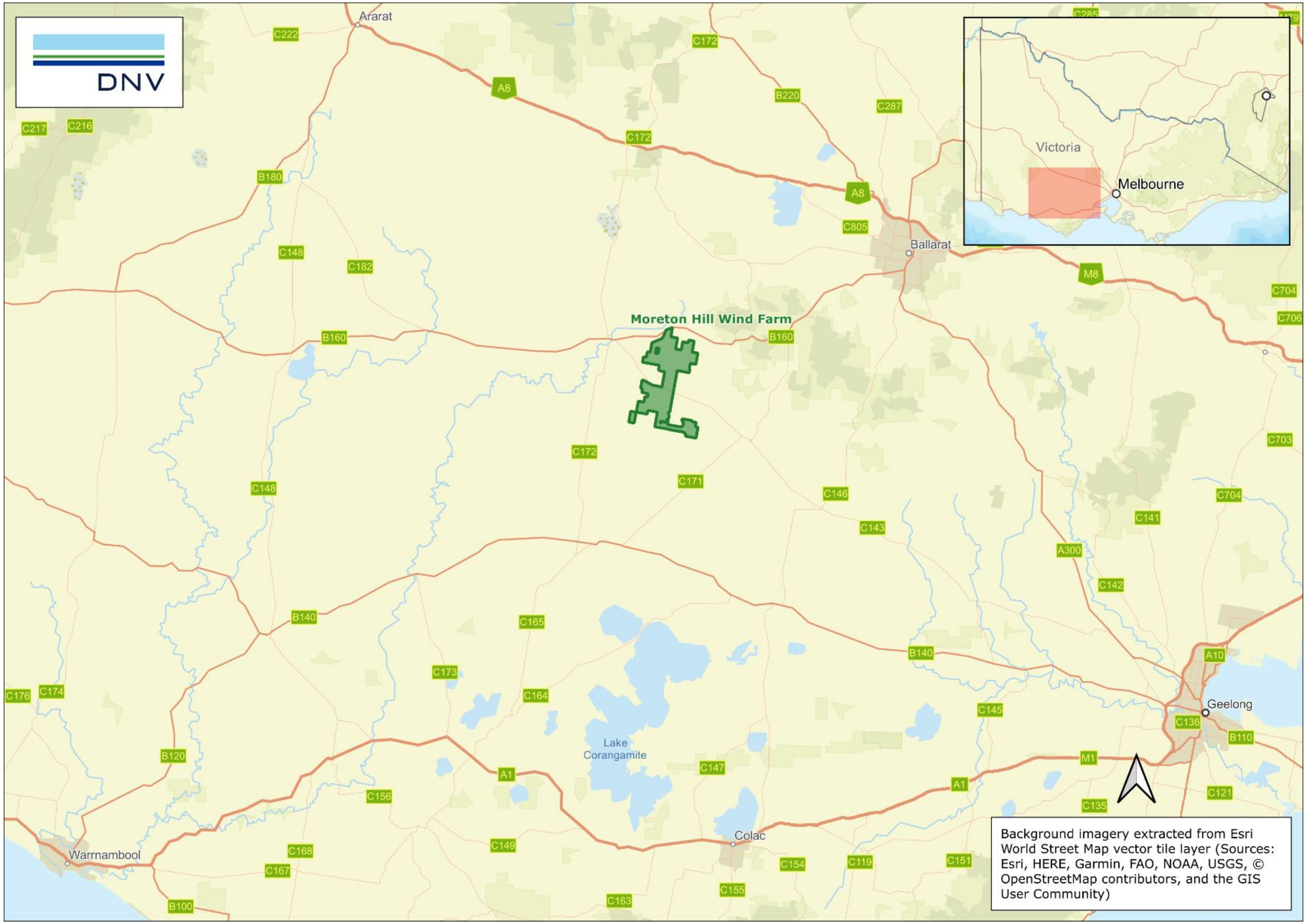

Figure 2 Location of the Project

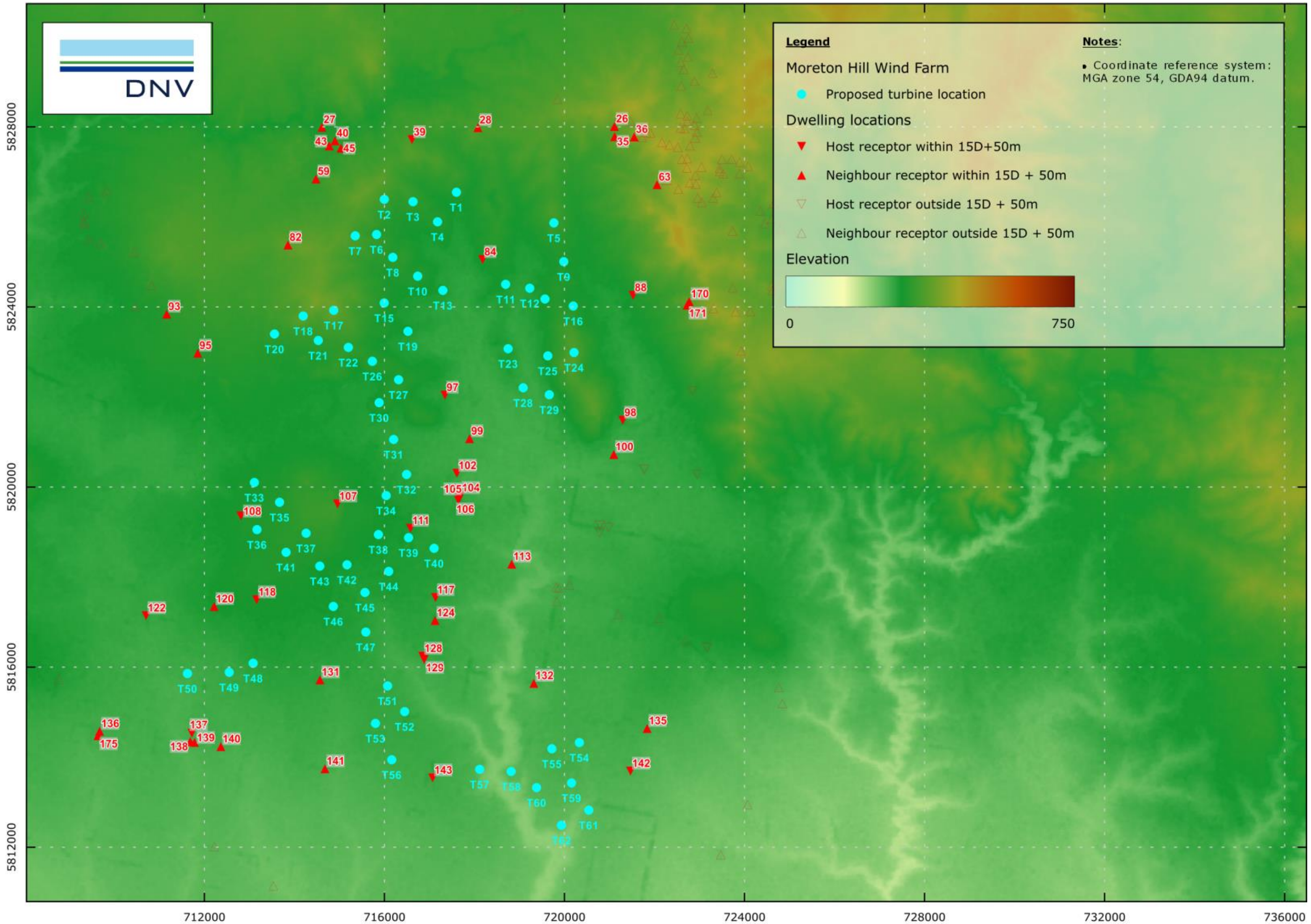

Figure 3 Elevation map of the Project

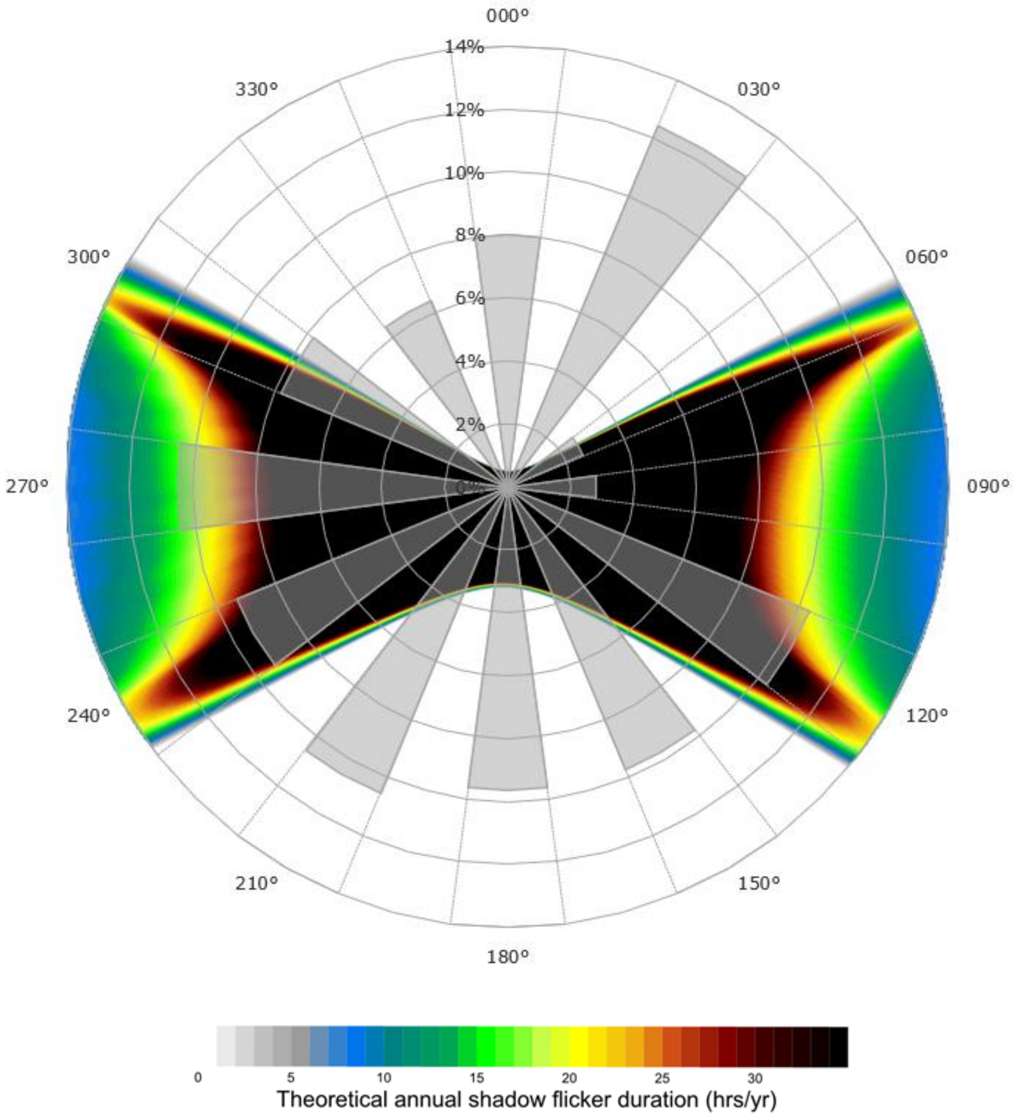

Figure 4 Indicative shadow flicker map and wind direction frequency distribution

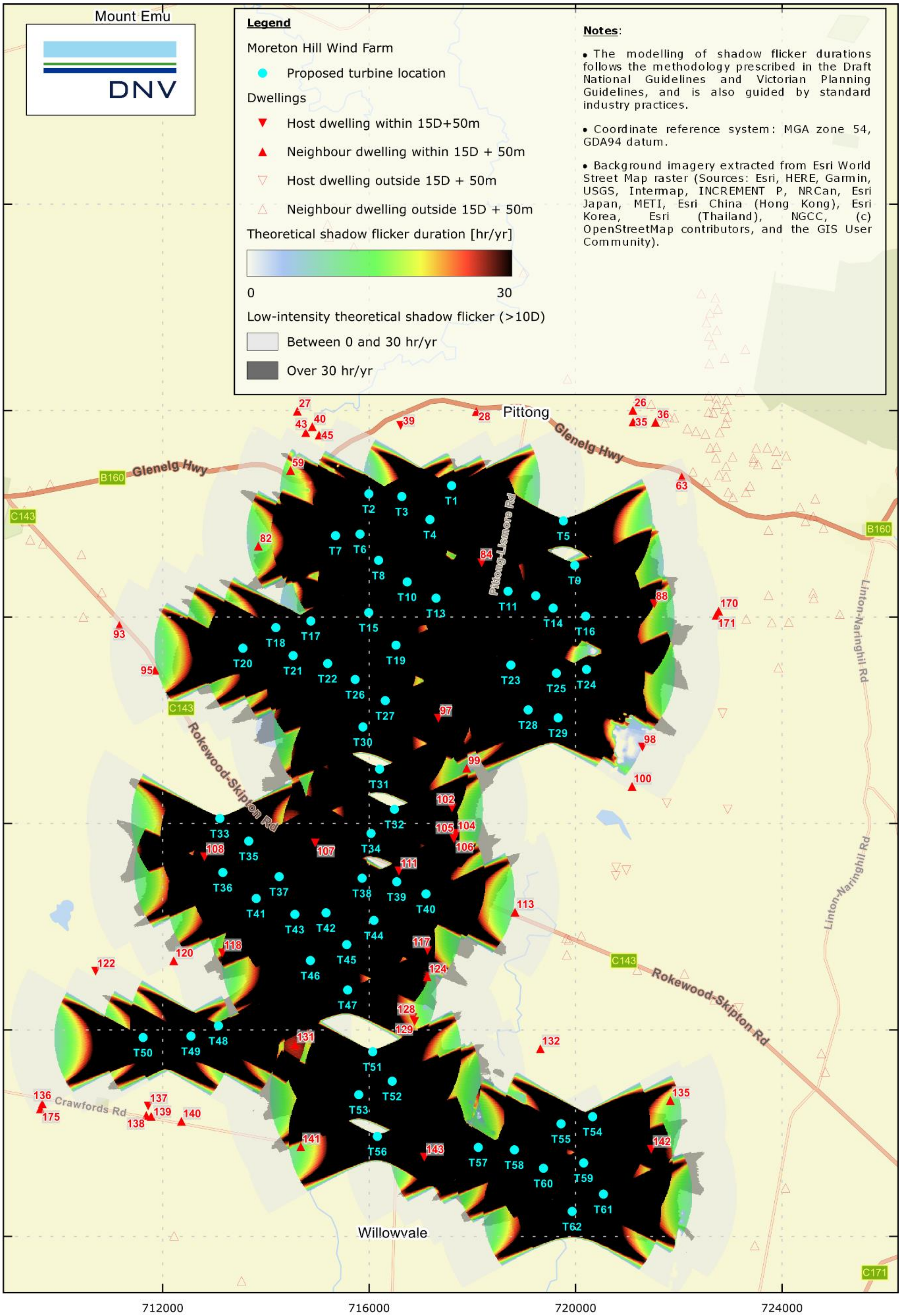

Figure 5 Theoretical annual shadow flicker duration map

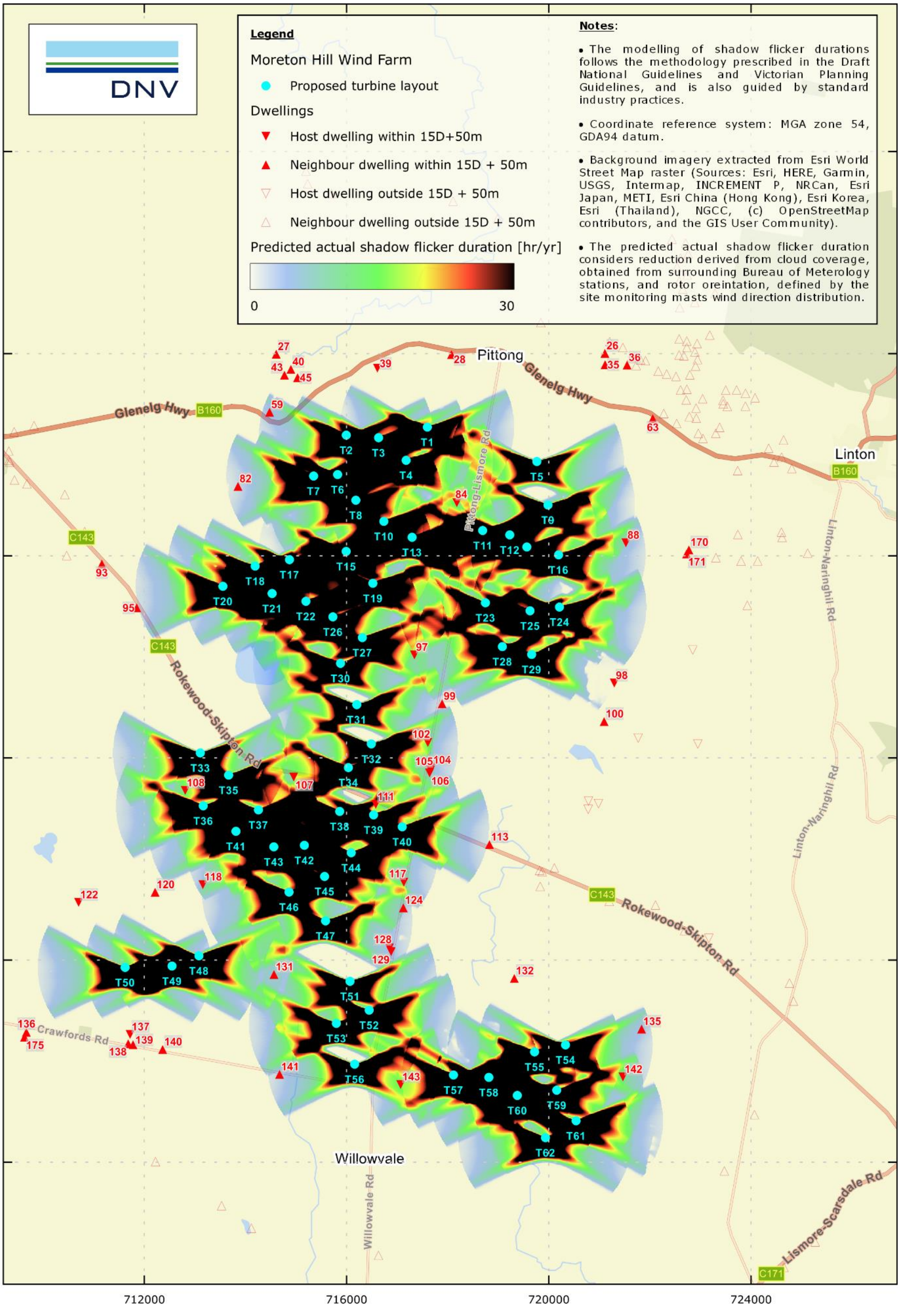

Figure 6 Predicted actual annual shadow flicker duration map

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimising the performance of a wind farm, analysing sensor data from a gas pipeline or certifying a food company’s supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

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