YATHROO WIND FARM

Shadow Flicker and Blade Glint Assessment

Umwelt (Australia) Pty Ltd

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EXECUTIVE SUMMARY

DNV has been commissioned by Umwelt (Australia) Pty Ltd ("Umwelt" or "the Customer") to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Yathroo Wind Farm ("the Project") in Western Australia. 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 against limits specified in the Draft National Wind Farm Development Guidelines (Draft National Guidelines). The methodology used in this assessment has been informed by these guidelines and various standard industry practices.

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 65 wind turbines with a maximum rotor diameter of 182 m and a hub height of 170 m has been considered in this assessment. The locations of 46 dwellings in the vicinity of the Project have been provided by the Customer, of which up to 24 may potentially be affected by shadow flicker based on their distances from the proposed turbine locations.

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.

Outcomes of the assessment

Based on this assessment, two dwellings are expected to experience shadow flicker at or above a moderate level of intensity within 50 m of the dwelling. For the purposes of this assessment, shadow flicker at or above a moderate level of intensity is defined as shadow flicker which is likely to cause annoyance for most people and is assumed to occur up to a distance of 10 rotor diameters from the wind turbines. Of these two dwellings, both are "involved" with the Project.

Out of the two dwellings predicted to experience shadow flicker at or above a moderate level of intensity, both are predicted to experience theoretical shadow flicker durations below the recommended limit of 30 hours per year within 50 m of the dwelling. For these same two dwellings, when considering the likely reduction in shadow flicker due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of the dwelling are also below the recommended limit of 10 hours per year.

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.

If required, the effects of shadow flicker may be reduced through a number of mitigation measures 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 to shut down turbines when shadow flicker is likely to occur.

The effects of blade glint have not been quantified in this study as the Draft National Guidelines do not provide any quantification methodology. The guidelines, however, recommend that the turbine blades used have a surface finish with a low reflectivity to avoid occurrences of blade glint.

1 INTRODUCTION

Umwelt (Australia) Pty Ltd ("Umwelt" or "the Customer") has commissioned DNV to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Yathroo Wind Farm ("the Project") in Western Australia. The results of this work are reported here.

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 Draft National Wind Farm Development Guidelines (Draft National Guidelines) [1]. The methodology used in this study has been informed by these guidelines and various standard industry practices.

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The site

The Project is located approximately 10 km south of Dandaragan in Western Australia.

The terrain at the site is mildly undulating with base elevations for the proposed turbine layout ranging from approximately 110 m to 260 m above sea level. The site is mainly comprised of areas of open agricultural land, areas of scattered native trees, and a few small pockets of densely treed bushland. A digital elevation model of the Project terrain was provided by the Customer [2] and was supplemented by a digital elevation model of the surrounding terrain derived from publicly available NASADEM data [3].

2.2 The Project

2.2.1 Proposed wind farm layout

The Project is proposed to consist of 65 wind turbines [4]. A map of the site showing the turbine layout and terrain elevations considered in this assessment 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 theoretical turbine model with a rotor diameter of 182 m and hub height of 170 m.

2.2.2 Dwelling locations

The locations of 46 dwellings in the vicinity of the Project have been provided by the Customer [5]. According to information provided by the Customer [6], all dwellings in the vicinity of the Project that may potentially be affected by shadow flicker are single storey in height.

For the purposes of this assessment, 24 dwellings have been identified as having the potential to experience shadow flicker based on their distances from the proposed turbine locations, and these have been considered in this assessment. Of those 24 dwellings, 13 have been identified by the Customer as "involved" with the Project.

The remaining 22 dwellings are at locations that are considered unlikely to be impacted by shadow flicker at intensities typically considered sufficient to cause annoyance, as discussed further in Sections 3.1 and 4.1.2, and have not been considered further in this assessment.

The dwellings considered in this assessment are shown in Figure 3 and presented in Table 2.

It should be noted that the scope of the work reported here does not include a comprehensive survey of dwellings in the vicinity of the Project, and so DNV is relying on dwelling information provided by the Customer.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

The development of wind farms in Western Australia is governed by the Western Australian Planning Commission's Position Statement on renewable energy facilities ("the WA Position statement"), published in March 2020 [7]. However, the WA Position Statement does not address the potential for wind farms to cause shadow flicker impacts at nearby dwellings. Therefore DNV has relied on other suitable guidelines to assess the shadow flicker for the Project, as discussed below.

The Environment Protection and Heritage Council (EPHC), in conjunction with Local Governments and the Planning Ministers' Council, released a draft version of the National Wind Farm Development Guidelines in July 2010 (Draft National Guidelines) [1]. The Draft National Guidelines cover a range of issues across the different stages of wind farm development. In relation to shadow flicker, the Draft National Guidelines provide background information, a proposed methodology, recommended limits, and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm.

The Draft National Guidelines recommend that the modelled theoretical shadow flicker duration at any dwelling should not exceed 30 hours per year at any dwelling, and that the actual or measured shadow flicker duration should not exceed 10 hours per year. The Draft National 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 the dwelling. These limits are assumed to apply to a single dwelling, and it is noted that there is no requirement under the Draft National Guidelines to assess shadow flicker durations at locations other than in the vicinity of dwellings.

The impact of shadow flicker is typically only significant up to a limited distance from the wind turbines. 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 suggest a shadow flicker distance limit equal to 265 times the maximum blade chord length, which would correspond to approximately 1000 to 1600 m for modern wind turbines (which typically have maximum blade chord lengths of 4 to 6 m). However, the UK wind industry considers that a distance limit of around 10 rotor diameters from a turbine [8, 9] or approximately 1200 m to 1900 m for modern wind turbines (which typically have rotor diameters of 120 m to 190 m), is appropriate.

For the purposes of this assessment, DNV has considered the guidance and recommendations given in the Draft National Guidelines in relation to shadow flicker along with the shadow flicker distance limit applied by the UK wind industry, as discussed further in Section 4.1.2.

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].

A methodology for the quantification of blade glint impacts as well as a regulatory limit are not provided by the Draft National Guidelines [1]. However, the Draft National Guidelines suggest that the Customer ensures the blades of the wind turbines have a finish with low reflectivity.

In relation to blade glint, guidance from the Draft National Guidelines [1] 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 of the property from the turbine (the further the observer is from the turbine, the less pronounced the effect will be)
- 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)
- 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).

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 provided dwellings and has determined the highest shadow flicker duration within 50 m of each of these locations.

In the absence of detailed dwelling height information, shadow flicker is generally calculated at dwellings at heights of 2 m, to represent ground floor windows, and 6 m, to represent second floor windows. According to information provided by the Customer [6], all dwellings in the vicinity of the Project that may potentially be affected by shadow flicker are single storey in height. 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. As noted in Section 3.1, the UK wind industry considers that 10 rotor diameters is appropriate [8, 9] while the Draft National Guidelines suggest a distance limit equivalent to 265 times the maximum blade chord [1].

For the current assessment, DNV has applied a maximum shadow length of 10 times the rotor diameter (10D), corresponding to a distance limit of 1820 m for the Project, which DNV considers is more appropriate than a limit of 265 times the maximum blade chord. Up to this distance limit, it is assumed that shadow flicker will be at or above a "moderate level of intensity" as defined in the Draft National Guidelines. 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 calculated the shadow flicker to a distance of up to 15 times the rotor diameter (15D), or 2730 m, which should include shadow flicker below a "moderate level of intensity".

In this assessment, 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, described as "low intensity" shadow flicker in this report, is assumed to occur beyond a distance of 10D and up to a distance of approximately 15D from the wind turbines.

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 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. As it is not possible to predict when future unscheduled turbine down-time will occur, an assumption for turbine availability has not been included in the assessment.

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 dwelling.

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 stations:

- Moora (08091), located approximately 37 km northeast of the centre of the Project [10]
- Lancelin (09114), located approximately 39 km west-southwest of the centre of the Project [11]
- Jurien Bay (09131), located approximately 86 km northwest of the centre of the Project [12]
- Pearce RAAF (09053), located approximately 97 km south-southeast of the centre of the Project [13]
- Wongan Hills (08137), located approximately 99 km east of the centre of the Project [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 28% and 55%, and the average annual cloud cover is approximately 43%. This implies that on an average day, 43% 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 considered to be 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 for the site was derived from publicly available wind direction data [15] [16] and used to estimate the reduction in shadow flicker duration due to rotor orientation. The site wind rose is shown overlaid on the indicative shadow flicker map in Figure 4. The 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.

While the calculation of the predicted actual shadow flicker duration considers the likely reductions due to cloud cover and rotor orientation, it does not take into account other potential reductions due to low wind speed (or turbine shutdown), vegetation, or other shielding effects around each dwelling.

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

5.1.1 Predicted shadow flicker durations

Shadow flicker predictions were generated at the provided dwelling locations, and the results are summarised in Table 4.

The results of the theoretical and predicted actual shadow flicker modelling are also shown in the form of shadow flicker maps in Figure 5 and Figure 6 respectively. The shadow flicker values presented in these maps assume a receptor height of 2 m above ground level (agl) for each modelled grid point, based on information provided by the Customer that all dwellings in the vicinity of the Project that may potentially be affected by shadow flicker are single storey in height [6].

Based on this assessment, two dwellings (H007 and H009) are expected to experience shadow flicker at or above a moderate level of intensity within 50 m of the dwelling. For the purposes of this assessment, shadow flicker at or above a moderate level of intensity is defined as shadow flicker which is likely to cause annoyance for most people and is assumed to occur up to a distance of 10 rotor diameters from the wind turbines. Of these two dwellings, both are "involved" with the Project.

Out of the two dwellings predicted to experience shadow flicker at or above a moderate level of intensity, both are predicted to experience theoretical shadow flicker durations below the recommended limit of 30 hours per year within 50 m of the dwelling. For these same two dwellings, when considering the likely reduction in shadow flicker due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of the dwelling are also below the recommended limit of 10 hours per year.

When considering cloud cover and rotor orientation, it is estimated that there will be an approximate 62% reduction in the theoretical shadow flicker durations at the two dwellings where shadow flicker above a moderate level of intensity is predicted.

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, as discussed in Section 4.1.2, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by low intensity shadow flicker assumed by this distance limit. To inform the potential for this outcome, although not part of the methodology outlined in the Draft National Guidelines, DNV has also calculated the theoretical shadow flicker impacts for the Project for an increased distance limit of 15D that is intended to include shadow flicker of low intensity. The results of this additional assessment are also included in the map presented in Figure 5.

These results indicate that, in addition to the dwellings expected to be affected by shadow flicker at or above a moderate level of intensity, 21 additional dwellings may have the potential to be exposed to low intensity shadow flicker. These dwellings are noted in Table 4.

5.1.2 Mitigation options

If required, the effects of shadow flicker may be reduced through a number of mitigation measures. These include the removal or relocation of turbines, the use of turbines with a smaller rotor diameter, installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies to shut down turbines when shadow flicker is likely to occur.

5.2 Blade glint

As discussed in Section 4.2, blade glint is not expected to be an issue for the Project provided that a non-reflective paint is applied to the wind turbine blades.

6 CONCLUSIONS

A shadow flicker assessment was carried out for dwelling locations in the vicinity of the Project.

For the purpose of this assessment, DNV has considered a layout consisting of 65 turbines with a rotor diameter of 182 m and a hub height of 170 m. These dimensions represent the maximum turbine dimensions currently under consideration for the Project.

Based on this assessment, two dwellings are expected to experience shadow flicker at or above a moderate level of intensity within 50 m of the dwelling. For the purposes of this assessment, shadow flicker at or above a moderate level of intensity is defined as shadow flicker which is likely to cause annoyance for most people and is assumed to occur up to a distance of 10 rotor diameters from the wind turbines. Of these two dwellings, both are “involved” with the Project.

Out of the two dwellings predicted to experience shadow flicker at or above a moderate level of intensity, both are predicted to experience theoretical shadow flicker durations below the recommended limit of 30 hours per year within 50 m of the dwelling. For these same two dwellings, when considering the likely reduction in shadow flicker due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of the dwelling are also below the recommended limit of 10 hours per year.

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

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Table 1 Proposed turbine layout for the Project [4](continued)

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]	Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
T001	376711	6588269	258	T035	379366	6594265	171
T002	377121	6587897	252	T036	378694	6594615	212
T003	377844	6587488	232	T037	379690	6583500	229
T004	378427	6587185	244	T038	380206	6583033	236
T005	378824	6586687	228	T039	377683	6583366	184
T006	379130	6586015	230	T040	378488	6583096	216
T007	377850	6585055	197	T041	378941	6582664	203
T008	379093	6584946	223	T042	377277	6582603	161
T009	379855	6584642	226	T043	377063	6581578	174
T010	380265	6585269	194	T044	377421	6580886	199
T011	380591	6586091	212	T045	376726	6579896	229
T012	379881	6587660	228	T046	377259	6579506	235
T013	379532	6588299	202	T047	371754	6583441	156
T014	379259	6589213	169	T048	372314	6583238	180
T015	377296	6589335	246	T049	370130	6583422	126
T016	377017	6590261	192	T050	370794	6582979	109
T017	376673	6590974	164	T051	371235	6582526	118
T018	376456	6591931	143	T052	371161	6582044	132
T019	378313	6590284	176	T053	369474	6582553	109
T020	378005	6591011	160	T054	369931	6582109	114
T021	377727	6591889	146	T055	370492	6586362	162
T022	380156	6589935	169	T056	369868	6586835	184
T023	379523	6590701	150	T057	371047	6587239	170
T024	379255	6591701	156	T058	370851	6587751	183
T025	380670	6591231	167	T059	370201	6588032	225
T026	377576	6592969	162	T060	369607	6588242	221
T027	377284	6593559	174	T061	369174	6588630	212
T028	377184	6594607	221	T062	370215	6589436	190
T029	380141	6592179	182	T063	370823	6590088	181
T030	379620	6592815	164	T064	371141	6589343	169
T031	378789	6593483	154	T065	371605	6588942	139
T032	380972	6592510	238				
T033	381115	6593682	195				
T034	380072	6593865	158				

1. Coordinate system: MGA zone 50, GDA94 datum. Coordinates were provided by the Customer in a different coordinate system and/or datum and have been converted using mapping software, which may result in small discrepancies depending on the software and transformation approach used.

Table 2 Locations of dwellings considered in this assessment [5]

Dwelling ID[1]	Easting[2] [m]	Northing[2] [m]	Dwelling status	Nearest turbine	
				Distance[3] [m]	Turbine ID
H001	*372941*	*6587196*	*Involved*	*1894 m*	*T057*
H002	*375235*	*6594717*	*Involved*	*1952 m*	*T028*
H003	*381763*	*6588980*	*Involved*	*1869 m*	*T022*
H007	*375432*	*6594610*	*Involved*	*1752 m*	*T028*
H008	*375112*	*6595186*	*Involved*	*2151 m*	*T028*
H009	*368350*	*6586805*	*Involved*	*1518 m*	*T056*
H011	*375102*	*6595251*	*Involved*	*2179 m*	*T028*
H013	*376418*	*6586164*	*Involved*	*1811 m*	*T007*
H017	*381769*	*6588946*	*Involved*	*1892 m*	*T022*
H041	*375211*	*6594801*	*Involved*	*1983 m*	*T028*
H081	*372505*	*6585617*	*Involved*	*2146 m*	*T055*
H150	*382485*	*6588827*	*Involved*	*2579 m*	*T022*
H156	*382738*	*6590081*	*Involved*	*2366 m*	*T025*
H195	379575	6578152	Non-Involved	2683 m	T046
H240	382288	6584481	Non-Involved	2171 m	T010
H250	381331	6581815	Non-Involved	1658 m	T038
H277	382461	6594955	Non-Involved	1853 m	T033
H342	373993	6588254	Non-Involved	2485 m	T065
H356	373767	6589266	Non-Involved	2186 m	T065
H369	382463	6586883	Non-Involved	2033 m	T011
H418	367353	6581207	Non-Involved	2512 m	T053
H440	375038	6583549	Non-Involved	2431 m	T042
H455	373928	6588049	Non-Involved	2489 m	T065
H504	373570	6585092	Non-Involved	2239 m	T048

1. Dwellings "involved" with the Project are indicated by *underlined italic text*.
2. Coordinate system: MGA zone 50, GDA94 datum. Coordinates were provided by the Customer in a different coordinate system and/or datum and have been converted using mapping software, which may result in small discrepancies depending on the software and transformation approach used.
3. The shadow flicker assessment has considered dwellings up to a maximum distance of 15D + 50 m from the Project wind turbines.

Table 3 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1820 m
Year of calculation	2037
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)[1]	2 m
Receptor height (double storey)[1]	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 dwelling location

1. According to information provided by the Customer, all dwellings in the vicinity of the Project that may potentially be affected by shadow flicker are single storey in height [6].

Table 4 Theoretical and predicted actual annual shadow flicker duration

Dwelling ID[1]	Easting[2] [m]	Northing[2] [m]	Dwelling status	Contributing turbines[3]	Theoretical annual At dwelling [hr/yr] 2 m	Theoretical annual At dwelling [hr/yr] 6 m	Theoretical annual Max within 50 m [hr/yr] 2 m	Theoretical annual Max within 50 m [hr/yr] 6 m	Predicted actual annual[4] At dwelling [hr/yr] 2 m	Predicted actual annual[4] At dwelling [hr/yr] 6 m	Predicted actual annual[4] Max within 50 m [hr/yr] 2 m	Predicted actual annual[4] Max within 50 m [hr/yr] 6 m
H001[5]	372941	6587196	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H002[5]	375235	6594717	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H003[5]	381763	6588980	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H007	375432	6594610	Involved	T028	11.3	11.2	11.9	11.8	4.2	4.2	4.5	4.5
H008[5]	375112	6595186	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H009	368350	6586805	Involved	T056	12.5	13.3	14.1	14.6	4.7	5.0	5.3	5.4
H011[5]	375102	6595251	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H013[5]	376418	6586164	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H017[5]	381769	6588946	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H041[5]	375211	6594801	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H081[5]	372505	6585617	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H150[5]	382485	6588827	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H156[5]	382738	6590081	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H195[5]	379575	6578152	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H240[5]	382288	6584481	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H250[5]	381331	6581815	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H277[5]	382461	6594955	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H342[5]	373993	6588254	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H356[5]	373767	6589266	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H369[5]	382463	6586883	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H418[5]	367353	6581207	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H440[5]	375038	6583549	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H455[5]	373928	6588049	Non-Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recommended duration limits (hr/yr)					**30**	**30**	**30**	**30**	**10**	**10**	**10**	**10**

1. Dwellings are included in this table only if, in the area within 50 m of those dwellings, shadow flicker is predicted at a distance of up to 15D from Project turbines.
2. Coordinate system: MGA zone 50, GDA94 datum. Coordinates were provided by the Customer in a different coordinate system and/or datum and have been converted using mapping software, which may result in small discrepancies depending on the software and transformation approach used.
3. Contributing turbines shown are for the theoretical shadow flicker calculated at 2 m above ground level.
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 low-intensity shadow flicker.

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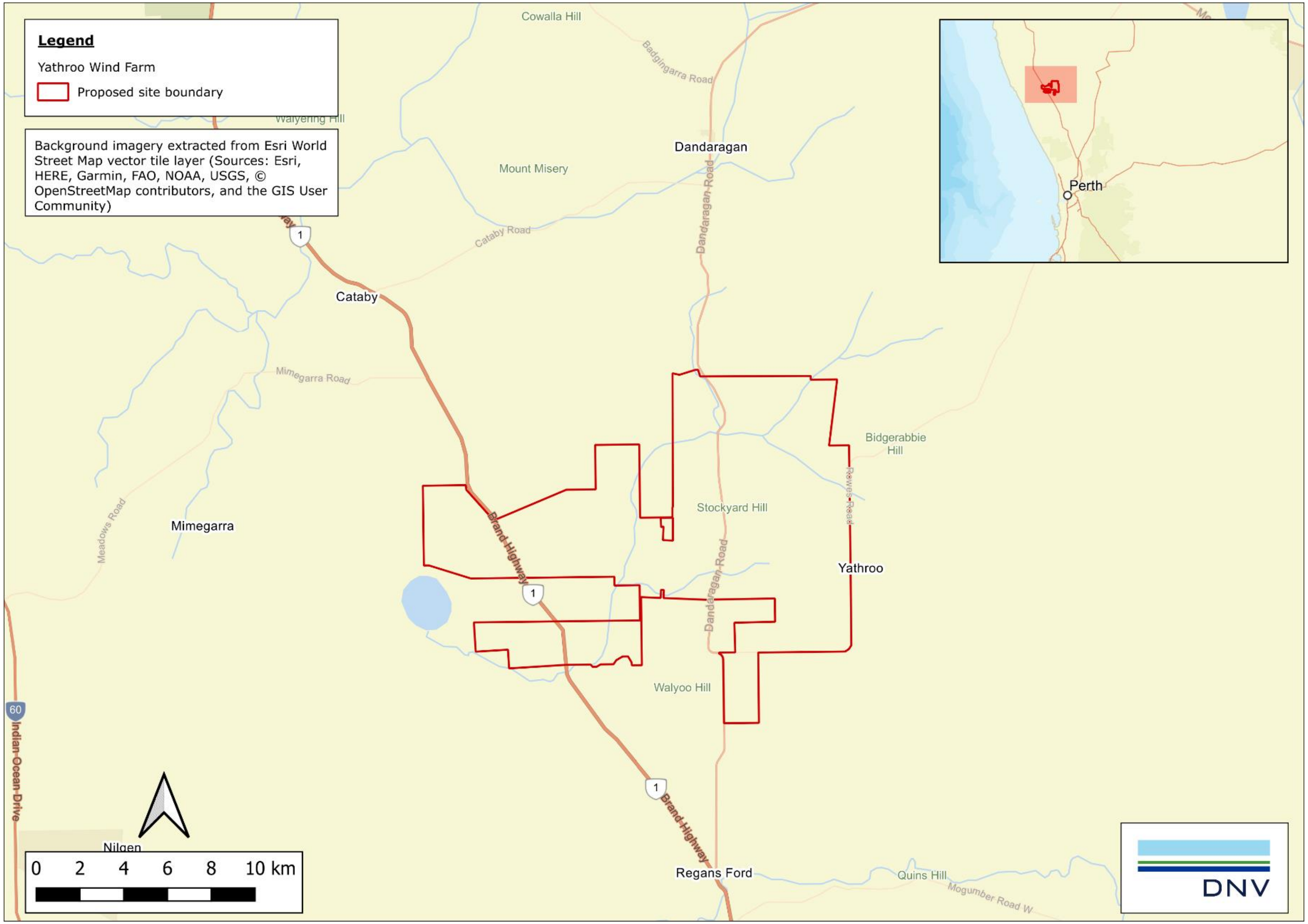

Figure 2 Location of the Project

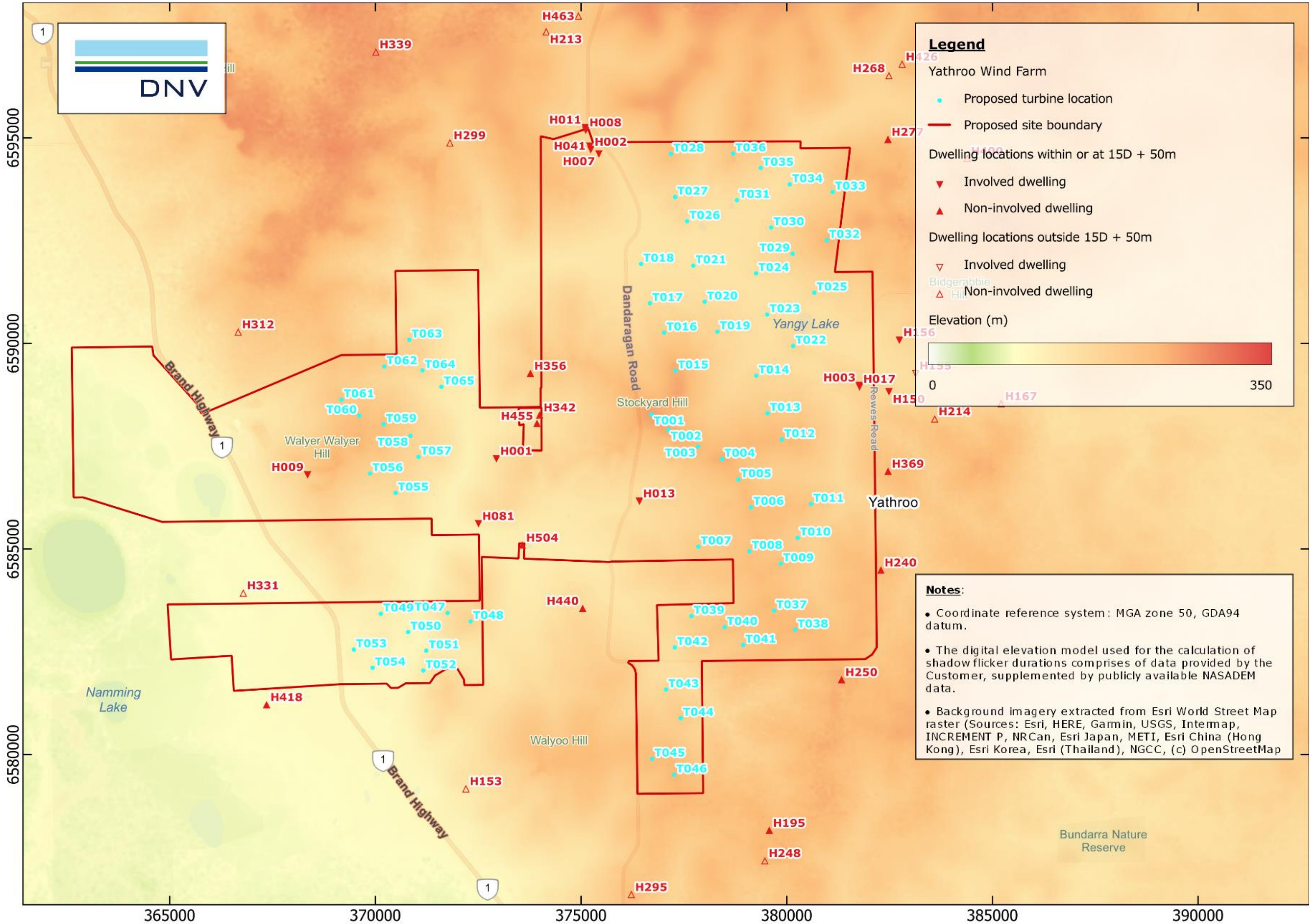

Figure 3 Map of the proposed Project, showing proposed turbine locations, nearby dwellings, and terrain elevation

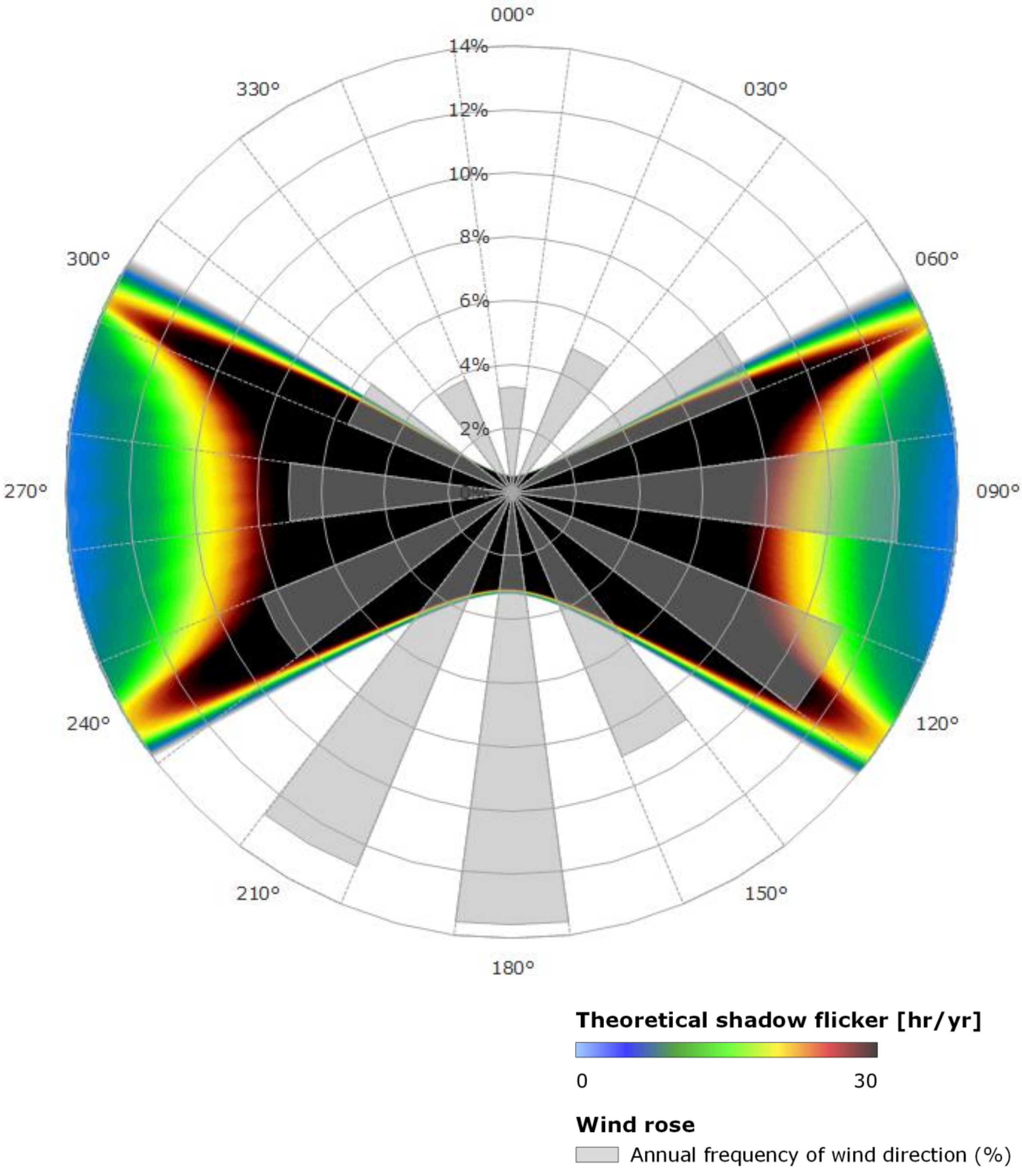

Figure 4 Indicative shadow flicker map and wind direction frequency distribution

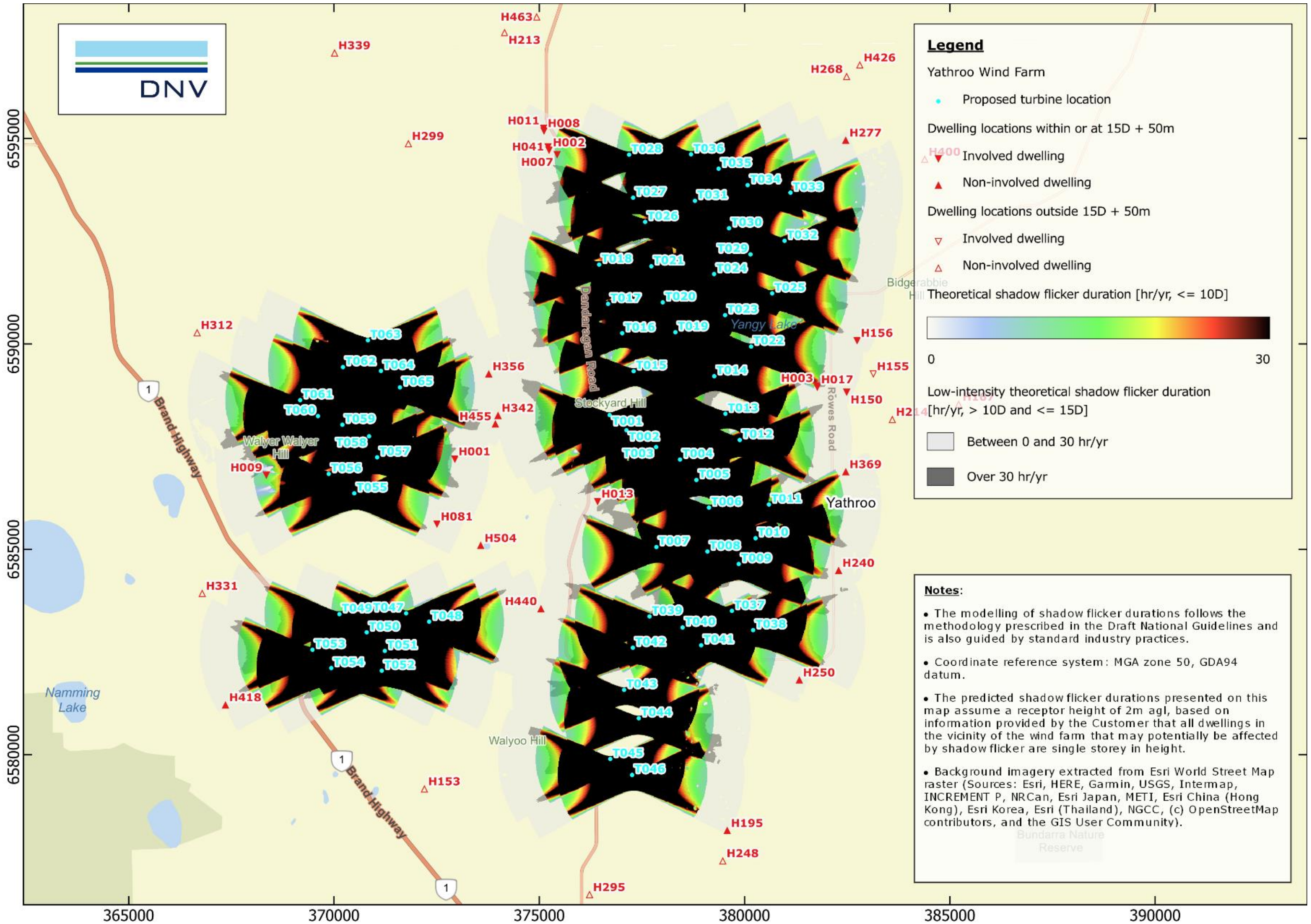

Figure 5 Theoretical annual shadow flicker duration map for the Project

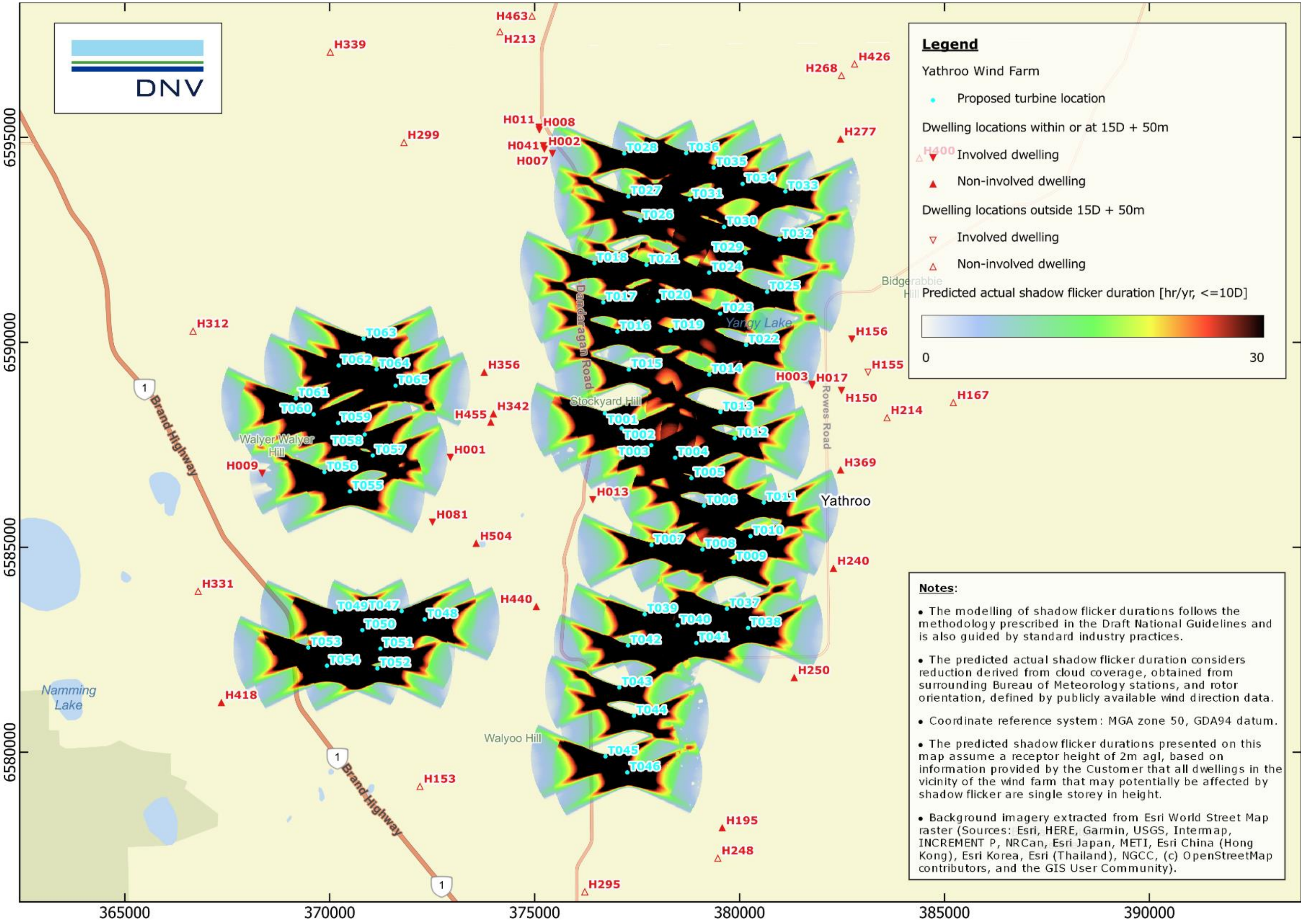

Figure 6 Predicted actual annual shadow flicker duration map for the Project

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