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GELLIONDALE WIND FARM

Shadow Flicker and Blade Glint Assessment

Synergy Wind Pty Ltd

Report No.: 10326979-AUME-R-01-D
Date: 23 May 2023
Status: Final

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Project name:	Gelliondale Wind Farm	DNV Energy Systems
Report title:	Shadow Flicker and Blade Glint Assessment	Renewables Advisory
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Date of issue:	23 May 2023	
Project No.:	10326979	
Report No.:	10326979-AUME-R-01-D	

Task and objective:

Wind Farm Shadow Flicker and Blade Glint Assessment

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Document classification:

Customer's Discretion

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Keywords:
Gelliondale Wind Farm, shadow flicker, blade glint

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	13-10-2022	Initial issue – DRAFT	ZN	JJ	TG
B	07-12-2022	Document re-issued as FINAL	ZN	JJ	TG
C	10-05-2023	Modelling update considering updated dwellings list	ZN	JL	JJ
D	23-05-2023	Document re-issued as FINAL	ZN	JL	JJ

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EXECUTIVE SUMMARY

DNV has been commissioned by Synergy Wind Pty Ltd ("the Proponent") to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Gelliondale Wind Farm ("the Project") in southeast 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 13 wind turbines with a proposed rotor diameter of up to of 164 m and hub height of 128 m, resulting in an upper tip height of 210 m, has been modelled. Ninety-eight dwellings in the area surrounding the Project have been considered for this assessment. Thirteen of these dwellings are host dwellings belonging to wind farm host landowners or landowners who have entered into a formal agreement with the Proponent. The remaining 85 dwellings are neighbour 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 22 dwellings are predicted to experience some shadow flicker above a moderate level of intensity, of which nine are host dwellings and 13 are neighbour dwellings.

Out of the nine host dwellings predicted to experience some shadow flicker above a moderate level of intensity, all nine 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 eight 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 at four dwellings exceeding 100 hours per year. Of these four dwellings, the Proponent has advised DNV that dwellings H08 and H09 are on lands owned by Synergy Wind entities and are slated to be unoccupied upon construction of a wind farm, while dwellings H07 and H11 are occupied by hosts aware of the level of potential for shadow flicker, and the issue will continue to receive attention and management by agreement.

Out of the 13 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.

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 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 Proponent ensures that the turbine blades used have a surface finish with a low reflectivity to avoid occurrences of blade glints.

1 INTRODUCTION

Synergy Wind Pty Ltd ("the Proponent") has commissioned DNV to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Gelliondale Wind Farm ("the Project") in southeast Victoria. The results of this work are reported here. This document has been prepared in accordance with the short form agreement L2C-224266-AUME-SFA-01-A, executed 15 February 2022, 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 July 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 Gelliondale Wind Farm (“the Project”) is located in the south Gippsland region of Victoria, approximately 7 km south-west of Yarram, 3 km west of Alberton, and 8 km east of Welshpool. 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 6 km from the site was acquired from publicly available data [7, 8].

2.2 The project

2.2.1 Proposed wind farm layout

The Project is composed of 13 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 164 m and a hub height of 128 m, such that the upper tip height of the turbine is 210 m [3]. The maximum blade chord length for this hypothetical turbine, defined as the dimension through the thickest part of the blade, is 4.238 m [9].

2.2.2 Shadow receptor locations

A list of 909 receptors surrounding the proposed Gelliondale Wind Farm was provided to DNV by the Proponent [10], of which 565 have been identified by the Proponent as dwellings, and the remaining 344 receptors have been identified as cabins or sheds. Ninety-eight dwellings have been identified as having the potential to experience shadow flicker, and these have been considered in this assessment. The coordinates of these 98 dwellings are presented in Table 2.

Out of the 98 dwellings identified:

- thirteen are host dwellings belonging to wind farm host landowners or landowners who have entered into a formal agreement with the Proponent, and
- eighty-five are neighbour dwellings.

The remaining 467 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 Proponent.

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 Proponent 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, and 6 m, to represent second floor windows. 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 [11], 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, 12]. 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, 12]. 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 1640 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 2460 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:

- Morwell (Latrobe Valley Airport) (085280), located approximately 48 km northwest of the centre of the site [13],
- Olsens Bridge (Morwell River Prison) (085106), located approximately 27 km north of the centre of the site [14],
- Wilsons Promontory Lighthouse (085096), located approximately 56 km south of the centre of the site [15], and
- Wonthaggi (086127), located approximately 85 km west of the centre of the site [16].

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 61% and 74%, and the average annual cloud cover is approximately 69%. This means that on an average day, 69% 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 previously derived from data collected by an on-site mast 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 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

As discussed in Section 3.2, a methodology for the quantification of blade glint impacts were not provided by any of the Victorian Planning Guidelines [1], and the Draft National Guidelines [2].

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 worst case between the results at 2 m and 6 m above ground for each modelled grid point.

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 22 dwellings are predicted to experience some shadow flicker above a moderate level of intensity, nine of which are host dwellings and 13 of which are neighbour dwellings.

Out of the nine host dwellings, all nine 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 eight 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 at four dwellings exceeding 100 hours per year. Of these four dwellings, the Proponent has advised DNV that dwellings H08 and H09 are on lands owned by Synergy Wind entities and are slated to be unoccupied upon construction of a wind farm, while dwellings H07 and H11 are occupied by hosts aware of the level of potential for shadow flicker, and the issue will continue to receive attention and management by agreement [17].

Out of the 13 neighbour dwellings predicted to experience some shadow flicker above a moderate level of intensity, none are predicted to experience theoretical shadow flicker durations within 50 m of the dwelling that exceed the limit recommended by the current guidelines.

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 35 dwellings. These dwellings are noted in Table 4.

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 13 hypothetical turbines each with a rotor diameter of 164 m and a hub height of 128 m, resulting in a turbine upper tip height of 210 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, 22 dwellings are predicted to experience some shadow flicker above a moderate level of intensity, nine of which are host dwellings and 13 of which are neighbour dwellings.

Out of the nine host dwellings, all nine 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 eight host dwellings are expected to remain above the limit recommended in the guidelines.

Out of the 13 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.

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

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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]
GWT01	459101	5721212	3
GWT02	459315	5721623	4
GWT03	459650	5722924	9
GWT04	462360	5723612	9
GWT05	462850	5723361	9
GWT06	463560	5723252	8
GWT07	464422	5723401	7
GWT08	464966	5723089	7
GWT09	465168	5723721	6
GWT10	466840	5726262	9
GWT11	467329	5725914	8
GWT12	467499	5724919	6
GWT13	467574	5724242	4

Note:
1. *Coordinate system: UTM zone 55S, WGS84 datum* [3].
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
H01	Host	458025	5721403	1093	GWT01
H02	Host	458501	5721772	821	GWT01
H03	Host	459349	5723517	665	GWT03
H04	Host	460504	5723858	1266	GWT03
H05	Host	464020	5723677	488	GWT07
H06	Host	465572	5724509	886	GWT09
H07	Host	466861	5725604	561	GWT11
H08	Host	467097	5724126	491	GWT13
H09	Host	467292	5724169	291	GWT13
H10	Host	468091	5725646	808	GWT11
H11	Host	468259	5724398	703	GWT13
H12	Host	468387	5725686	1082	GWT11
H13	Host	459174	5723481	733	GWT03
N032	Neighbour	456782	5720820	2352	GWT01
N035	Neighbour	456961	5720204	2366	GWT01
N036	Neighbour	456966	5719953	2479	GWT01
N038	Neighbour	457354	5720365	1941	GWT01
N039	Neighbour	457420	5721301	1683	GWT01
N041	Neighbour	457646	5724221	2387	GWT03
N043	Neighbour	457910	5720036	1674	GWT01
N044	Neighbour	458209	5720224	1331	GWT01
N045	Neighbour	458255	5724125	1841	GWT03
N046	Neighbour	458517	5722411	1121	GWT02
N048	Neighbour	458734	5723596	1136	GWT03
N049	Neighbour	458871	5724191	1487	GWT03
N050	Neighbour	458877	5725244	2445	GWT03
N051	Neighbour	458998	5719763	1453	GWT01
N052	Neighbour	459982	5719130	2261	GWT01
N053	Neighbour	460111	5719590	1911	GWT01
N055	Neighbour	461192	5720028	2403	GWT01
N057	Neighbour	462018	5721038	2467	GWT05
N058	Neighbour	462519	5721656	1737	GWT05
N067	Neighbour	463356	5724710	1441	GWT05
N068	Neighbour	463398	5724328	1088	GWT06
N073	Neighbour	463821	5725012	1719	GWT07
N074	Neighbour	463822	5725680	2357	GWT07
N079	Neighbour	463958	5724677	1358	GWT07
N081	Neighbour	464066	5724476	1132	GWT07
N085	Neighbour	464278	5724560	1168	GWT07
N088	Neighbour	464393	5724553	1137	GWT09

Receptor ID	Landowner status	Easting[1] [m]	Northing[1] [m]	Distance to nearest turbine [m]	Nearest turbine ID
N092	Neighbour	464632	5727402	2485	GWT10
N093	Neighbour	464705	5727527	2482	GWT10
N094	Neighbour	464723	5727344	2377	GWT10
N096	Neighbour	464746	5727334	2352	GWT10
N097	Neighbour	464805	5727514	2389	GWT10
N099	Neighbour	464828	5727267	2249	GWT10
N100	Neighbour	464830	5727303	2264	GWT10
N101	Neighbour	464920	5726958	2042	GWT10
N103	Neighbour	465012	5727704	2328	GWT10
N107	Neighbour	465134	5727632	2188	GWT10
N109	Neighbour	465152	5726702	1744	GWT10
N110	Neighbour	465326	5726915	1649	GWT10
N111	Neighbour	465341	5727011	1676	GWT10
N112	Neighbour	465363	5727616	2004	GWT10
N113	Neighbour	465384	5725596	1601	GWT10
N115	Neighbour	465624	5725326	1535	GWT10
N116	Neighbour	465657	5725283	1536	GWT10
N117	Neighbour	465658	5725357	1489	GWT10
N119	Neighbour	465725	5724878	1284	GWT09
N120	Neighbour	465954	5727554	1567	GWT10
N121	Neighbour	466038	5724451	1136	GWT09
N122	Neighbour	466061	5727421	1396	GWT10
N123	Neighbour	466440	5728061	1843	GWT10
N124	Neighbour	466491	5727792	1569	GWT10
N125	Neighbour	466580	5728555	2308	GWT10
N126	Neighbour	466729	5728009	1751	GWT10
N127	Neighbour	466778	5728057	1796	GWT10
N128	Neighbour	466856	5721983	2190	GWT08
N129	Neighbour	466910	5721990	2233	GWT08
N130	Neighbour	466928	5727796	1537	GWT10
N131	Neighbour	466948	5721875	2324	GWT08
N132	Neighbour	467134	5728108	1869	GWT10
N133	Neighbour	467278	5722331	1934	GWT13
N134	Neighbour	467335	5722557	1702	GWT13
N135	Neighbour	467672	5727004	1115	GWT10
N137	Neighbour	467900	5727786	1856	GWT10
N138	Neighbour	467997	5722526	1767	GWT13
N139	Neighbour	468130	5723078	1290	GWT13
N140	Neighbour	468183	5727934	2145	GWT10
N141	Neighbour	468180	5727040	1411	GWT11
N142	Neighbour	468221	5727026	1426	GWT11

Receptor ID	Landowner status	Easting[1] [m]	Northing[1] [m]	Distance to nearest turbine [m]	Nearest turbine ID
N143	Neighbour	468312	5722799	1621	GWT13
N146	Neighbour	468403	5723337	1227	GWT13
N147	Neighbour	468414	5723412	1181	GWT13
N148	Neighbour	468517	5722375	2092	GWT13
N151	Neighbour	468854	5726872	1801	GWT11
N154	Neighbour	469009	5726568	1803	GWT11
N155	Neighbour	469159	5725195	1683	GWT12
N156	Neighbour	469202	5724778	1709	GWT12
N158	Neighbour	469516	5724609	1976	GWT13
N159	Neighbour	469709	5724438	2144	GWT13
N160	Neighbour	469851	5724561	2299	GWT13
N161	Neighbour	469926	5724573	2375	GWT13
N162	Neighbour	470000	5724614	2454	GWT13
N223	Neighbour	460077	5719523	1951	GWT01
N349	Neighbour	460586	5719671	2140	GWT01
N386	Neighbour	468364	5722806	1639	GWT13
N387	Neighbour	469245	5724764	1751	GWT13

Note:
1. *Coordinate system: UTM zone 55S, WGS84 datum* [3].

Table 3 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1640 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
Receptor height (double storey)	6 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]				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]	
					2 m	6 m	2 m	6 m	2 m	6 m	2 m	6 m
H01	Host	458025	5721403	GWT01 GWT02	**38.0**	**37.2**	**42.8**	**41.9**	9.5	9.2	**10.6**	**10.4**
H02	Host	458501	5721772	GWT02	**46.2**	**45.5**	**57.7**	**56.5**	**11.4**	**11.2**	**13.5**	**13.3**
H04[5]	Host	460504	5723858	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H05	Host	464020	5723677	GWT04 GWT05 GWT07 GWT08 GWT09	**41.0**	**40.1**	**79.0**	**81.0**	**10.6**	**10.4**	**15.9**	**16.2**
H06[5]	Host	465572	5724509	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H07	Host	466861	5725604	GWT11	**135.1**	**136.4**	**153.4**	**153.5**	**27.4**	**27.9**	**31.4**	**31.5**
H08	Host	467097	5724126	GWT13	**100.5**	**101.0**	**122.3**	**122.9**	**23.9**	**24.0**	**28.7**	**28.9**
H09	Host	467292	5724169	GWT13	**268.9**	**270.7**	**412.8**	**417.1**	**60.8**	**61.3**	**89.9**	**90.6**
H10	Host	468091	5725646	GWT10 GWT11	**58.6**	**57.9**	**65.4**	**64.9**	**11.8**	**11.7**	**13.1**	**13.0**
H11	Host	468259	5724398	GWT12 GWT13	**143.7**	**141.0**	**171.6**	**171.4**	**30.9**	**30.5**	**38.7**	**38.6**
H12	Host	468387	5725686	GWT10 GWT11	22.1	21.8	**35.4**	**35.0**	4.9	4.9	7.6	7.5
N032[5]	Neighbour	456782	5720820	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N035[5]	Neighbour	456961	5720204	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N036[5]	Neighbour	456966	5719953	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N038[5]	Neighbour	457354	5720365	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N039	Neighbour	457420	5721301	GWT01	0.0	0.0	8.1	7.9	0.0	0.0	2.0	2.0
N046	Neighbour	458517	5722411	GWT03	20.7	20.4	23.5	23.0	4.6	4.5	5.1	5.0
N055[5]	Neighbour	461192	5720028	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N067[5]	Neighbour	463356	5724710	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N068[5]	Neighbour	463398	5724328	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N081[5]	Neighbour	464066	5724476	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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]	
					2 m	6 m	2 m	6 m	2 m	6 m	2 m	6 m
N085[5]	Neighbour	464278	5724560	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N088[5]	Neighbour	464393	5724553	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N092[5]	Neighbour	464632	5727402	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N093[5]	Neighbour	464705	5727527	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N094[5]	Neighbour	464723	5727344	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N096[5]	Neighbour	464746	5727334	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N099[5]	Neighbour	464828	5727267	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N100[5]	Neighbour	464830	5727303	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N101[5]	Neighbour	464920	5726958	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N109[5]	Neighbour	465152	5726702	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N110	Neighbour	465326	5726915	GWT10	0.0	0.0	23.9	23.4	0.0	0.0	5.6	5.5
N111	Neighbour	465341	5727011	GWT10	0.0	0.0	17.0	16.7	0.0	0.0	4.1	4.0
N113	Neighbour	465384	5725596	GWT10	11.8	11.4	13.1	12.8	2.6	2.5	2.8	2.8
N115	Neighbour	465624	5725326	GWT10	16.5	15.7	24.6	23.7	3.2	3.0	5.0	4.9
N116	Neighbour	465657	5725283	GWT10	4.6	3.5	15.2	14.4	0.6	0.4	2.9	2.7
N117	Neighbour	465658	5725357	GWT10	19.2	18.4	26.8	26.1	3.8	3.6	5.6	5.4
N119[5]	Neighbour	465725	5724878	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N121	Neighbour	466038	5724451	GWT12 GWT13	20.9	20.4	22.8	22.2	5.1	4.9	5.6	5.4
N128[5]	Neighbour	466856	5721983	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N129[5]	Neighbour	466910	5721990	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N131[5]	Neighbour	466948	5721875	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N133[5]	Neighbour	467278	5722331	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

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]	
					2 m	6 m	2 m	6 m	2 m	6 m	2 m	6 m
N134[5]	Neighbour	467335	5722557	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N141	Neighbour	468180	5727040	GWT10	2.7	2.8	9.9	9.7	0.4	0.4	2.3	2.3
N142	Neighbour	468221	5727026	GWT10	7.3	7.3	14.5	14.3	1.5	1.6	3.7	3.7
N147	Neighbour	468414	5723412	GWT13	0.0	0.0	5.1	3.5	0.0	0.0	0.4	0.2
N151[5]	Neighbour	468854	5726872	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N154[5]	Neighbour	469009	5726568	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N155	Neighbour	469159	5725195	GWT12	0.0	0.0	9.1	8.8	0.0	0.0	2.5	2.4
N156[5]	Neighbour	469202	5724778	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N158[5]	Neighbour	469516	5724609	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N159[5]	Neighbour	469709	5724438	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N160[5]	Neighbour	469851	5724561	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N161[5]	Neighbour	469926	5724573	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N162[5]	Neighbour	470000	5724614	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N387[5]	Neighbour	469245	5724764	-	0.0	0.0	0.0	0.0	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: UTM zone 55S, WGS84 datum* [3].
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.*

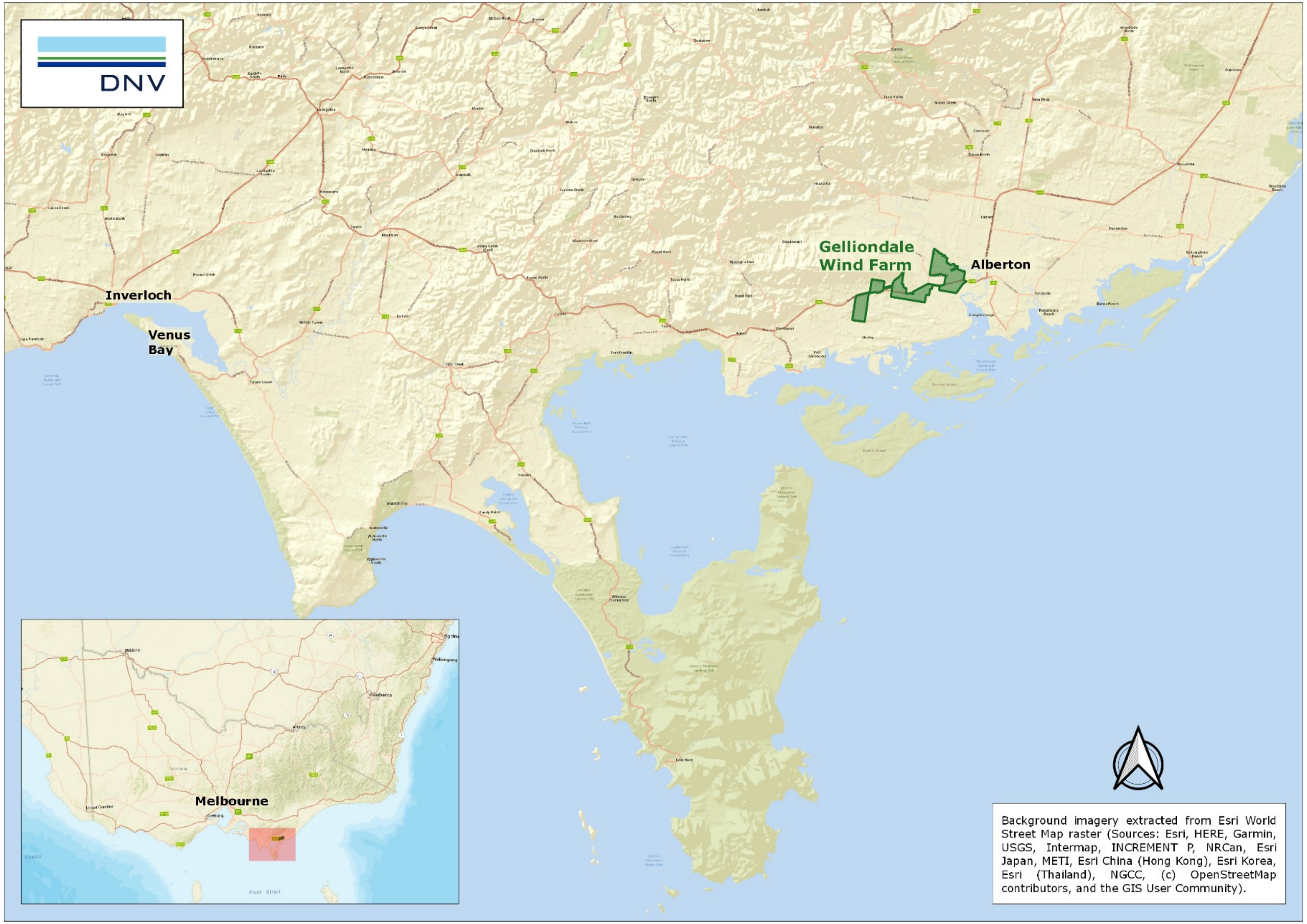

Figure 2 Location of the Project

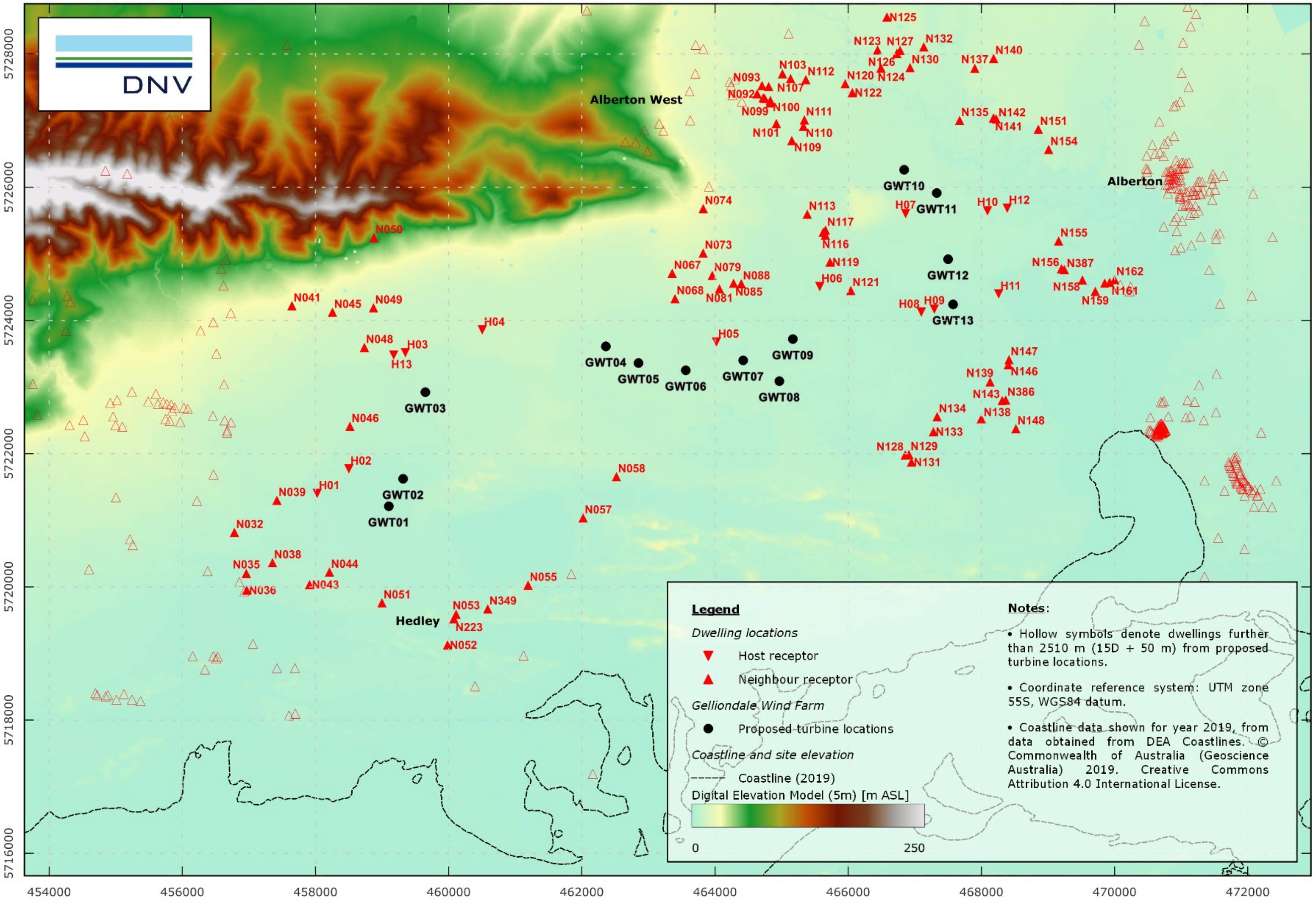

Figure 3 Elevation map of the Project

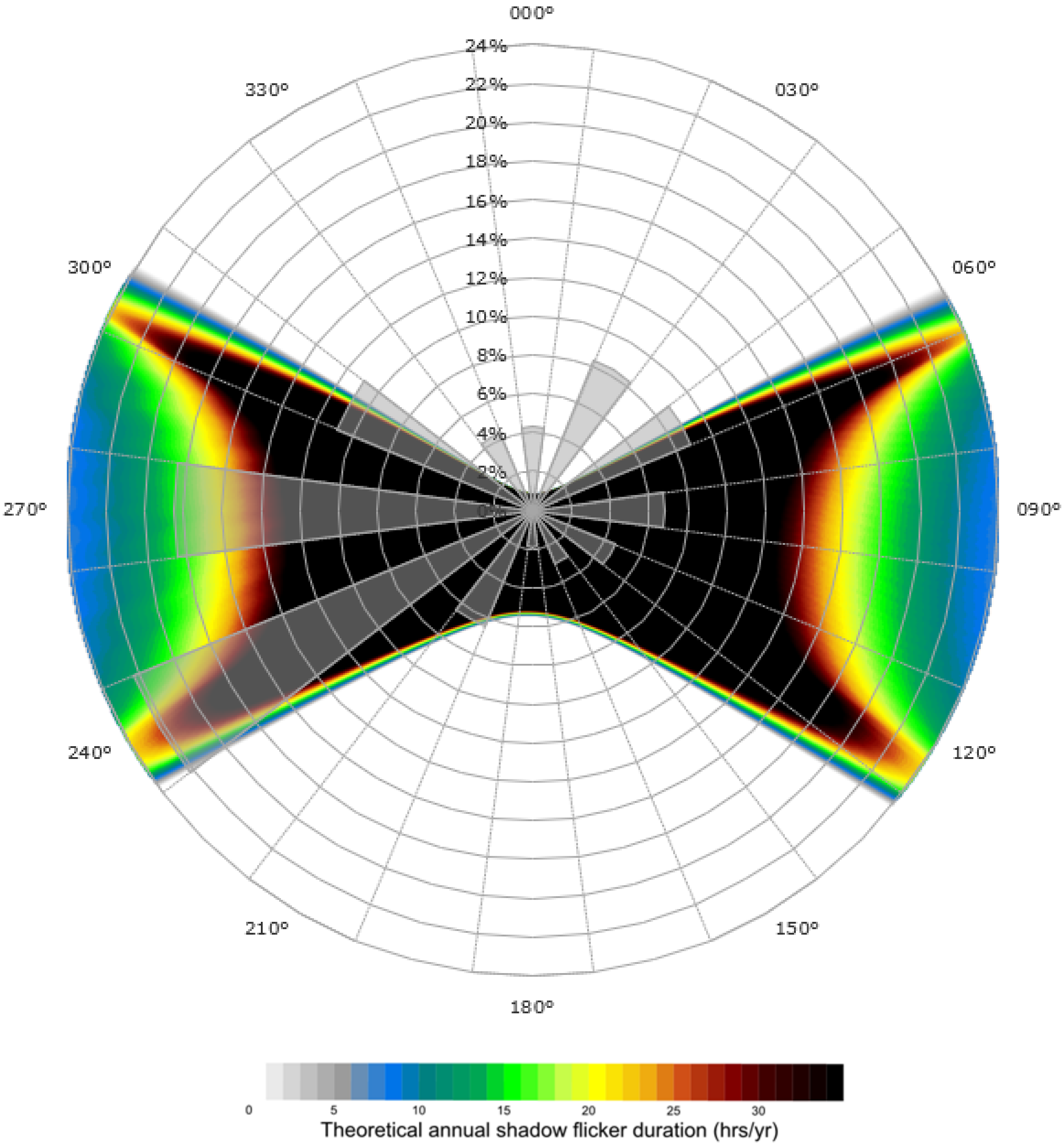

Figure 4 Indicative shadow flicker map and wind direction frequency distribution

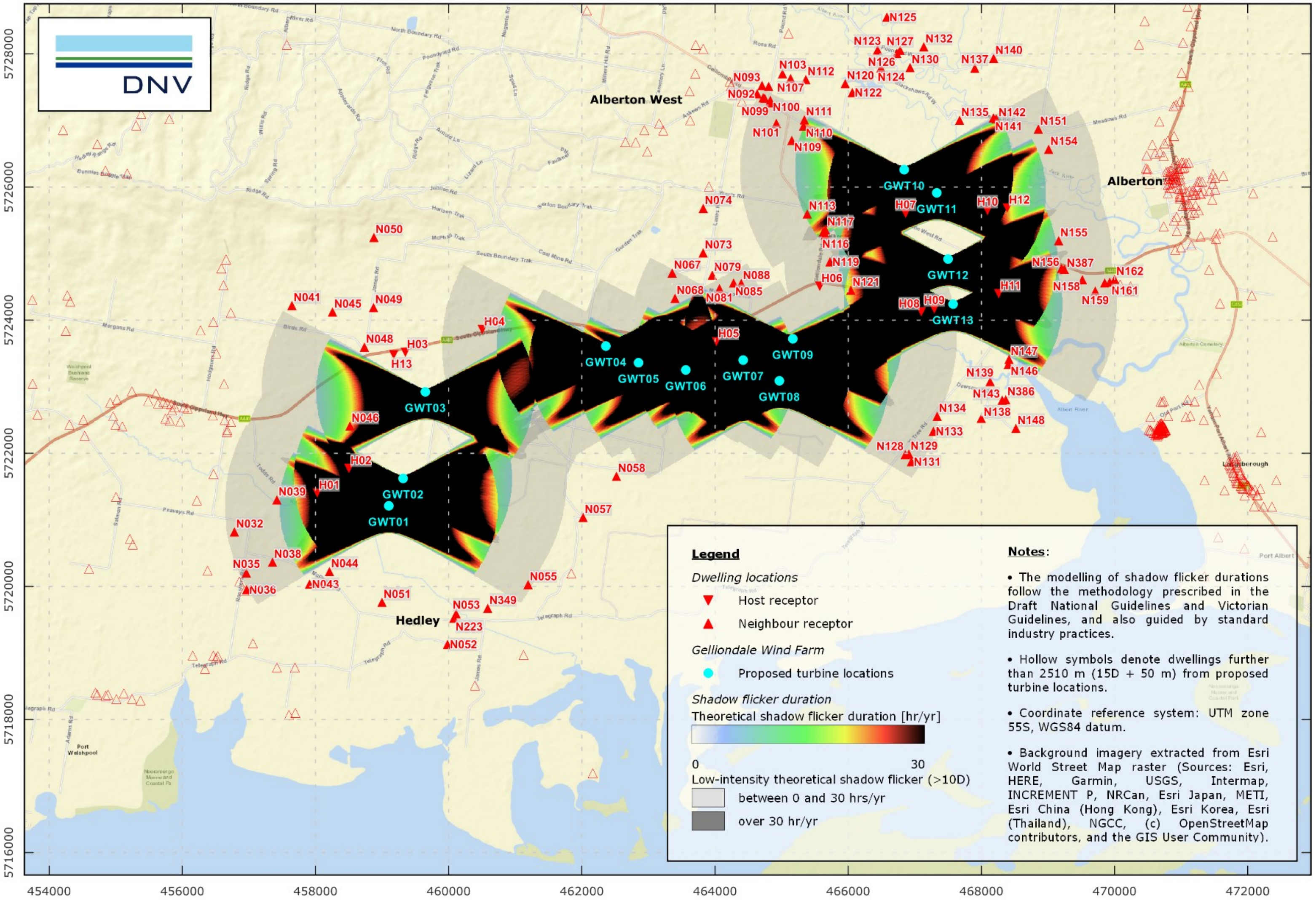

Figure 5 Theoretical annual shadow flicker duration map

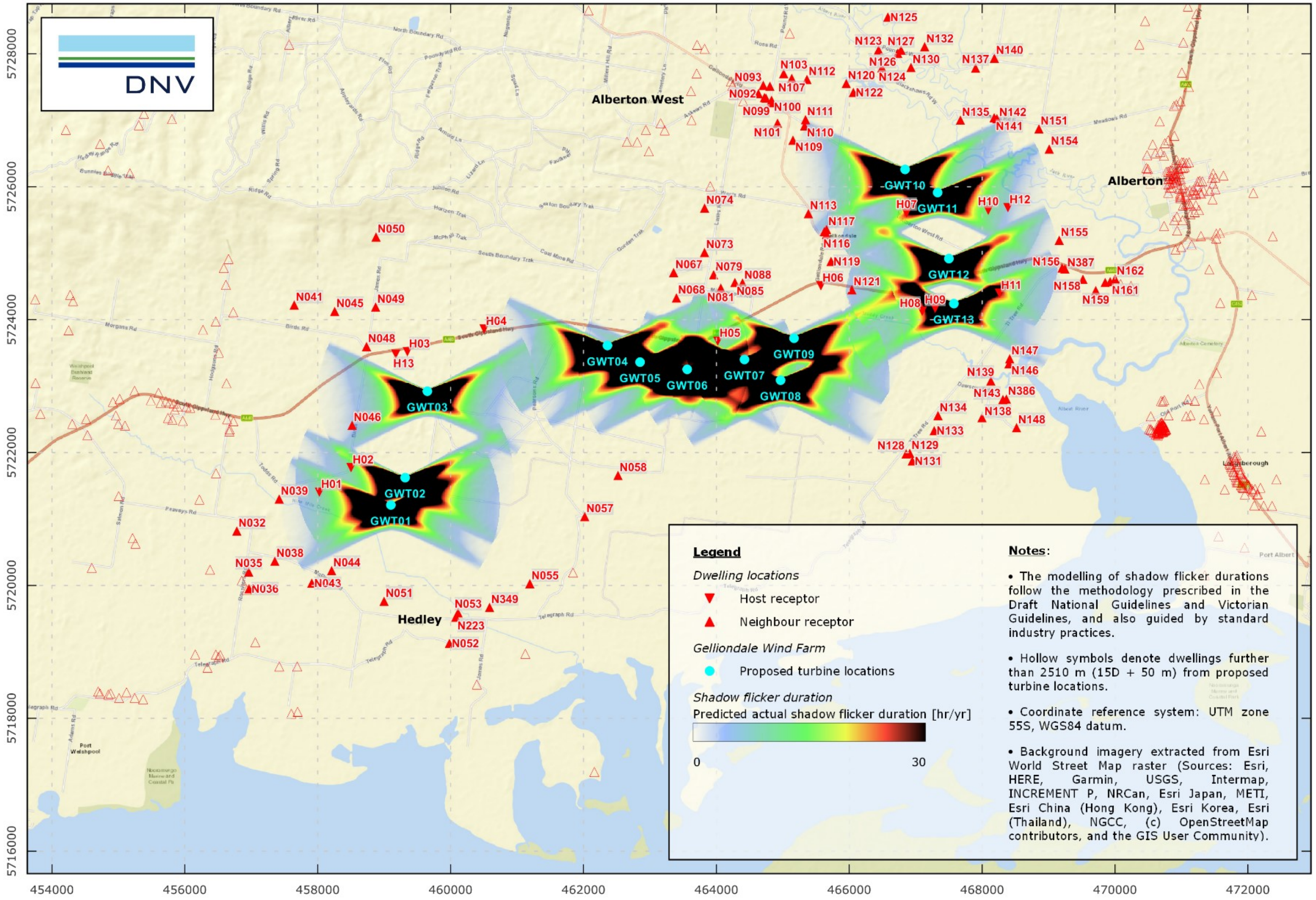

Figure 6 Predicted actual annual shadow flicker duration map

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