WOOLSTHORPE WIND FARM

Shadow Flicker and Blade Glint Assessment

Woolsthorpe Asset Pty Ltd ATF Woolsthorpe Asset Trust

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Contact person:	James Taylor	
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DNV – Energy Systems
Renewables Advisory
Level 12, 350 Queen Street
Melbourne VIC 3000
Australia
Tel: +61 3 8615 1515
ABN 19 094 520 760

Task and objective:
Woolsthorpe Wind Farm Shadow Flicker and Blade Glint Assessment

Prepared by:	Verified by:	Approved by:
J Jobin Principal Engineer Project Development & Analytics	**N Brammer** Senior Engineer Project Development & Analytics	**T Gilbert** Principal Engineer, Head of Section Project Developmetn & Analytics

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EXECUTIVE SUMMARY

DNV has been commissioned by Woolsthorpe Asset Pty Ltd ATF Woolsthorpe Asset Trust ("the Customer") to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Woolsthorpe Wind Farm ("the Project") in Victoria. The results of the shadow flicker assessment are described in this document.

Background and methodology

DNV has assessed the expected annual shadow flicker durations for the Project in accordance with condition 27 of the Project's planning permit [1], the Victorian Planning Guidelines [2] and the Draft National Wind Farm Development Guidelines [3] (Draft National Guidelines). The methodology used in this study has been informed by these guidelines and various standard industry practices.

Condition 27 of the Project's planning permit stipulates that the shadow flicker duration must not exceed 30 hours per year at any dwelling existing as of 7 June 2016. Furthermore, 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 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 rotor diameter of 164 m and hub height of 148 m has been considered. The locations of 44 dwellings have been provided by the Customer, with one of these dwellings (V) understood to be a stakeholder dwelling.

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

Based on this assessment, a total of three dwellings (B, C & V) are expected to experience some shadow flicker, two of which (B & C) are understood to be non-stakeholder dwellings.

Out of these three dwellings, only one (V) is predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling. It should also be noted that the theoretical shadow flicker durations modelled at this dwelling are particularly high. However, DNV understand it would be exempt from the prescribed limit as it is located on land where the wind farm will be built. Condition 27 of the Project's planning permit provides further guidance on this matter.

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

When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at both non-stakeholder dwellings (B & C) is predicted to be below the recommended limit of 10 hours per year within 50 m of the dwelling. However, exceedance is still predicted at dwelling V.

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 in calculating the number of shadow flicker hours.

Considering the close proximity of the proposed Hawkesdale Wind Farm project, DNV has also modelled the combined shadow flicker impact of the Project and its proposed neighbour. From this modelling, none of the provided dwelling locations are expected to be subject to cumulative shadow flicker above a moderate level of intensity from both projects.

Since a non-reflective finish is proposed for the wind turbine blades, blade glint is not expected to be an issue for the Project.

1 INTRODUCTION

Woolsthorpe Asset Pty Ltd ATF Woolsthorpe Asset Trust ("the Customer") has commissioned DNV to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Woolsthorpe Wind Farm ("the Project") in western Victoria. The results of this work are reported here.

This assessment evaluates the shadow flicker durations in the vicinity of the Project in accordance with condition 27 of the Project's planning permit [1], 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 [2], and the National Wind Farm Development Guidelines – Draft (Draft National Guidelines) prepared by the Environment Protection and Heritage Council (EPHC) in July 2010 [3]. The potential cumulative shadow flicker effects resulting from the combined impact of the Project and the nearby Hawkesdale Wind Farm have also been considered in this assessment.

This document has been prepared in accordance with DNV proposal L2C-221663-AUME-P-01 Issue B, dated 2 February 2022, and is subject to the terms and conditions in that agreement.

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The site

The Project is located in western Victoria, approximately 22 km north-northwest of Warrnambool as illustrated in Figure 2.

The terrain within the site boundary is relatively simple with elevations ranging between approximately 90 m and 130 m above sea level, with the highest areas located to the north. Ground cover on site comprises primarily farmland, interspersed with some areas of bushes and small patches of trees. A larger area of forestry is located immediately to the south. Elevation data for the Project site was provided by the Customer [4], and a map representing the terrain at the Project is included in Figure 3.

2.2 The project

2.2.1 Proposed wind farm layout

The Project is proposed to consist of 13 wind turbines [5]. 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 the GE 164-6.0 MW turbine model with a rotor diameter of 164 m, a hub height of 148 m, and an upper tip height of 230 m [6].

2.2.2 Shadow receptor locations

Details of 44 dwellings neighbouring the wind farm were provided to DNV by the Customer [7, 8, 9]. The coordinates of those dwellings are presented in Table 3. Based on the information provided, DNV understands that one of these dwellings is a stakeholder dwelling.

DNV has modelled all listed dwellings as habitable building structures. Dwellings situated more than 2460 m from turbine locations are considered unlikely to be impacted by shadow flicker, as discussed further in Sections 3.1 and 4.1.

DNV has not carried out a detailed and comprehensive survey of sensitive land uses and building locations in the area and is relying on information provided by the Customer.

2.3 Neighbouring wind farm

The project is located in a region of high wind farm development activity, with several other wind farm projects at different stages of development proposed, or operating, in the area.

Upon review of publicly known projects, DNV has identified the proposed Hawkesdale Wind Farm (HWF), located immediately northwest of the Project. The proposed turbine locations for this project [10] are listed in Table 2 and presented in Figure 3. Based on the information provided on the project [10], the layout is expected to use Vestas V136-4.2 MW turbines, with a rotor diameter of 136 m and a 112 m hub height.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

In relation to shadow flicker, condition 27 of the Project's planning permit [1] requires the following:

"Shadow flicker from the wind energy facility must not exceed 30 hours per annum at any dwelling existing at 7 June 2016.

This condition does not apply to any dwelling on land on which part of the wind energy facility is erected. Any required exemption must be given effect by an agreement with the landowner which is registered on the title to the land and will apply to any occupant of the dwelling. The agreement must be entered into before the use commences."

Furthermore, the Victorian Planning Guidelines [2] currently state:

"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."

In addition, the Draft National Guidelines [3] include recommendations for shadow flicker limits relevant to wind farms in Australia.

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 equivalent to assessing shadow flicker durations within the 'garden fenced area'. In most cases this approach is expected to be conservative, 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 [11] or approximately 1200 m to 1700 m for modern wind turbines (which typically have rotor diameters of 120 m to 170 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).

3.2 Blade glint

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

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

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 the turbines 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 could 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 UK wind industry considers that 10 rotor diameters is appropriate [11], while the Draft National Guidelines suggest a distance equivalent to 265 times the maximum blade chord as an appropriate limit.

For the current assessment, DNV has applied a maximum shadow length of 10 times the rotor diameter (10D), which corresponds to a distance limit of 1640 m for the Project and 1360 m for the neighbouring HWF project. Under the Draft National Guidelines, this will be conservative for any turbine with a maximum blade chord of less than 6.2 m for the Project and less than 5.1 m for the neighbouring HWF. 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, DNV has also assessed the shadow flicker for an increased distance limit of 15 times the rotor diameter (15D), or 2460 m for the Project, which should include shadow flicker below a "moderate level of intensity".

The model also makes the following assumptions and simplifications:

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

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 4.

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 overestimate of 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 above 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 four Bureau of Meteorology (BoM) stations:

- Warrnambool Airport (090172), located approximately 12 km from the site [12]
- Warrnambool Post Office (090082), located approximately 22 km from the site [13]
- Heywood Forestry (090048), located approximately 65 km from the site [14].

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 59% and 72%, and the average annual cloud cover is approximately 67%. This means that on an average day, 67% 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. Wind direction frequency distributions derived from wind modelling at the site were provided by the Customer [15] and used to estimate the reduction in shadow flicker duration due to rotor orientation. The modelled 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, provided the blades are coated with a non-reflective paint, and it is not considered further here since it is understood that a non-reflective finish will be applied to the wind turbine blades.

5 ASSESSMENT RESULTS

5.1 Shadow flicker

Shadow flicker assessments were carried out at all provided habitable dwelling locations, or 'receptors', as outlined in Table 3.

The theoretical and predicted actual shadow flicker durations at all considered dwellings identified to be affected by shadow flicker are presented in Table 5. The maximum predicted shadow flicker durations within 50 m of these receptors are also presented in these tables. 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, three dwellings (B, C & V) are predicted to experience some shadow flicker based on the methodology recommended by the Draft National Guidelines, two of which (B & C) are understood to be non-stakeholder dwellings. One of these dwellings (V) is also predicted to experience theoretical shadow flicker durations, within 50 m of the dwelling, that exceed the limit recommended by the current guidelines. It should also be noted that the theoretical shadow flicker durations modelled at this dwelling are particularly high. However, DNV understand it would be exempt from the prescribed limit as it is located on land where the wind farm will be built. Condition 27 of the Project's planning permit provides further guidance on this matter.

When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at both non-stakeholder dwellings (B & C) is predicted to be below the recommended limit of 10 hours per year within 50 m of the dwelling. However, exceedance is still predicted at dwelling V.

Beyond the 10D 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 part of the methodology outlined in the Draft National Guidelines, DNV has also assessed the shadow flicker impacts for the Project for an increased distance limit that is intended to include shadow flicker below a "moderate level of intensity". For the purpose of this assessment, 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 that nine additional dwellings have the potential to be exposed to shadow flicker below a "moderate level of intensity". These dwellings are noted in Table 5.

Shadow flicker impacts can be reduced through a number of measures. These include the relocation of turbines, installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies which shut down turbines when shadow flicker is likely to occur.

5.2 Potential for cumulative shadow flicker impact

As mentioned in Section 2.3, the Hawkesdale Wind Farm project is currently proposed in the vicinity of the Project.

In order to assess the likelihood of nearby dwellings being subject to shadow flicker from both projects, DNV has completed theoretical shadow flicker modelling for the two projects in combination, each with their respective distance limits. In order to reduce computation time, modelling was conducted with a reduced grid resolution of 20 m and only at 2 m above ground. The results from this modelling are presented in Figure 7.

From the results of the combined modelling presented in Figure 7, it can be seen that no dwellings are expected to be subject to shadow flicker from both projects if the 10D distance limit is assumed. However, it could be possible for dwelling D to be subject to some level of cumulative shadow flicker below a "moderate level of intensity" from the Project. Similarly, dwelling C, which is currently expected to experience shadow flicker from the Project, could also be subject to shadow flicker below a "moderate level of intensity" from the neighbouring HWF project.

5.3 Blade glint

As discussed in Section 4.2, blade glint is generally not a problem for modern wind turbines provided that the blades are coated with a non-reflective paint.

Since a non-reflective finish is proposed for the wind turbine blades, blade glint is not expected to be an issue for the Project.

6 CONCLUSION

A shadow flicker assessment was carried out at all provided dwelling locations in the vicinity of the Project.

For the purpose of this assessment, DNV has considered a layout consisting of 13 turbines with a rotor diameter of 164 m and a hub height of 148 m. The results of the shadow flicker assessment based on this layout configuration are summarised in Table 5.

Based on DNV's modelling, three dwellings are predicted to experience some shadow flicker based on the methodology recommended by the Draft National Guidelines (B, C & V), two of which are non-stakeholder dwellings (B & C). One of these dwellings (V) is also predicted to experience theoretical shadow flicker durations, within 50 m of the dwelling, that exceed the limit recommended by the current guidelines. It should also be noted that the theoretical shadow flicker durations modelled at dwelling V are particularly high. However, DNV understand it would be exempt from the prescribed limit as it is located on land where the wind farm will be built. Condition 27 of the Project's planning permit provides further guidance on this matter.

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

When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at both non-stakeholder dwellings (B & C) is predicted to be below the recommended limit of 10 hours per year within 50 m of the dwelling. However, exceedance is still predicted at dwelling V.

The prediction of the actual shadow flicker duration presented here does not take into account any reduction due to low wind speed, vegetation, or other shielding effects around each receptor in calculating the number of shadow flicker hours.

Considering the close proximity of the proposed Hawkesdale Wind Farm project, DNV has also modelled the combine shadow flicker impact of the Project and its proposed neighbour. From this modelling, none of the provided dwelling locations are expected to be subject to cumulative shadow flicker above a moderate level of intensity from both projects.

Since a non-reflective finish is proposed for the wind turbine blades, blade glint is not expected to be an issue for the Project.

7 REFERENCES

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[14] Bureau of Meteorology, "Climate statistics for Australian locations - Heywood Forestry," [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_090048_All.shtml. [Accessed 17 February 2022].

[15] Email from J. Taylor (Customer) to J. Jobin (DNV), 18 February 2022.

[16] "211020_Woolsthorpe_Layout_ Buffer 1.5 km_DEF.kmz," file provided by J Taylor (Customer) to J. Jobin (DNV), 2 February 2022.

[17] "211103 Woolsthorpe_alternative WTs_DNVGL.xlsx," file provided by J Taylor (Customer) to J. Jobin (DNV), 2 February 2022.

Table 1 Proposed turbine layout for the Project site [5]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
WT_1	620875	5773543	108
WT_2	621300	5774230	112
WT_3	620403	5771965	97
WT_4	620854	5775019	120
WT_5	621465	5773275	109
WT_6	620159	5776552	130
WT_7	621993	5773311	107
WT_8	620090	5771495	93
WT_9	620169	5775784	127
WT_10	620101	5773861	111
WT_11	620920	5775920	127
WT_12	620194	5772868	100
WT_13	620912	5772741	103

1. Coordinate system: UTM zone 54, WGS84 datum.

Table 2 Turbine layout for the proposed HWF project [10]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
A1	619671	5781176	153
A2	620172	5781015	150
A3	618586	5781146	151
A4	619146	5780893	153
A5	619609	5780614	152
A7	620094	5780236	151
A8	620638	5780006	150
A9	620119	5779583	150
A11	620053	5778891	144
A14	619547	5778196	141
A15	620059	5777899	141
A19	618570	5779965	143
A20	618946	5779579	138
A21	618205	5779539	140
A22	618547	5779081	133
A23	617655	5779529	135
A24	617859	5779071	133
A25	618005	5778561	132
A26	617120	5779155	130
A27	617483	5778675	131
A28	617218	5776574	111
A30	618020	5775441	111
A31	617707	5775280	106

1. Coordinate system: UTM zone 54, WGS84 datum.

Table 3 Shadow receptor locations [7, 8]

Receptor ID	Easting[1] [m]	Northing[1] [m]	Landowner status	Distance to nearest turbine [m] [2] (nearest turbine ID)
A	620216	5777302	Non-stakeholder	752 (WT_6)
B	622381	5775266	Non-stakeholder	1519 (WT_11)
C	619675	5774799	Non-stakeholder	1030 (WT_10)
D	618444	5776714	Non-stakeholder	1723 (WT_6)
E	623460	5772107	Non-stakeholder	1898 (WT_7)
F	623375	5772083	Non-stakeholder	1849 (WT_7)
G	623072	5772096	Non-stakeholder	1625 (WT_7)
H	623007	5772036	Non-stakeholder	1629 (WT_7)
I	622938	5772135	Non-stakeholder	1509 (WT_7)
J	623047	5771848	Non-stakeholder	1803 (WT_7)
K	621628	5770428	Non-stakeholder	1872 (WT_8)
L	624176	5771861	Non-stakeholder	2621 (WT_7)
M	624356	5771690	Non-stakeholder	2866 (WT_7)
N	624724	5772526	Non-stakeholder	2842 (WT_7)
O	624924	5772855	Non-stakeholder	2966 (WT_7)
P	624546	5773201	Non-stakeholder	2555 (WT_7)
Q	624626	5773736	Non-stakeholder	2667 (WT_7)
R	621680	5778020	Non-stakeholder	2114 (WT_6)
S	621654	5778872	Non-stakeholder	2760 (WT_6)
T	617789	5777091	Non-stakeholder	2431 (WT_6)
U	621352	5777428	Non-stakeholder	1480 (WT_6)
V	620472	5775168	Stakeholder	410 (WT_4)
HW004	616033	5780823	Non-stakeholder	5938 (WT_6)
HW027	616357	5781126	Non-stakeholder	5948 (WT_6)
HW028	616426	5781208	Non-stakeholder	5968 (WT_6)
HW040	616158	5780602	Non-stakeholder	5693 (WT_6)
HW047	615450	5776222	Non-stakeholder	4721 (WT_6)
HW048	616095	5776902	Non-stakeholder	4079 (WT_6)
HW053	616062	5778791	Non-stakeholder	4669 (WT_6)
HW060	621742	5779721	Non-stakeholder	3542 (WT_6)
HW061	621184	5780890	Non-stakeholder	4457 (WT_6)
HW062	621658	5780772	Non-stakeholder	4478 (WT_6)
HW064	620170	5782883	Non-stakeholder	6331 (WT_6)
HW072	617583	5782502	Non-stakeholder	6484 (WT_6)
HW075	615400	5779251	Non-stakeholder	5471 (WT_6)
HW080	615970	5775825	Non-stakeholder	4199 (WT_9)
HW081	616129	5776023	Non-stakeholder	4047 (WT_9)
HW101	616891	5780292	Non-stakeholder	4967 (WT_6)
HW167	616572	5781162	Non-stakeholder	5841 (WT_6)
HW171	615929	5779036	Non-stakeholder	4905 (WT_6)
HW172	616722	5780826	Non-stakeholder	5485 (WT_6)
HW173	616570	5781069	Non-stakeholder	5769 (WT_6)
HW174	616425	5781083	Non-stakeholder	5871 (WT_6)
HW197	617360	5782729	Non-stakeholder	6782 (WT_6)

1. Coordinate system: UTM zone 54, WGS84 datum.
2. Distance to neighbouring project not considered.

Table 4 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1640 m
Year of calculation	2034
Minimum elevation of the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere (disc for turbine orientation reduction calculation)
Sun modelled as	Disc
Offset between rotor and tower	None
Receptor height (single storey)	2 m
Receptor height (double storey)	6 m
Locations used for determining maximum shadow flicker within 50 m of each dwelling	8 points evenly spaced (every 45°) on 25 m and 50 m radius circles centred on the provided house location

Table 5 Theoretical and predicted actual annual shadow flicker duration

House ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Theoretical annual				Predicted actual annual[3]			
					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
B	Non-stakeholder	622381	5775266	WT_4 WT_11	26.1	25.5	28.1	27.8	5.5	5.4	5.9	5.8
C	Non-stakeholder	619675	5774799	WT_4	18.9	18.7	20.6	20.4	3.9	3.8	4.2	4.1
D [4]	Non-stakeholder	618444	5776714	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E [4]	Non-stakeholder	623460	5772107	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F [4]	Non-stakeholder	623375	5772083	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
G [4]	Non-stakeholder	623072	5772096	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H [4]	Non-stakeholder	623007	5772036	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I [4]	Non-stakeholder	622938	5772135	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
J [4]	Non-stakeholder	623047	5771848	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K [4]	Non-stakeholder	621628	5770428	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T [4]	Non-stakeholder	617789	5777091	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V	Stakeholder	620472	5775168	WT_4	**108.9**	**113.3**	**172.6**	**176.1**	**23.6**	**24.9**	**42.1**	**43.1**
	Recommended duration limits				***30 hr/yr***				***10 hr/yr***			

1. *Dwellings identified in Table 3 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 54, WGS84 datum.*
3. *Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.*
4. *Dwelling is not predicted to experience any shadow flicker above a moderate level of intensity, but may experience some shadow flicker below a moderate level of intensity.*

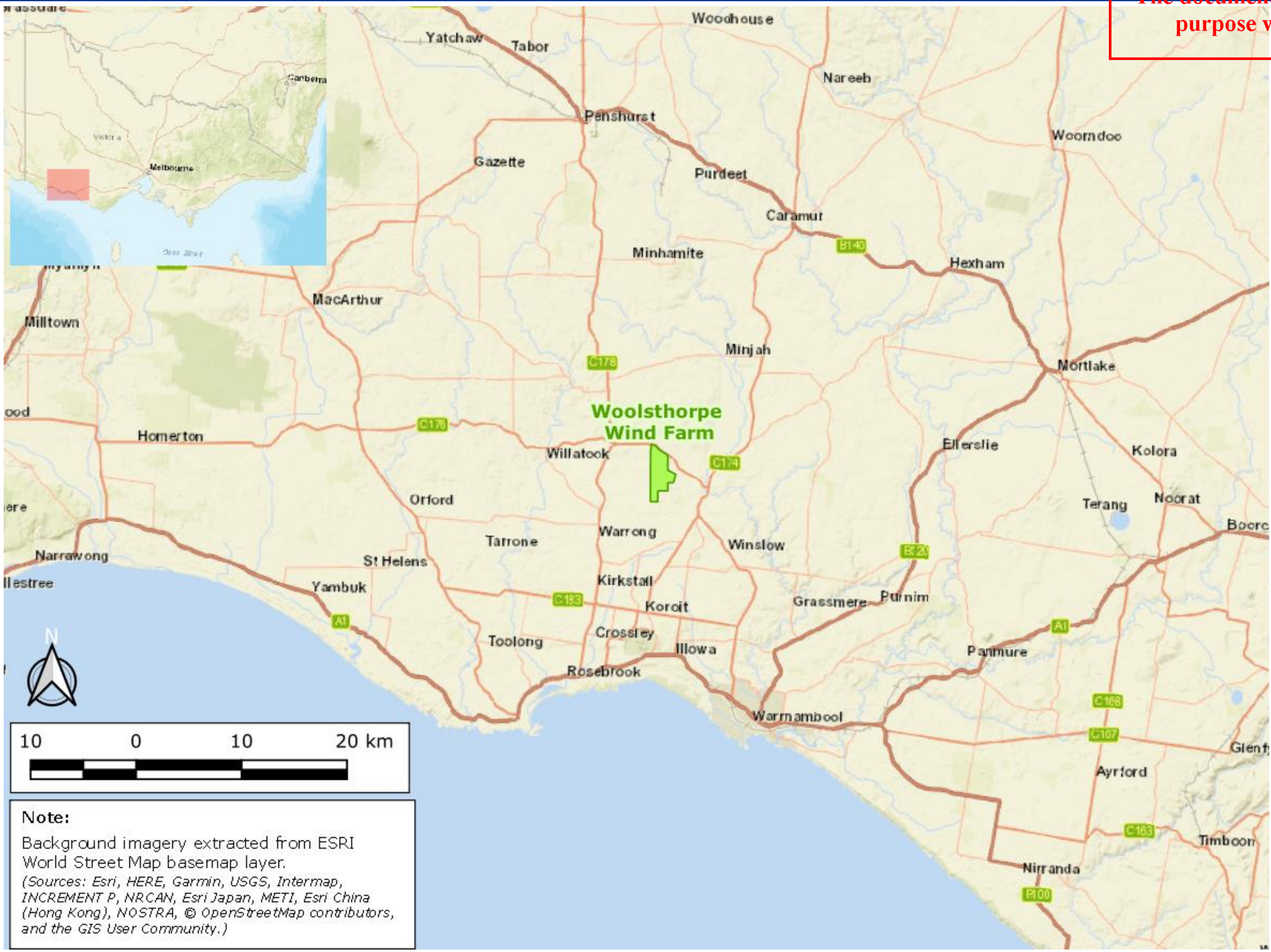

Figure 2 Location of the Project

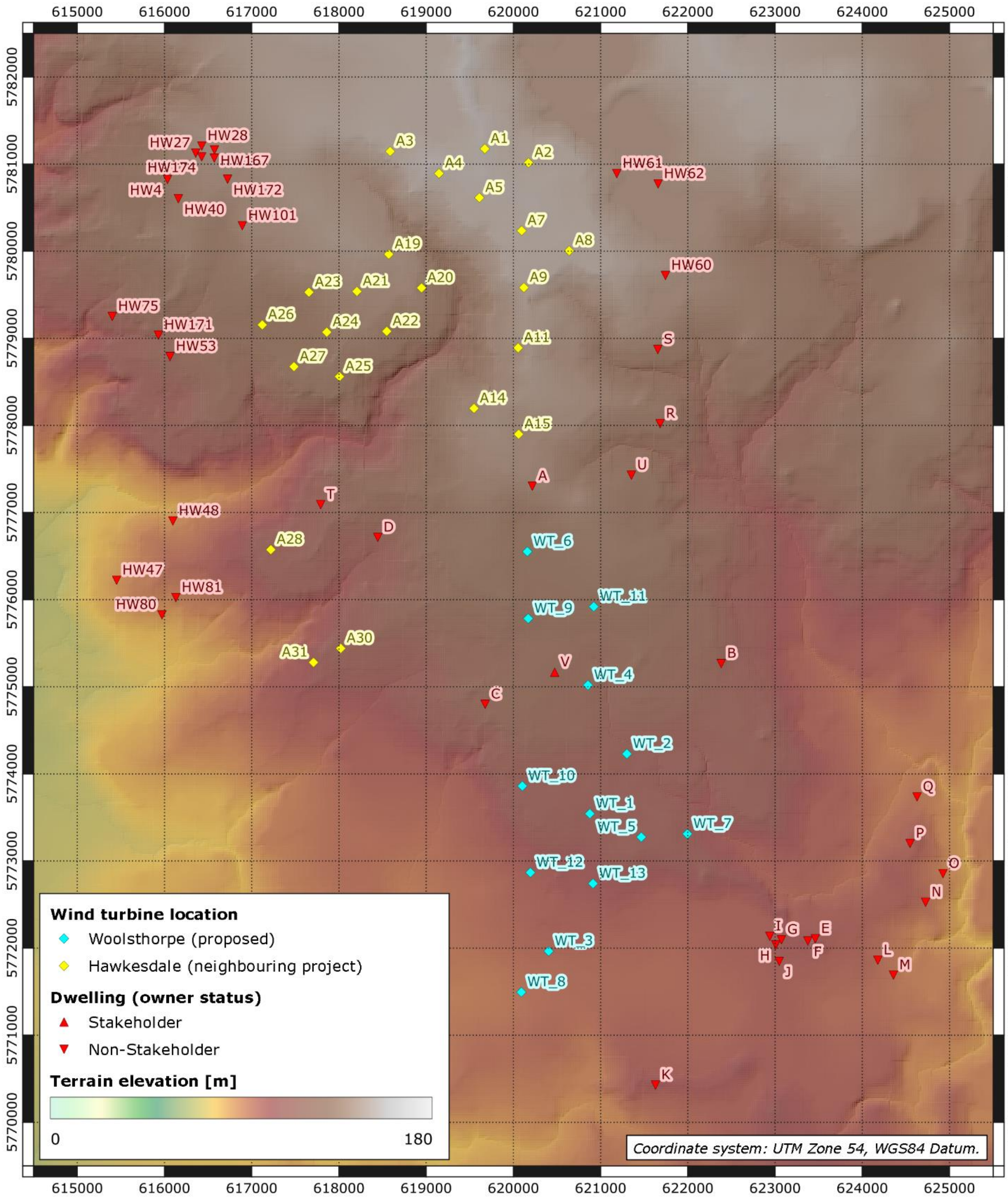

Figure 3 Elevation map of the Project

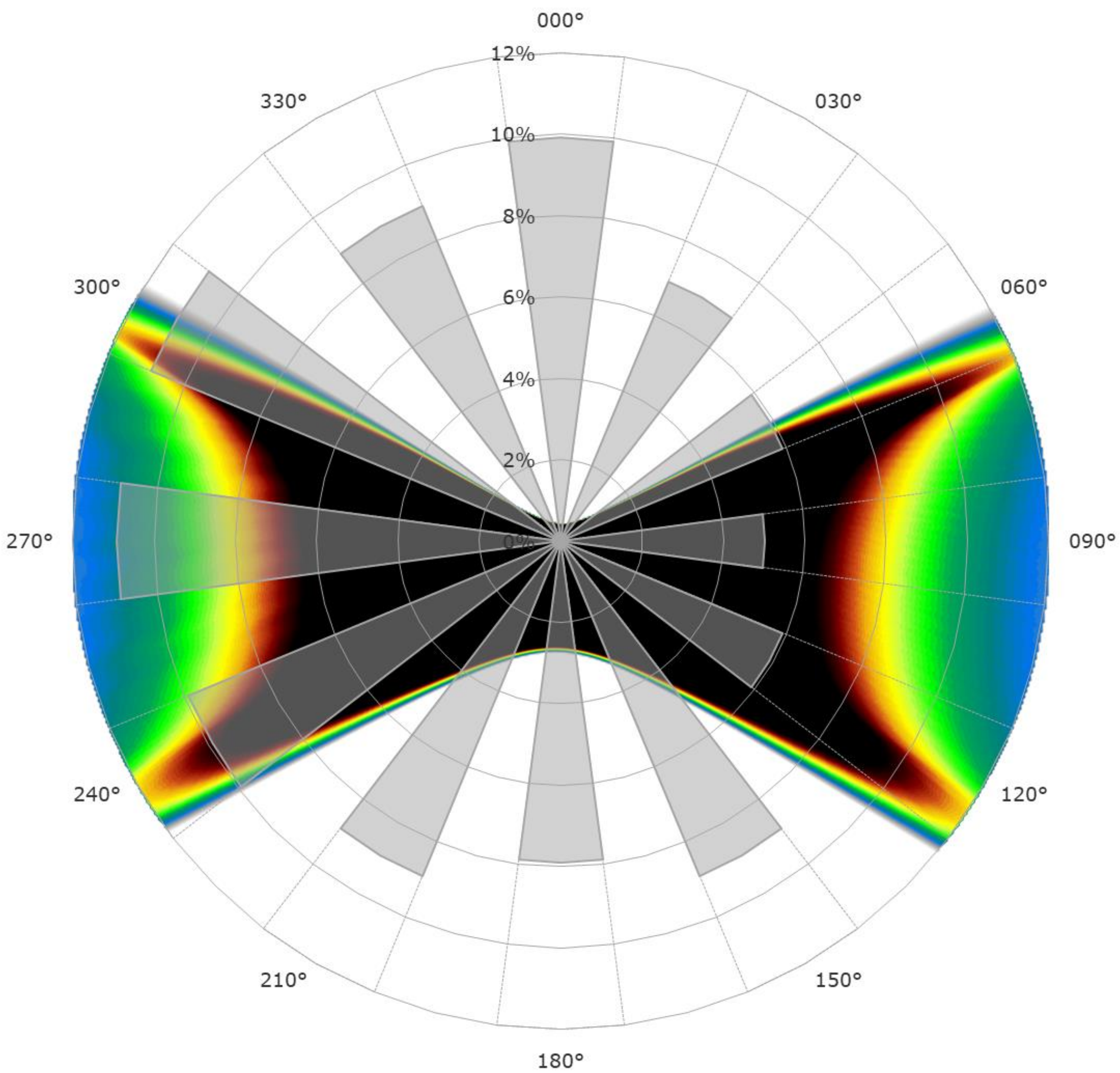

Figure 4 Indicative shadow flicker map and wind direction frequency distribution

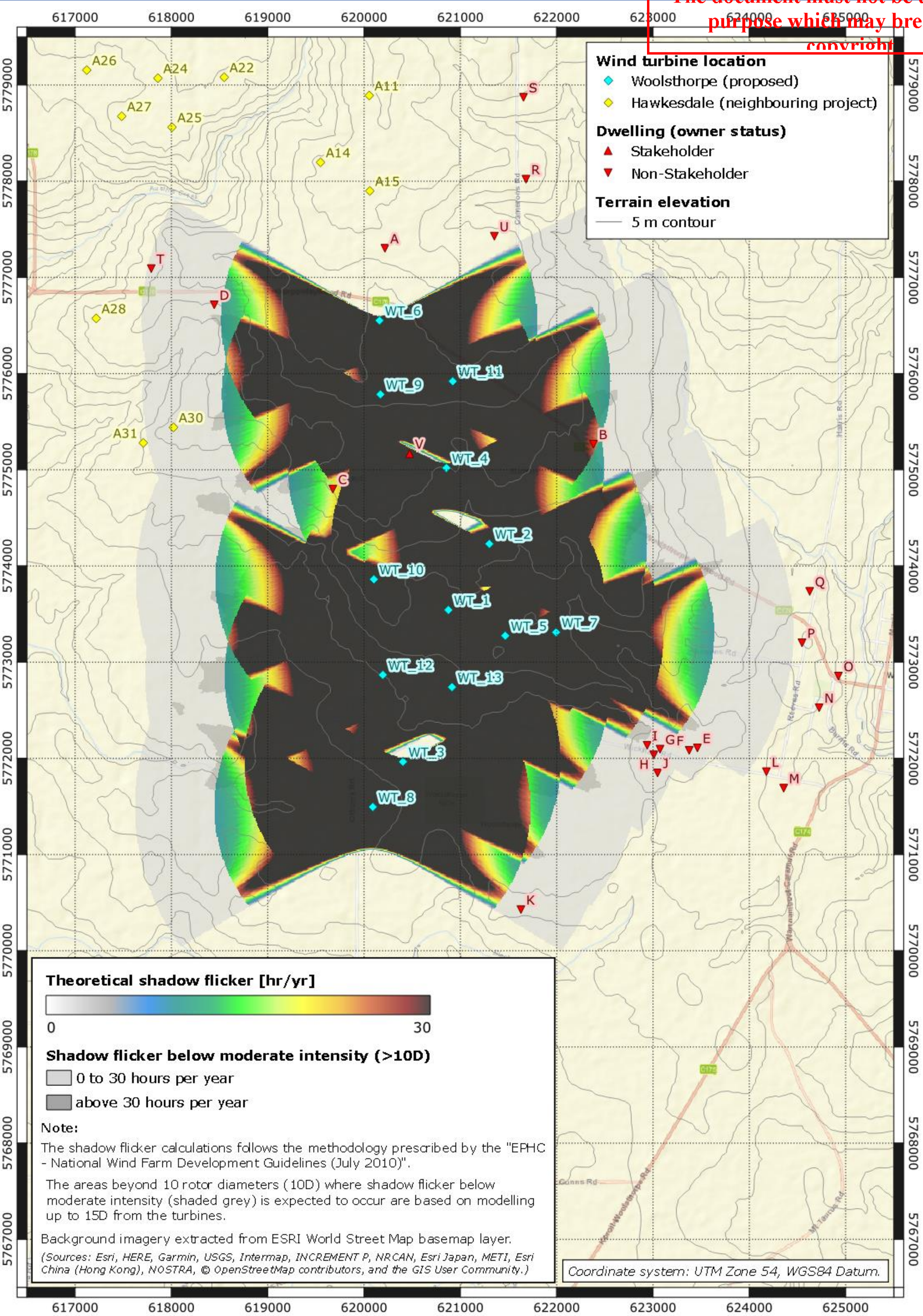

Figure 5 Theoretical annual shadow flicker duration map

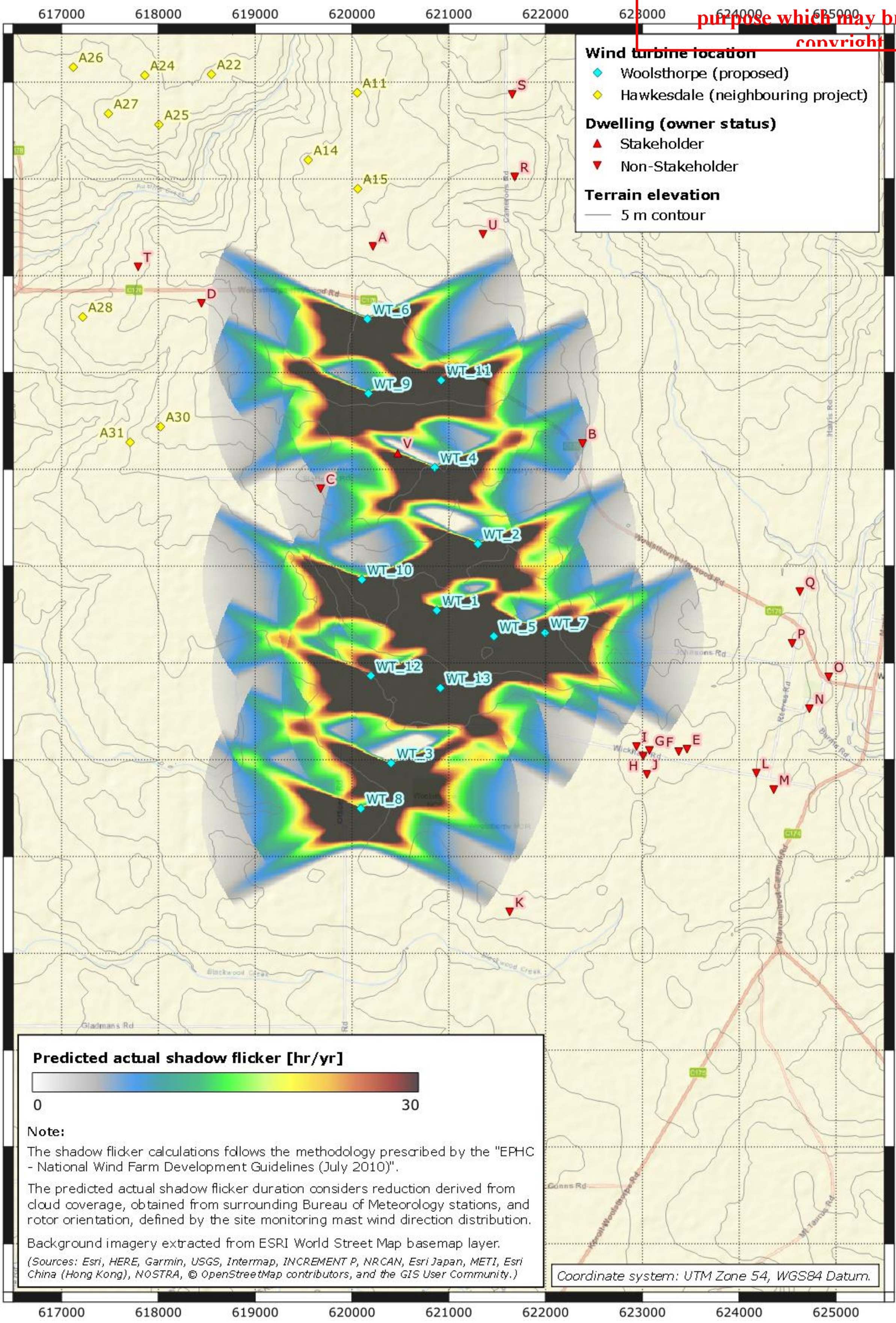

Figure 6 Predicted actual annual shadow flicker duration map

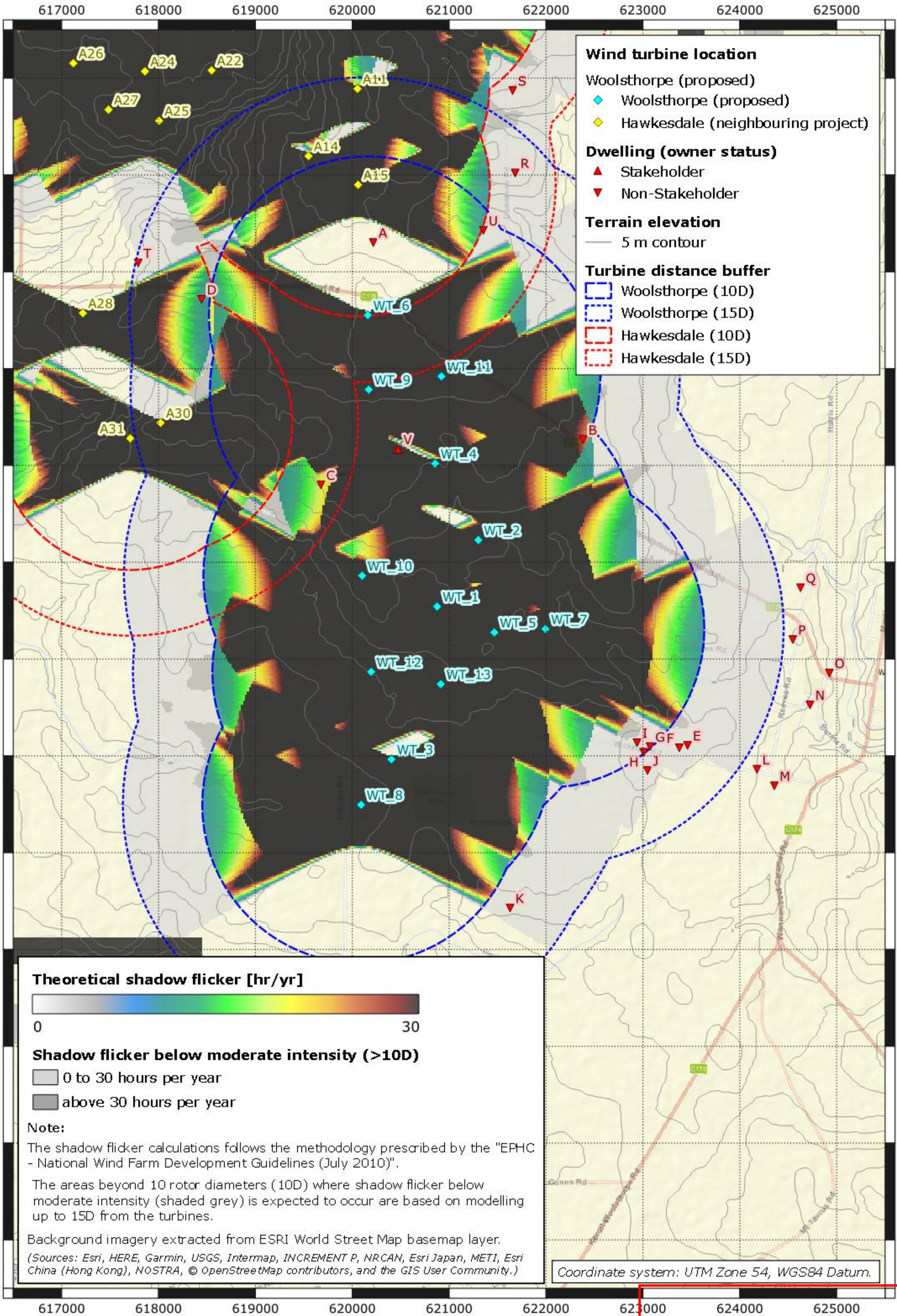

Figure 7 Combined theoretical shadow flicker duration map at 2 m

About DNV

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