HAWKESDALE WIND FARM

Shadow Flicker and Blade Glint Assessment

Hawkesdale Asset Pty Ltd

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Hawkesdale Wind Farm Shadow Flicker and Blade Glint Assessment

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Reference to part of this report which may lead to misinterpretation is not permissible.

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	02 Nov 2020	First issue – DRAFT	N Brammer	M Quan	J Jobin
B	09 Nov 2020	Added comparison to previous assessment and reference to the Project's Planning Permit	N Brammer	M Quan	J Jobin
C	16 April 2021	Inclusion of two additional dwellings identified by Customer	M Quan	J Jobin	T Gilbert
D	19 April 2021	FINAL	M Quan	J Jobin	T Gilbert
E	03 Jun 2021	Updated dwelling co-ordinates	N Brammer	M Quan	T Gilbert
F	07 Jun 2021	Updated dwelling list - FINAL	N Brammer	M Quan	T Gilbert

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EXECUTIVE SUMMARY

DNV has been commissioned by Hawkesdale Asset Pty Ltd ("Hawkesdale Asset" or "the Customer") as trustee for Hawkesdale Asset Trust (HAPL), a wholly owned subsidiary of Global Power Generation Australia Pty Ltd (GPGA), to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Hawkesdale 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 the Planning Permit for the Project [1], Victorian Planning Guidelines [2], and 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.

Conditions 53 and 54 of the Planning Permit require that the shadow flicker durations at any nearby dwelling existing as at 28 February 2017 do not exceed 30 hours per year, unless the landowner has entered into an agreement to accept shadow flicker above this limit. Similarly, 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 23 wind turbines with a rotor diameter of 136 m and hub height of 112 m has been considered. Thirty-one dwellings have been identified within 2090 m of the Project, seven of which are stakeholder 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 total of nine dwellings are expected to experience some shadow flicker, three of which are stakeholder dwellings. Out of these dwellings, none are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling. Therefore, since the theoretical shadow flicker durations at all dwellings are below the required limit, the Project is expected to comply with Condition 53 of the Planning Permit, and Condition 54 does not apply. When considering the likely reduction due to cloud cover and rotor orientation, the shadow flicker at all of the dwellings is predicted to be below the recommended limit of 10 hours per year within 50 m of the dwelling.

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.

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.

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

1 INTRODUCTION

Hawkesdale Asset Pty Ltd ("Hawkesdale Asset" or "the Customer") as trustee for Hawkesdale Asset Trust (HAPL), a wholly owned subsidiary of Global Power Generation Australia Pty Ltd (GPGA), has commissioned DNV to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Hawkesdale Wind Farm ("the Project") in western Victoria. The results of this work are reported here. This document has been prepared in accordance with DNV proposal L2C-207265-AUME-P-01 Issue A, dated 13 October 2020, and is subject to the terms and conditions in that agreement.

DNV has previously conducted a shadow flicker assessment for the Project site, as reported in DNV report 170485-AUME-R-02 Issue C dated 22 December 2015 [4], based on a different turbine layout and configuration.

This assessment evaluates the shadow flicker durations in the vicinity of the Project for the current proposed turbine layout and configuration in accordance with the Hawkesdale Wind Farm Planning Permit (Planning Permit) dated 21 December 2017 [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 March 2019 [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].

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The site

The Project is located in western Victoria, approximately 2 km southeast of Hawkesdale and 25 km north-northwest of Warrnambool as illustrated in Figure 1.

The terrain at the site is characterised by gentle rolling hills with elevations ranging between approximately 110 m and 150 m above sea level. Ground cover on site comprises primarily grasses, interspersed with some areas of bushes and small patches of trees. Elevation data for the Project site was provided by the Customer [5], and a map representing the terrain at the Project is included in Figure 2.

2.2 The project

2.2.1 Proposed wind farm layout

The Project is proposed to consist of 23 wind turbines [6]. A map of the site with the proposed turbine layout is shown in Figure 2, and the coordinates of the proposed turbine locations are given in Table 1.

As requested by the Customer, DNV has modelled the shadow flicker based on the Vestas V136-4.2 MW turbine model with a rotor diameter of 136 m, a hub height of 112 m, and an upper tip height of 180 m [7]. The maximum blade chord length for the V136-4.2 MW, defined as the dimension through the thickest part of the blade, is 4.1 m [8].

2.2.2 Shadow receptor locations

A list of dwellings neighbouring the wind farm was provided to DNV by the Customer [9]. The coordinates of those dwellings within 2090 m of proposed turbine locations (which corresponds to 15 times the maximum proposed rotor diameter plus 50 m) are presented in Table 2. DNV understands that those dwellings identified in Table 2 as stakeholder dwellings are dwellings for which the landowner has entered into an agreement with the Customer to accept shadow flicker durations above the limits required by the Planning Permit for the Project.

DNV has modelled all listed dwellings as habitable building structures. Dwellings situated more than 2090 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.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

In relation to shadow flicker, Conditions 53 and 54 of the Planning Permit for the Project [1] state:

"53. Shadow flicker from the wind energy facility must not exceed 30 hours per annum at any dwelling existing at 28 February 2017.

54. This condition does not apply if the operator of the wind energy facility has entered into an agreement with a landowner under which the landowner acknowledges and accepts that shadow flicker may exceed 30 hours per annum at the landowner's dwelling."

This is consistent with the Victorian Planning Guidelines [2], which 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 [10] 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).

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 [10], 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 1360 m. Under the Draft National Guidelines, this will be conservative for any turbine with a maximum blade chord of less than 5.1 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, DNV has also assessed the shadow flicker for an increased distance limit of 15 times the rotor diameter (15D), or 2040 m, 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 3.

To illustrate typical results, an indicative shadow flicker map for a turbine located in a relatively flat area is shown in Figure 3. 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 three Bureau of Meteorology (BoM) stations:

- Warrnambool Airport (090172), located approximately 19 km from the site [11]
- Warrnambool Post Office (090082), located approximately 30 km from the site [12]
- Hamilton (090044), located approximately 53 km from the site [13].

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 57% and 71%, and the average annual cloud cover is approximately 66%. This means that on an average day, 66% 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 measurements at the site were provided by the Customer [14] 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 3.

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.

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 2.

The theoretical and predicted actual shadow flicker durations at all dwellings identified to be affected by shadow flicker 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 4 and Figure 5. 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, nine dwellings are predicted to experience some shadow flicker based on the methodology recommended by the Draft National Guidelines, three of which are stakeholder dwellings. Out of these dwellings, none are predicted to experience theoretical shadow flicker durations that exceed the limit recommended by the current guidelines and required by the Planning Permit. In the previous shadow flicker assessment reported in [4], two non-stakeholder dwellings were predicted to experience shadow flicker durations above the required limit. Since the predicted theoretical shadow flicker durations at all dwellings are below the required limit for the currently proposed turbine layout and configuration, the Project is expected to comply with Condition 53 of the Planning Permit, and Condition 54 does not apply. When considering the predicted actual shadow flicker duration, which takes into account the reduction in shadow flicker due to cloud cover and rotor orientation, no dwellings are expected to experience actual shadow flicker durations above the limit recommended in the guidelines.

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 4. These results indicate that 13 additional dwellings have the potential to be exposed to shadow flicker below a “moderate level of intensity”. These dwellings are noted in Table 4.

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 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.

6 CONCLUSION

A shadow flicker assessment was carried out at all dwelling locations in the vicinity of the Project. For the purpose of this assessment, DNV has considered a layout consisting of 23 turbines with a rotor diameter of 136 m and a hub height of 112 m. The results of the shadow flicker assessment based on this layout configuration are summarised in Table 4.

Based on DNV's modelling, nine dwellings are predicted to experience some shadow flicker based on the methodology recommended by the Draft National Guidelines, three of which are stakeholder dwellings. Out of these dwellings, none are predicted to experience theoretical shadow flicker durations that exceed the limit recommended by the current guidelines and required by the Planning Permit. Therefore, since the predicted theoretical shadow flicker durations at all dwellings are below the required limit for the currently proposed turbine layout and configuration, the Project is expected to comply with Condition 53 of the Planning Permit, and Condition 54 does not apply. When considering the predicted actual shadow flicker duration, which takes into account the reduction in shadow flicker due to cloud cover and rotor orientation, no dwellings are expected to experience actual shadow flicker durations above the limit recommended in the guidelines.

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.

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.

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

[1] "Hawkesdale Wind Farm Planning Permit," Permit No.: 20060221-A, 21 December 2017.

[2] Department of Environment, Land, Water and Planning, "Development of Wind Energy Facilities in Victoria, Policy and Planning Guidelines," March 2019.

[3] Environment Protection and Heritage Council (EPHC), "National Wind Farm Development Guidelines - Draft," July 2010.

[4] DNV, "Hawkesdale Wind Farm Shadow Flicker Assessment," Document No.: 170485-AUME-R-02-C, 22 December 2015.

[5] Elevation data provided by G. Roux (Hawkesdale Asset), 7 October 2020.

[6] Ryan Corner Development Pty Ltd, "Hawkesale Wind Farm, General Layout with Aerial Orthophoto," 23 September 2020.

[7] Ryan Corner Development Pty Ltd, "Hawkesdale Wind Farm Development Plan, Wind Turbine Dimensions Profile & Elevation View," Drawing No: HDWF-DP-02-v10, 4 September 2020.

[8] Vestas Wind Systems A/S, "4 MW Platform," 2020.

[9] "HDWF_Dwellings_5km_Revised_20210528.xls," provided by G. Abou Abdallah (ERM), 28 May 2021.

[10] "Planning for Renewable Energy - A Companion Guide to PPS22," Office of the Deputy Prime Minister, UK, 2004.

[11] Bureau of Meteorology, "Climate statistics for Australian locations - Warrnambool Airport," [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_090172_All.shtml. [Accessed 15 October 2020].

[12] Bureau of Meteorology, "Climate statistics for Australian locations - Warrnambool (Post Office)," [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_090082_All.shtml. [Accessed 15 October 2020].

[13] Bureau of Meteorology, "Climate statistics for Australian locations - Hamilton," [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_090044_All.shtml. [Accessed 15 October 2020].

[14] Email from G. Roux (Hawkesdale Asset) to N. Brammer (DNV), 22 October 2020.

Table 1 Proposed turbine layout for the Project site [6]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
A1	619671	5781176	150
A2	620172	5781015	147
A3	618586	5781146	146
A4	619146	5780893	149
A5	619609	5780614	148
A7	620094	5780236	147
A8	620638	5780006	146
A9	620119	5779583	145
A11	620053	5778891	143
A14	619547	5778196	141
A15	620059	5777899	142
A19	618570	5779965	141

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
A20	618946	5779579	138
A21	618205	5779539	137
A22	618547	5779081	133
A23	617655	5779529	131
A24	617859	5779071	133
A25	618005	5778561	130
A26	617120	5779155	127
A27	617483	5778675	130
A28	617218	5776574	112
A30	618020	5775441	113
A31	617707	5775280	107

1. Coordinate system: MGA zone 54, GDA94 datum.

Table 2 Shadow receptor locations within 2090 m of turbines at the Project [9]

Receptor ID	Landowner status	Easting[1] [m]	Northing[1] [m]	Distance to nearest turbine [m] (and nearest turbine ID)
HW4	Non-stakeholder	616033	5780823	1991 (A26)
HW27	Non-stakeholder	616357	5781126	2058 (A23)
HW28	Non-stakeholder	616426	5781208	2081 (A23)
HW40	Non-stakeholder	616158	5780602	1737 (A26)
HW47	Non-stakeholder	615450	5776222	1802 (A28)
HW48	Stakeholder	616095	5776902	1170 (A28)
HW53	Non-stakeholder	616062	5778791	1119 (A26)
HW58	Non-stakeholder	621682	5778021	1628 (A15)
HW59	Non-stakeholder	621653	5778875	1520 (A8)
HW60	Non-stakeholder	621742	5779721	1140 (A8)
HW61	Stakeholder	621184	5780890	1020 (A2)
HW62	Non-stakeholder	621658	5780772	1276 (A8)
HW64	Non-stakeholder	620170	5782883	1778 (A1)
HW72	Non-stakeholder	617583	5782502	1687 (A3)
HW75	Non-stakeholder	615400	5779251	1722 (A26)
HW78	Non-stakeholder	619677	5774797	1778 (A30)
HW80	Stakeholder	615970	5775825	1456 (A28)
HW81	Stakeholder	616129	5776023	1221 (A28)
HW89	Non-stakeholder	618435	5776719	1226 (A28)
HW90	Stakeholder	620217	5777300	620 (A15)
HW101	Non-stakeholder	616891	5780292	1079 (A23)
HW164	Stakeholder	617680	5777267	833 (A28)
HW165	Non-stakeholder	618381	5776665	1167 (A28)
HW166	Stakeholder	617789	5777091	771 (A28)
HW167	Non-stakeholder	616572	5781162	1959 (A23)
HW170	Non-stakeholder	621353	5777428	1377 (A15)
HW171	Non-stakeholder	615929	5779036	1197 (A26)
HW172	Non-stakeholder	616722	5780826	1597 (A23)
HW173	Non-stakeholder	616570	5781069	1884 (A23)
HW174	Non-stakeholder	616425	5781083	1982 (A23)
HW197	Non-stakeholder	617360	5782729	2002 (A3)

1. Coordinate system: MGA zone 54, GDA94 datum.

Table 3 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1360 m
Year of calculation	2033
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 4 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
HW47[4]	Non-stakeholder	615450	5776222	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW48	Stakeholder	616095	5776902	A28	19.1	19.2	23.3	22.9	4.6	4.6	5.5	5.5
HW53[5]	Non-stakeholder	616062	5778791	A26	16.8	16.5	18.9	18.6	3.3	3.3	3.7	3.7
HW58[4]	Non-stakeholder	621682	5778021	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW59[4]	Non-stakeholder	621653	5778875	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW60[5]	Non-stakeholder	621742	5779721	A8	14.2	13.8	15.6	15.4	2.9	2.8	3.2	3.1
HW61[5]	Stakeholder	621184	5780890	A2	17.2	16.8	19.0	18.8	3.8	3.7	4.2	4.1
HW62[4]	Non-stakeholder	621658	5780772	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW75[4]	Non-stakeholder	615400	5779251	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW78[4]	Non-stakeholder	619677	5774797	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW80[5]	Non-stakeholder	615970	5775825	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW81[5]	Stakeholder	616129	5776023	A28	19.8	19.5	23.8	23.8	3.6	3.5	4.2	4.2
HW89	Non-stakeholder	618435	5776719	A28	11.5	11.2	13.0	12.5	2.7	2.6	3.0	2.9
HW101[4]	Non-stakeholder	616891	5780292	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW164[4]	Stakeholder	617680	5777267	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW165	Non-stakeholder	618381	5776665	A28	12.9	12.5	14.4	13.9	2.9	2.8	3.3	3.2
HW166[4]	Stakeholder	617789	5777091	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW167[4]	Non-stakeholder	616572	5781162	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW170	Non-stakeholder	621353	5777428	A15	0.0	0.0	11.6	11.2	0.0	0.0	2.3	2.3
HW171[5]	Non-stakeholder	615929	5779036	A26	12.4	12.1	13.4	13.4	2.7	2.6	3.0	2.9
HW172[4]	Non-stakeholder	616722	5780826	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HW173[4]	Non-stakeholder	616570	5781069	-	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***			

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. *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.*
5. *Dwelling is not predicted to experience shadow flicker durations above the specified limits when only shadow flicker above a moderate level of intensity is considered, but may experience shadow flicker durations above the specified limits when shadow flicker below a moderate level of intensity is considered.*

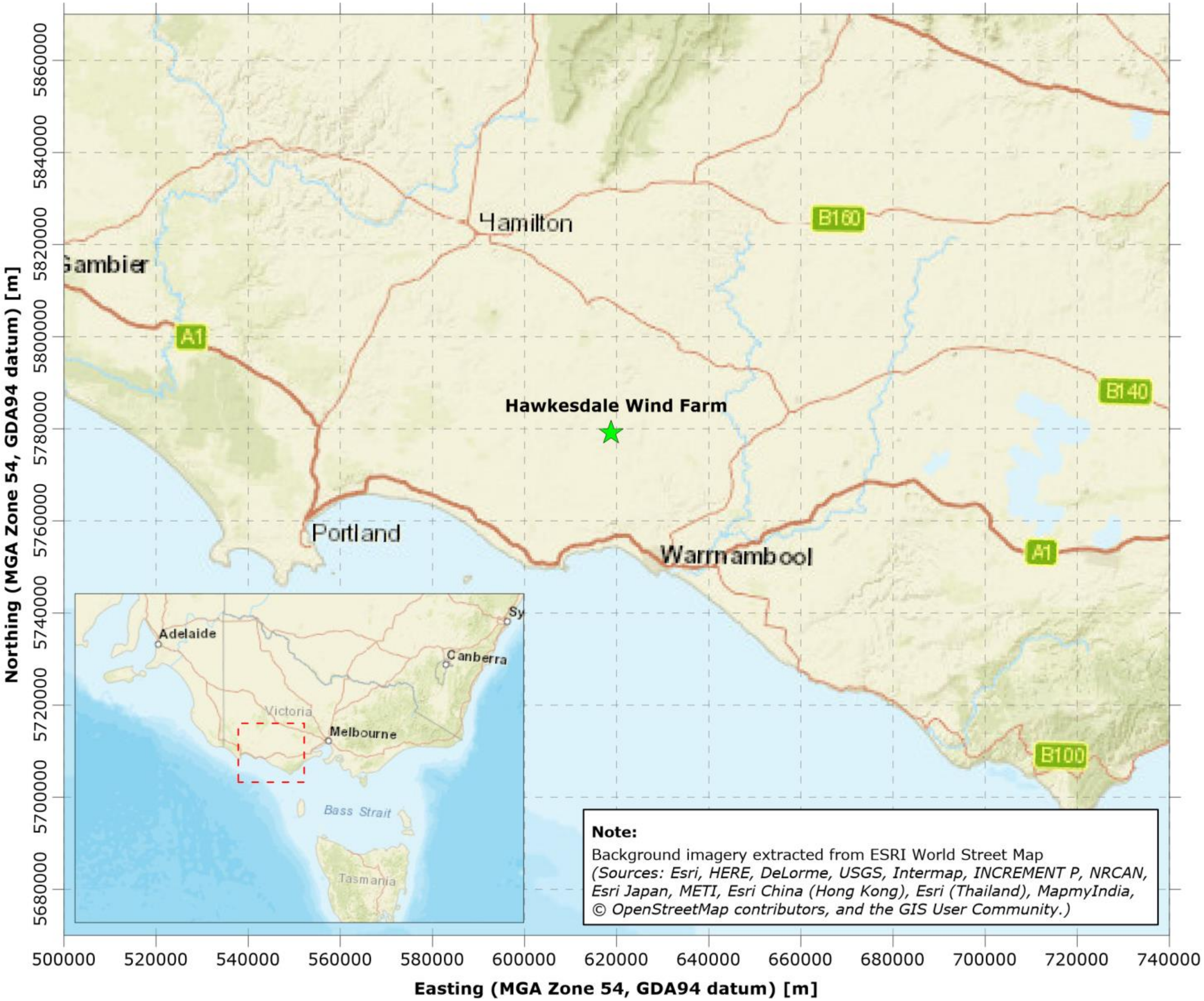

Figure 1 Location of the Project

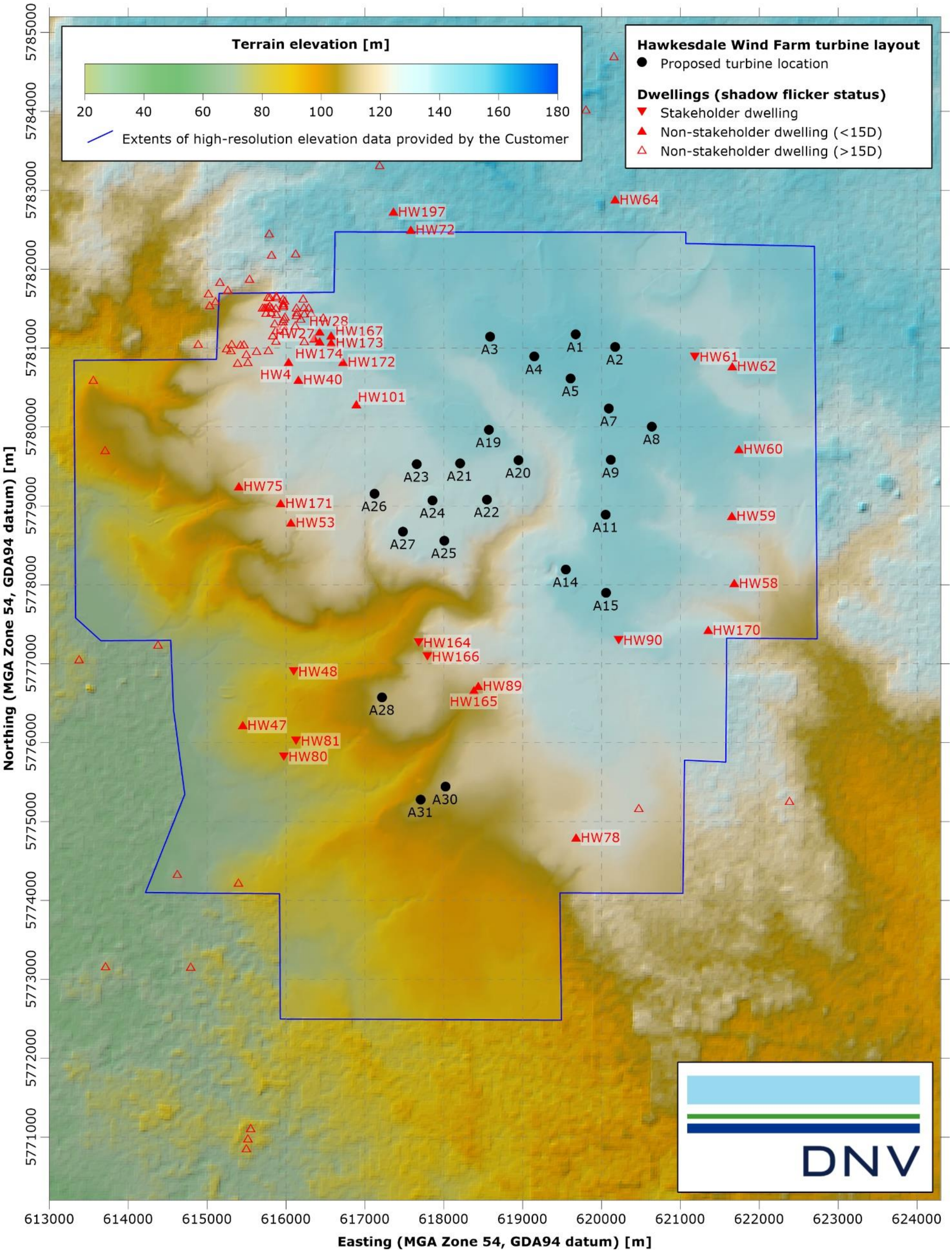

Figure 2 Elevation map of the Project

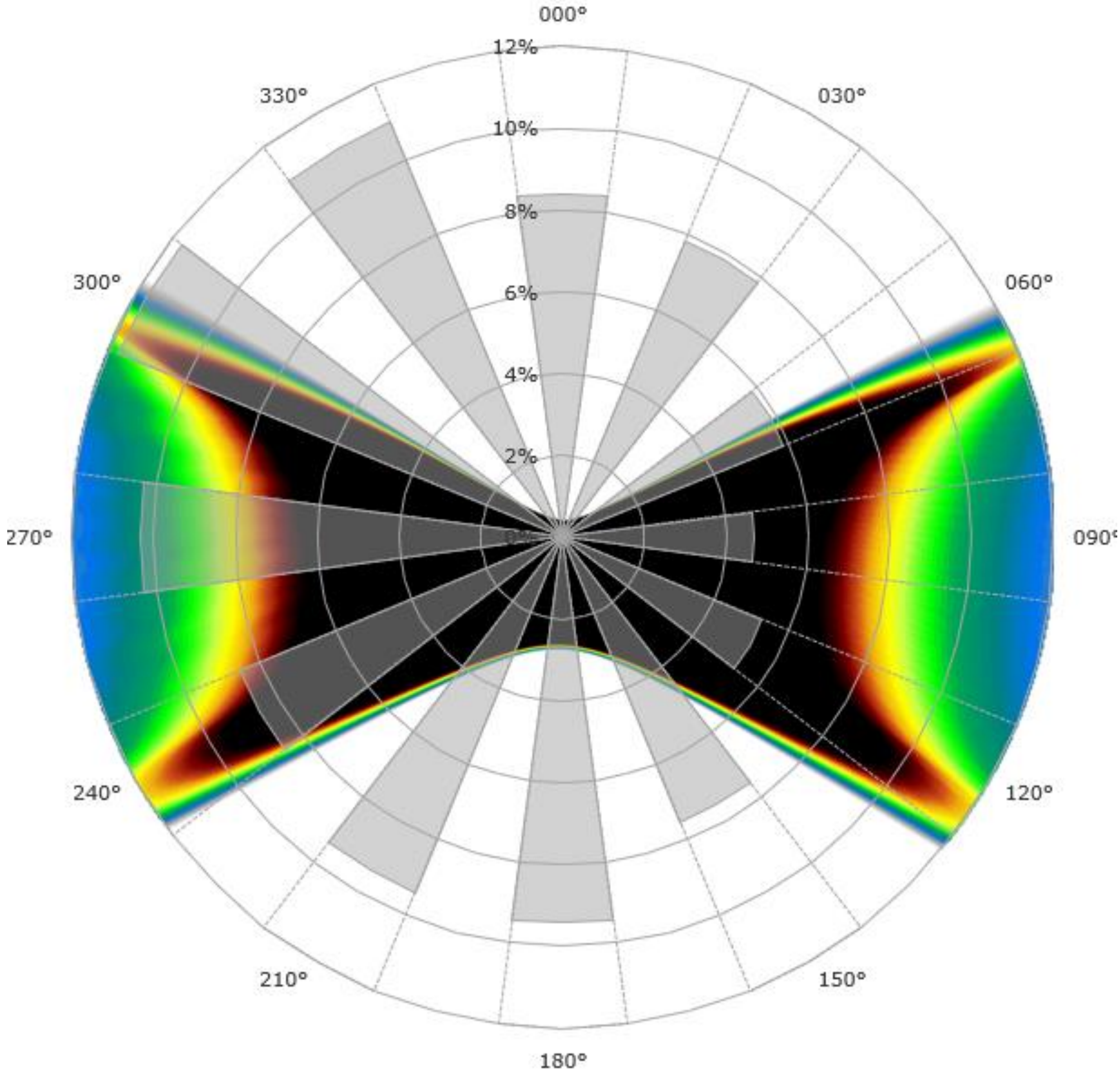

Figure 3 Indicative shadow flicker map and wind direction frequency distribution

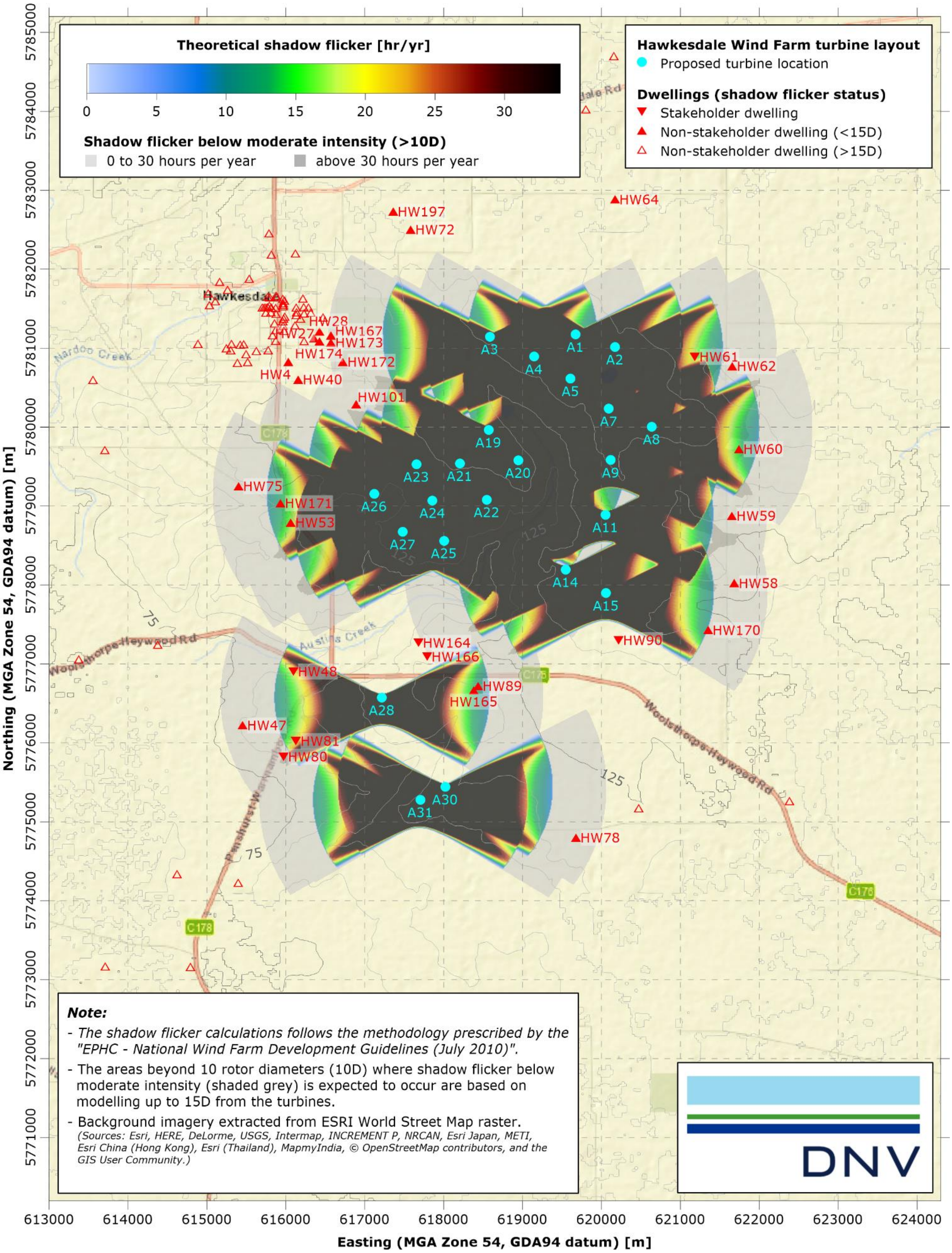

Figure 4 Theoretical annual shadow flicker duration map

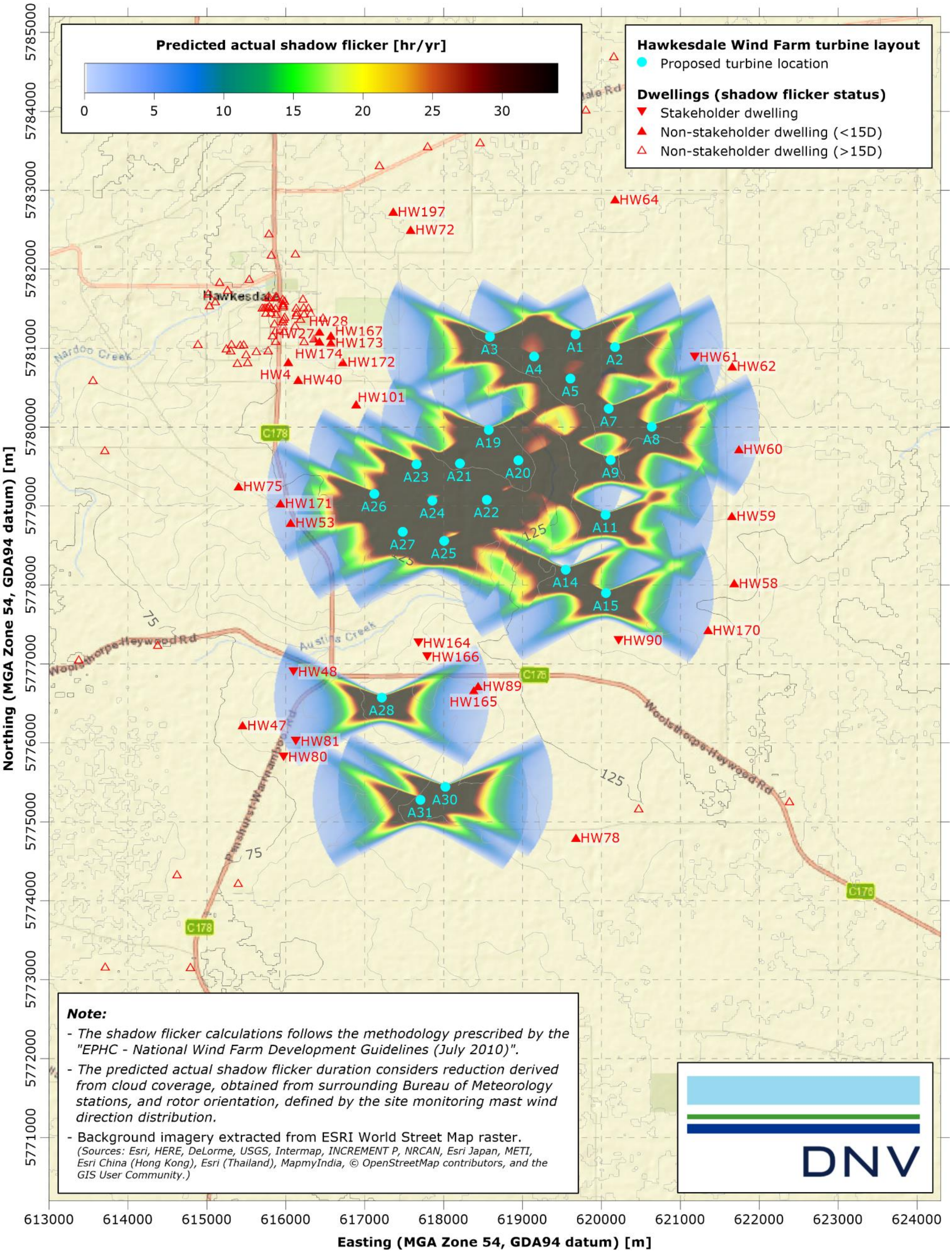

Figure 5 Predicted actual annual shadow flicker duration map

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.