



WEST ARTHUR WIND FARM

Shadow Flicker and Blade Glint Assessment

West Arthur Energy Pty Ltd

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Customer: West Arthur Energy Pty Ltd
Level 7, 140 St Georges Terrace,
Perth WA, 6000
Customer contact: Ben Kraft
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DNV Energy Systems
Level 12, 350 Queen Street
Melbourne Vic 3000
Australia
Tel: +61 3 8615 1515
ABN 19 094 520 760

Objective: West Arthur Wind Farm Shadow Flicker and Blade Glint Assessment

Prepared by:

Verified by:

Approved by:

David Price
Senior Engineer
Technical Planning
Energy Analytics & Measurements (ANZ)

Zhi Ng
Senior Engineer
Technical Planning
Energy Analytics & Measurements (ANZ)

Kevin Bleibler
Principal Engineer, Head of Section
Energy Analytics & Measurements (ANZ)

Peter Degorski
Senior Engineer
Energy Analytics & Measurements (ANZ)

Naomi Brammer
Senior Engineer - Team Lead
Technical Planning
Energy Analytics & Measurements (ANZ)

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Table of contents

1	INTRODUCTION.....	1
2	DESCRIPTION OF THE SITE AND PROJECT	2
2.1	The site	2
2.2	The Project	2
3	REGULATORY REQUIREMENTS.....	3
3.1	Shadow flicker	3
3.2	Blade glint	3
4	ASSESSMENT METHODOLOGY	5
4.1	Shadow flicker	5
4.2	Blade glint	9
5	ASSESSMENT RESULTS	10
5.1	Shadow flicker	10
5.2	Blade glint	11
6	CONCLUSIONS	12
7	REFERENCES.....	13
	APPENDIX A TABULATED DATA	14
	APPENDIX B MAPS.....	19

List of tables

Table 1	Proposed turbine layout for the Project [5]	14
Table 2	Locations of dwellings considered in this assessment [7, 8]	16
Table 3	Shadow flicker model settings for theoretical shadow flicker calculation.....	17
Table 4	Theoretical and predicted actual shadow flicker occurrence for alternate shadow flicker distance limits	18

List of figures

Figure 1	Examples of wind turbine shadows	5
Figure 2	Location of the Project	19
Figure 3	Map of the proposed Project, showing proposed turbine locations, nearby dwellings, and terrain elevation	20
Figure 4	Indicative shadow flicker map (assuming a 10D distance limit) and wind direction frequency distribution.....	21
Figure 5	Theoretical annual shadow flicker duration map for the Project.....	22
Figure 6	Predicted actual annual shadow flicker duration map for the Project.....	23

EXECUTIVE SUMMARY

DNV has been commissioned by West Arthur Energy Pty Ltd (“West Arthur Energy” or “the Customer”) to independently assess the expected annual shadow flicker durations in the vicinity of the proposed West Arthur Wind Farm (“WAWF” or “the Project”) in Western Australia. The results of the shadow flicker assessment are described in this document.

Background and methodology

At the request of the Customer, the assessment has been carried out considering the Draft Renewable Energy Planning Code and Guidelines [1], published by the Western Australian Planning Commission (“the Draft WA Code and Guidelines”). Where relevant, the assessment has also considered the Draft National Wind Farm Development Guidelines (“the Draft National Guidelines”) [2]. The methodology used in this assessment has been informed by these guidelines and various standard industry practices.

The Draft WA Code and Guidelines recommend limits of 30 hours per year and 30 minutes on any single day on the theoretical shadow flicker duration, and 10 hours per year on the predicted actual shadow flicker duration.

A Project layout consisting of 92 wind turbines, with a rotor diameter of 184 m and a hub height of 162 m, has been considered in this assessment. The locations of 29 dwellings in the vicinity of the Project have been provided by the Customer, of which up to 23 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.

For the shadow flicker assessment, it is necessary to make an assumption regarding the maximum length of shadow cast by a wind turbine that is likely to cause annoyance due to shadow flicker (referred to here as the “distance limit”). Within this distance limit, all shadow flicker intensity is regarded as being at or above a “moderate level of intensity” likely to cause annoyance. Beyond this distance limit, it is assumed that any shadow flicker experienced will be “below a moderate level of intensity” or “low-intensity”. Considering the Draft WA Code and Guidelines at the request of the Customer, DNV has assessed a maximum shadow length of 265 times the maximum blade chord (265C), which corresponds to a distance of 1192.5 m for this assessment. A shadow flicker distance limit of 10 times the turbine rotor diameter (10D) has also been assessed, which corresponds to a distance of 1840 m for this assessment, as this limit is normally used by DNV for assessing shadow flicker for wind farm projects.

Outcomes of the assessment

Based on DNV’s modelling, if a 265C shadow flicker distance limit is assumed, no dwellings are expected to experience shadow flicker at or above a moderate level of intensity within 50 m of the dwelling.

However, a 10D shadow flicker distance limit is normally used by DNV for assessing shadow flicker for wind farm projects. If a 10D shadow flicker distance limit is assumed, 12 dwellings (2 non-host and 10 host dwellings) are expected to experience shadow flicker at or above a moderate level of intensity within 50 m of the dwelling. Of these dwellings, 7 host dwellings are predicted to experience theoretical shadow flicker durations above the shadow flicker limit of 30 hours per year within 50 m of the dwelling (dwellings R10, R12, R13, R16, R21, R23 and R24). For all of these 7 host dwellings, and one additional host dwelling (R14), the theoretical shadow flicker durations within 50 m of the dwelling are predicted to exceed the shadow flicker limit of 30 minutes on a single day. When considering the likely reduction in shadow flicker due to cloud cover and rotor orientation, for all of these dwellings (except R14) the predicted actual shadow flicker durations within 50 m of the dwelling are also

above the shadow flicker limit of 10 hours per year. The predicted shadow flicker durations at some of the dwellings (dwellings R10, R12, R13, R16, R21, R23 and R24) significantly exceed the shadow flicker limits. It is noted that all of the dwellings where exceedances of the shadow flicker limits are predicted are on host lots, and the shadow flicker limits specified in the Draft WA Code and Guidelines are only intended to apply to non-host lots.

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 both the Draft WA Code and Guidelines and the Draft National Guidelines do not provide any quantification methodology. The Draft WA Code and Guidelines, however, require that the Customer ensures that the turbine blades are finished with a surface treatment of low reflectivity to minimise blade glint (such as using a non-reflective paint).

1 INTRODUCTION

West Arthur Energy Pty Ltd (“West Arthur Energy” or “the Customer”) has commissioned DNV to independently assess the expected annual shadow flicker durations in the vicinity of the proposed West Arthur Wind Farm (“WAWF” or “the Project”) in Western Australia. The results of this work are reported here. This document has been prepared in accordance with OPP-00433442-AUMEL-P-01 Issue C, dated 15 December 2025, and is subject to the terms and conditions in that agreement.

This assessment evaluates the shadow flicker durations in the vicinity of the Project for the current proposed turbine layout and configuration. At the request of the Customer, the assessment has been carried out in accordance with the Draft Renewable Energy Planning Code and Guidelines (“the Draft WA Code and Guidelines”) [1], published by the Western Australian Planning Commission. Where relevant, the assessment has also relied on the Draft National Wind Farm Development Guidelines (“the Draft National Guidelines”) [2]. 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 90 km east of Bunbury in Western Australia, with Collie being the closest major town approximately 45 km west of the Project.

The terrain at the site is moderately undulating, with turbine base elevations ranging from approximately 257 m to 368 m above sea level. The land at the site is rural and predominantly used for grazing, with some areas of dense native trees, as well as various creeks running throughout. A digital elevation model of the Project terrain was derived based on high resolution elevation data supplied by the Customer [3], which was extended using publicly available NASADEM data [4].

2.2 The Project

2.2.1 Proposed wind farm layout

The Project is proposed to consist of 92 wind turbines [5]. 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 the following dimensions [6]:

- rotor diameter of 184 m
- maximum blade chord of 4.5 m
- hub height of 162 m above ground level (AGL)
- upper tip height of 254 m AGL.

It is understood that these turbine dimensions represent the maximum turbine dimensions currently under consideration for the Project.

2.2.2 Dwelling locations

The locations of 29 dwellings in the vicinity of the Project, and which are associated with the Project, have been provided by the Customer [7, 8].

For the purposes of this assessment, 23 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 23 dwellings, 16 have been identified by the Customer as host dwellings and 7 have been identified as non-host dwellings [7, 8, 9].

The remaining six 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 [10]. However, the WA Position Statement does not address the potential for wind farms to cause shadow flicker impacts at nearby dwellings. The Western Australian Planning Commission has also recently published another document, the Draft Renewable Energy Planning Code and Guidelines ("the Draft WA Code and Guidelines") [1]. In the absence of firm legislation applicable to Western Australia, the Customer has requested the assessment be carried out in accordance with the Draft WA Code and Guidelines. The shadow flicker requirements and methodology in the Draft WA Code and Guidelines appear, in large part, to be based on those originally contained in draft guidelines published in July 2010 by the Environment Protection and Heritage Council (EPHC), in conjunction with Local Governments and the Planning Ministers' Council ("the Draft National Guidelines") [2].

Both the Draft WA Code and Guidelines and the Draft National Guidelines cover a range of issues across the different stages of wind farm development. In relation to shadow flicker, these documents provide contextual or background information, a proposed methodology, shadow flicker limits, and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm. In many aspects, the Draft National Guidelines is a more detailed and comprehensive document than the Draft WA Code and Guidelines. Therefore, DNV has considered the Draft WA Code and Guidelines in the first instance and, where information is lacking in that document, has supplemented this with information from the Draft National Guidelines.

Shadow flicker duration limits are specified in the Draft WA Code and Guidelines in Performance Outcome WF-PO5.1, as follows:

"Wind turbines are sited and operated to ensure that shadow flicker at any visually sensitive land use on non-host lots does not exceed:

- a. 30 hours per year and 30 minutes on any single day, based on theoretical shadow flicker modelling; or*
- b. 10 hours per year, based on predicted actual shadow flicker modelling."*

For the purposes of this assessment, DNV has been informed by the guidance and recommendations given in the Draft WA Code and Guidelines and the Draft National Guidelines in relation to shadow flicker. In addition, DNV has compared the shadow flicker results for a range of assumptions regarding the distance at which shadow flicker impacts are likely to cause annoyance, including those specified in the Draft WA Code and Guidelines as well as those 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 from rotating turbine blades, and has the potential to annoy people. Its occurrence depends on a combination of circumstances arising from the orientation of the nacelle, angle of the blade, angle of the sun, and the viewing angle of the observer. The reflectiveness of the surface of the blades is also important. Blade glint is not generally a problem for modern wind turbines [2].

Neither the Draft WA Code and Guidelines or the Draft National Guidelines provide a methodology for quantifying blade glint impacts or a regulatory limit. However, Performance Outcome WF-PO4.4 in the Draft WA Code and Guidelines requires that:

"Wind turbine blades are finished with a surface treatment of low reflectivity to minimise blade glint."

Guidance regarding blade glint is also provided in the Draft National Guidelines, which 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.

For this assessment, DNV has assessed the shadow flicker at the provided dwelling locations and has also determined the highest shadow flicker duration within 50 m of each of these locations.

In the absence of detailed dwelling height information, shadow flicker has been calculated at the 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.

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.”

For the shadow flicker assessment, it is necessary to make an assumption regarding the maximum length of shadow cast by a wind turbine that is likely to cause annoyance due to shadow flicker (referred to here as the “distance limit”). However, data from empirical studies of shadow flicker is very limited, and different people have different levels of awareness and sensitivity to shadow flicker.

Both the Draft WA Code and Guidelines and the Draft National Guidelines define a distance limit equal to 265 times the maximum blade chord length (265C), 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 (10D) from a turbine [11, 12] is appropriate; this would correspond to approximately 1500 m to 1900 m for rotor diameters of 150 m to 190 m, for example, which would be typical for modern wind turbines.

It should be noted, however, that the discussion in Appendix E of the Draft National Guidelines (on which the Draft WA Code and Guidelines appear to be based) suggests that the 265C distance limit was calibrated to generally align with the UK industry assumptions regarding maximum shadow flicker distances, for the typical turbine sizes current at the time the Draft National Guidelines were drafted. However, as turbine blades have developed in the period since the Draft National Guidelines were published in 2010, the maximum blade chord has generally not increased as significantly relative to increases in the blade length (and hence rotor diameter).

For modern wind turbines, a shadow flicker distance limit based on a 10D threshold will be significantly greater than the 265C assumption and will therefore be more conservative.

Based on the above considerations, and DNV's experience with wind farm projects in Australia, DNV considers that a maximum distance limit of 10D is more appropriate than a limit of 265C when assessing shadow flicker for current projects. Up to the 10D distance limit, it is assumed that any shadow flicker experienced will be at or above a "moderate level of intensity" and hence likely to cause annoyance.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be below a "moderate level of intensity" (also described as "low-intensity" shadow flicker in this report) and unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and therefore some people may still be affected by shadow flicker intensities below a moderate level of intensity. To account for this possibility, DNV typically assumes that shadow flicker below a moderate level of intensity may occur from a distance of 10D to approximately 15D from the wind turbines. However shadow flicker results in this region should be considered informative only, and not necessarily used to determine compliance with shadow flicker limits.

For this assessment, DNV has carried out shadow flicker modelling for the following shadow distance limit scenarios:

- 265C (1192.5 m): following guidance in the Draft WA Code and Guidelines, at the request of the Customer
- 10D (1840 m): to align with the distance limit DNV considers more appropriate for assessing shadow flicker at or above a moderate level of intensity
- 15D (2760 m): to provide informative guidance regarding the potential for people to experience low-intensity shadow flicker.

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.

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:

- Collie (009628), located approximately 52 km west of the centre of the Project [13]
- Wagin (010647), located approximately 61 km east of the centre of the Project [14]
- Kojonup (010582), located approximately 63 km southeast of the centre of the Project [15]
- Narrogin (010614), located approximately 70 km northeast of the centre of the Project [16]
- Wandering Comparison (010648), located approximately 81 km north of the centre of the Project [17]
- Donnybrook (009534), located approximately 84 km west-southwest of the centre of the Project [18]
- Katanning Comparison (010579), located approximately 86 km east-southeast of the centre of the Project [19]
- Dwellingup (009538), located approximately 98 km northwest of the centre of the Project [20].

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 34% and 64%, and the average annual cloud cover is approximately 52%. This implies that on an

average day, 52% 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 measured wind direction frequency distribution for the site derived by DNV as part of a previous analysis [21] was 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 while the method prescribed by the Draft WA Code and Guidelines for assessing actual shadow flicker duration allows for reductions due to cloud cover, it does not consider turbine orientation. 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 specified in the Draft WA Code and 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, angle of the sun, and viewing angle of the observer. 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 so this issue 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 for alternate shadow flicker distance limits (265C and 10D). 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 results presented in the table and maps represent the worst case between the results calculated at 2 m and 6 m AGL for the proposed turbine parameters.

Based on DNV's modelling, if a 265C shadow flicker distance limit is assumed, no dwellings are expected to experience shadow flicker at or above a moderate level of intensity within 50 m of the dwelling.

However, as discussed in Section 4.1.2, a 10D shadow flicker distance limit is normally used by DNV for assessing shadow flicker for wind farm projects. If a 10D shadow flicker distance limit is assumed, 12 dwellings (2 non-host and 10 host dwellings) are expected to experience shadow flicker at or above a moderate level of intensity within 50 m of the dwelling. Of these dwellings, 7 host dwellings are predicted to experience theoretical shadow flicker durations above the shadow flicker limit of 30 hours per year within 50 m of the dwelling (dwellings R10, R12, R13, R16, R21, R23 and R24). For all of these 7 host dwellings, and one additional host dwelling (R14), the theoretical shadow flicker durations within 50 m of the dwelling are predicted to exceed the shadow flicker limit of 30 minutes on a single day. When considering the likely reduction in shadow flicker due to cloud cover and rotor orientation, for all of these dwellings (except R14) the predicted actual shadow flicker durations within 50 m of the dwelling are also above the shadow flicker limit of 10 hours per year. The predicted shadow flicker durations at some of the dwellings (dwellings R10, R12, R13, R16, R21, R23 and R24) significantly exceed the shadow flicker limits. It is noted that all of the dwellings where exceedances of the shadow flicker limits are predicted are on host lots, and the shadow flicker limits specified in the Draft WA Code and Guidelines are only intended to apply to non-host lots.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be low-intensity (i.e. 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 beyond the 10D distance limit. To inform the potential for this outcome, although not part of the methodology outlined in the Draft WA Code and Guidelines or the Draft National Guidelines, DNV has also calculated the theoretical shadow flicker impacts for the Project for an increased distance limit of 15D, which 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 for a shadow flicker distance limit of 10D, 5 dwellings (host dwellings R2, R7, R8 and R17 and non-host dwelling R25) may have the potential to be exposed to low-intensity shadow flicker. These dwellings also included in the shadow flicker results table presented 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 92 turbines, with a rotor diameter of 184 m and a hub height of 162 m. It is understood that these dimensions represent the turbine dimensions currently under consideration for the Project.

Based on DNV's modelling, if a 265C shadow flicker distance limit is assumed, no dwellings are expected to experience shadow flicker at or above a moderate level of intensity within 50 m of the dwelling.

However, a 10D shadow flicker distance limit is normally used by DNV for assessing shadow flicker for wind farm projects. If a 10D shadow flicker distance limit is assumed, 12 dwellings (2 non-host and 10 host dwellings) are expected to experience shadow flicker at or above a moderate level of intensity within 50 m of the dwelling. Of these dwellings, 7 host dwellings are predicted to experience theoretical shadow flicker durations above the shadow flicker limit of 30 hours per year within 50 m of the dwelling (dwellings R10, R12, R13, R16, R21, R23 and R24). For all of these 7 host dwellings, and one additional host dwelling (R14), the theoretical shadow flicker durations within 50 m of the dwelling are predicted to exceed the shadow flicker limit of 30 minutes on a single day. When considering the likely reduction in shadow flicker due to cloud cover and rotor orientation, for all of these dwellings (except R14) the predicted actual shadow flicker durations within 50 m of the dwelling are also above the shadow flicker limit of 10 hours per year. The predicted shadow flicker durations at some of the dwellings (dwellings R10, R12, R13, R16, R21, R23 and R24) significantly exceed the shadow flicker limits. It is noted that all of the dwellings where exceedances of the shadow flicker limits are predicted are on host lots, and the shadow flicker limits specified in the Draft WA Code and Guidelines are only intended to apply to non-host lots.

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.

It is recommended that the Customer ensures 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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APPENDIX A TABULATED DATA

Table 1 Proposed turbine layout for the Project [5]

Turbine ID	Easting ¹ [m]	Northing ¹ [m]	Base elevation [m]	Turbine ID	Easting ¹ [m]	Northing ¹ [m]	Base elevation [m]
T1	465870	6305555	285	T47	471861	6306845	362
T2	467819	6305523	323	T48	471203	6306223	324
T3	468751	6305600	336	T49	474364	6307206	331
T4	466752	6304788	298	T50	474013	6306562	364
T5	467654	6304830	317	T51	472181	6306125	329
T6	468892	6304864	328	T52	473232	6306060	368
T7	464418	6304118	291	T53	473049	6305227	346
T8	466202	6303956	300	T54	474000	6305304	361
T9	468091	6303888	321	T55	472400	6304819	331
T10	468973	6304085	335	T56	473931	6304627	341
T11	465742	6302967	310	T57	473773	6303987	288
T12	466681	6303178	311	T58	472675	6303152	269
T13	468030	6303202	320	T60	472107	6302387	287
T14	469152	6303291	314	T61	472966	6302298	264
T15	470622	6303232	304	T62	473736	6302757	283
T16	471917	6303779	282	T63	472793	6301635	287
T17	467718	6302567	314	T64	473736	6301708	257
T18	468995	6302626	320	T65	471848	6305514	329
T19	467714	6301834	331	T66	472886	6303854	285
T20	468734	6302013	297	T67	474962	6305269	331
T21	466136	6301214	300	T69	473907	6298899	276
T22	468590	6301317	291	T73	475614	6297204	261
T23	467140	6301331	327	T74	475113	6296861	267
T24	465869	6300544	323	T75	472665	6308243	332
T25	468010	6300719	301	T76	472429	6307650	336
T26	468970	6300559	315	T77	473402	6307695	314
T27	468922	6299785	327	T78	472949	6306944	331
T28	465267	6298619	323	T79	478436	6308016	320
T29	466365	6298353	302	T80	478071	6307375	339
T30	469198	6298987	301	T81	477588	6306721	356
T31	468568	6298584	268	T82	480348	6306961	274
T32	467612	6298006	289	T83	481443	6306846	265
T33	470710	6298759	271	T84	477247	6306169	357
T34	467782	6297149	279	T85	478722	6306369	307
T35	468647	6297355	271	T86	478243	6305834	318
T36	471742	6301821	334	T87	479832	6305995	325
T37	473085	6300855	281	T88	480796	6306020	268
T38	469940	6300054	284	T89	477535	6305413	353
T39	473350	6299858	263	T90	479648	6305326	346
T40	469874	6299350	283	T91	480609	6305392	280
T41	470946	6299380	302	T92	478680	6305092	311
T42	473095	6299356	279	T93	479678	6304512	360
T43	474803	6298926	287	T94	480620	6304605	309
T44	466716	6305693	296	T95	480640	6303867	294
T45	469196	6306141	332	T96	471475	6307566	350

Table 1 Proposed turbine layout for the Project [5]
(continued)

Turbine ID	Easting¹ [m]	Northing¹ [m]	Base elevation [m]	Turbine ID	Easting¹ [m]	Northing¹ [m]	Base elevation [m]
T46	470060	6306308	351	T97	476623	6305788	348

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 [7, 8]

Dwelling ID ¹	Easting ² [m]	Northing ² [m]	Dwelling status	Nearest turbine	
				Distance [m] ³	Turbine ID
<u>R2</u>	<u>469530</u>	<u>6307814</u>	<u>Host</u>	<u>1597</u>	<u>T46</u>
<u>R5</u>	<u>480120</u>	<u>6308555</u>	<u>Host</u>	<u>1610</u>	<u>T82</u>
R6	475503	6303550	Non-host	1784	T57
<u>R7</u>	<u>474587</u>	<u>6308775</u>	<u>Host</u>	<u>1585</u>	<u>T49</u>
<u>R8</u>	<u>477265</u>	<u>6303924</u>	<u>Host</u>	<u>1513</u>	<u>T89</u>
R9	475094	6300410	Non-host	1512	T43
<u>R10</u>	<u>470522</u>	<u>6304737</u>	<u>Host</u>	<u>1508</u>	<u>T15</u>
<u>R11</u>	<u>472236</u>	<u>6310790</u>	<u>Host</u>	<u>2583</u>	<u>T75</u>
<u>R12</u>	<u>471768</u>	<u>6300519</u>	<u>Host</u>	<u>1302</u>	<u>T36</u>
<u>R13</u>	<u>470469</u>	<u>6301591</u>	<u>Host</u>	<u>1294</u>	<u>T36</u>
<u>R14</u>	<u>469992</u>	<u>6307805</u>	<u>Host</u>	<u>1499</u>	<u>T46</u>
<u>R16</u>	<u>469884</u>	<u>6297651</u>	<u>Host</u>	<u>1272</u>	<u>T35</u>
<u>R17</u>	<u>466861</u>	<u>6299631</u>	<u>Host</u>	<u>1348</u>	<u>T24</u>
R18	465177	6307574	Non-host	2135	T1
R19	477893	6302389	Non-host	2774	T93
<u>R20</u>	<u>464343</u>	<u>6301953</u>	<u>Host</u>	<u>1728</u>	<u>T11</u>
<u>R21</u>	<u>471911</u>	<u>6300440</u>	<u>Host</u>	<u>1245</u>	<u>T37</u>
R22	470045	6295480	Non-host	2339	T35
<u>R23</u>	<u>475593</u>	<u>6306515</u>	<u>Host</u>	<u>1261</u>	<u>T97</u>
<u>R24</u>	<u>475558</u>	<u>6306385</u>	<u>Host</u>	<u>1221</u>	<u>T97</u>
R25	477339	6299523	Non-host	2605	T43
<u>R28</u>	<u>476049</u>	<u>6295545</u>	<u>Host</u>	<u>1615</u>	<u>T74</u>
R29	475531	6295224	Non-host	1690	T74

1. Host dwellings 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	1192.5 m (265C), 1840 m (10D)
Year of calculation	2038
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 dwelling location

Table 4 Theoretical and predicted actual shadow flicker occurrence for alternate shadow flicker distance limits

Dwelling ID	Easting ¹ [m]	Northing ¹ [m]	Dwelling status	Predicted shadow flicker occurrence for alternate shadow flicker distance limits (based on the maximum shadow flicker between the 2 m or 6 m AGL results) ²											
				Theoretical (single day)				Theoretical (annual)				Predicted actual (annual) ³			
				At dwelling		Within 50 m of dwelling		At dwelling		Within 50 m of dwelling		At dwelling		Within 50 m of dwelling	
				265C ⁴	10D ⁵	265C ⁴	10D ⁵	265C ⁴	10D ⁵	265C ⁴	10D ⁵	265C ⁴	10D ⁵	265C ⁴	10D ⁵
R2 ⁶	469530	6307814	Host	-	-	-	-	-	-	-	-	-	-	-	-
R5	480120	6308555	Host	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes
R6	475503	6303550	Non-host	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes
R7 ⁶	474587	6308775	Host	-	-	-	-	-	-	-	-	-	-	-	-
R8 ⁶	477265	6303924	Host	-	-	-	-	-	-	-	-	-	-	-	-
R9	475094	6300410	Non-host	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes
R10	470522	6304737	Host	-	Over	-	Over	-	Over	-	Over	-	Over	-	Over
R11	472236	6310790	Host	-	-	-	-	-	-	-	-	-	-	-	-
R12	471768	6300519	Host	-	Over	-	Over	-	Over	-	Over	-	Over	-	Over
R13	470469	6301591	Host	-	Over	-	Over	-	Over	-	Over	-	Over	-	Over
R14	469992	6307805	Host	-	Over	-	Over	-	Yes	-	Yes	-	Yes	-	Yes
R16	469884	6297651	Host	-	Over	-	Over	-	Over	-	Over	-	Over	-	Over
R17 ⁶	466861	6299631	Host	-	-	-	-	-	-	-	-	-	-	-	-
R18	465177	6307574	Non-host	-	-	-	-	-	-	-	-	-	-	-	-
R19	477893	6302389	Non-host	-	-	-	-	-	-	-	-	-	-	-	-
R20	464343	6301953	Host	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes	-	Yes
R21	471911	6300440	Host	-	Over	-	Over	-	Over	-	Over	-	Over	-	Over
R22	470045	6295480	Non-host	-	-	-	-	-	-	-	-	-	-	-	-
R23	475593	6306515	Host	-	Over	-	Over	-	Over	-	Over	-	Over	-	Over
R24	475558	6306385	Host	-	Over	-	Over	-	Over	-	Over	-	Over	-	Over
R25 ⁶	477339	6299523	Non-Host	-	-	-	-	-	-	-	-	-	-	-	-
R28	476049	6295545	Host	-	-	-	-	-	-	-	-	-	-	-	-
R29	475531	6295224	Non-host	-	-	-	-	-	-	-	-	-	-	-	-

- 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.
- If the calculated shadow flicker duration (maximum value between 2 m or 6 m AGL results) at the specified location is:
 - zero, this is indicated by '-'
 - non-zero and below the shadow flicker limit, this is indicated by "Yes" in **green font**
 - non-zero and above the shadow flicker limit, this is indicated with "Over", in **red font** (theoretical shadow flicker) or **orange font** (predicted actual shadow flicker).
- Considering reductions in shadow flicker duration due to cloud cover and turbine orientation.
- Assuming a maximum shadow flicker distance of 265 x blade chord; the shadow flicker within this zone is considered at or above a moderate level of intensity.
- Assuming a maximum shadow flicker distance of 10 x rotor diameter; the shadow flicker within this zone is considered at or above a moderate level of intensity.
- Dwelling is not predicted to experience any shadow flicker at or above a moderate level of intensity, but may experience low-intensity shadow flicker based on a maximum shadow flicker distance of 15 x rotor diameter.

APPENDIX B MAPS

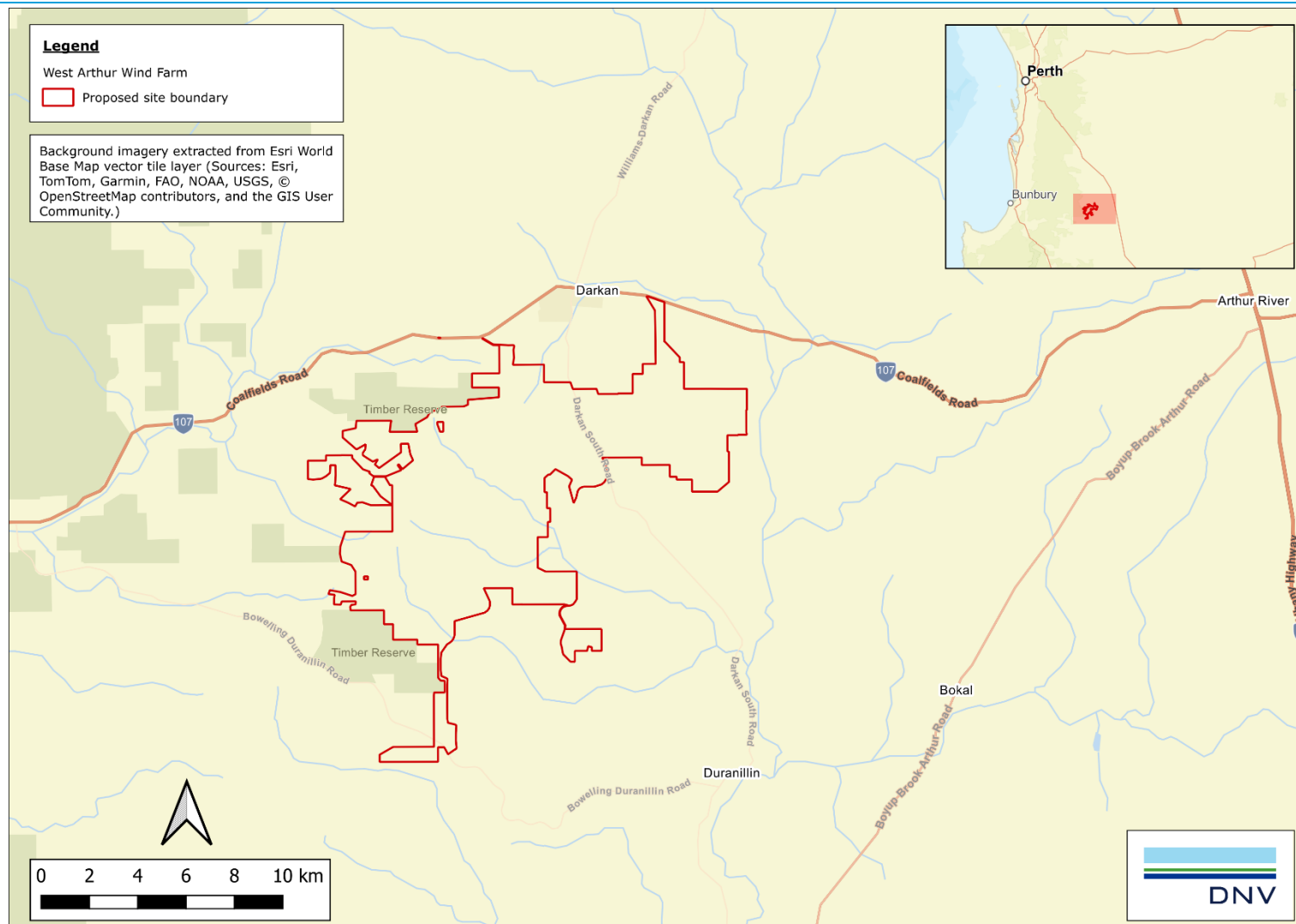


Figure 2 Location of the Project

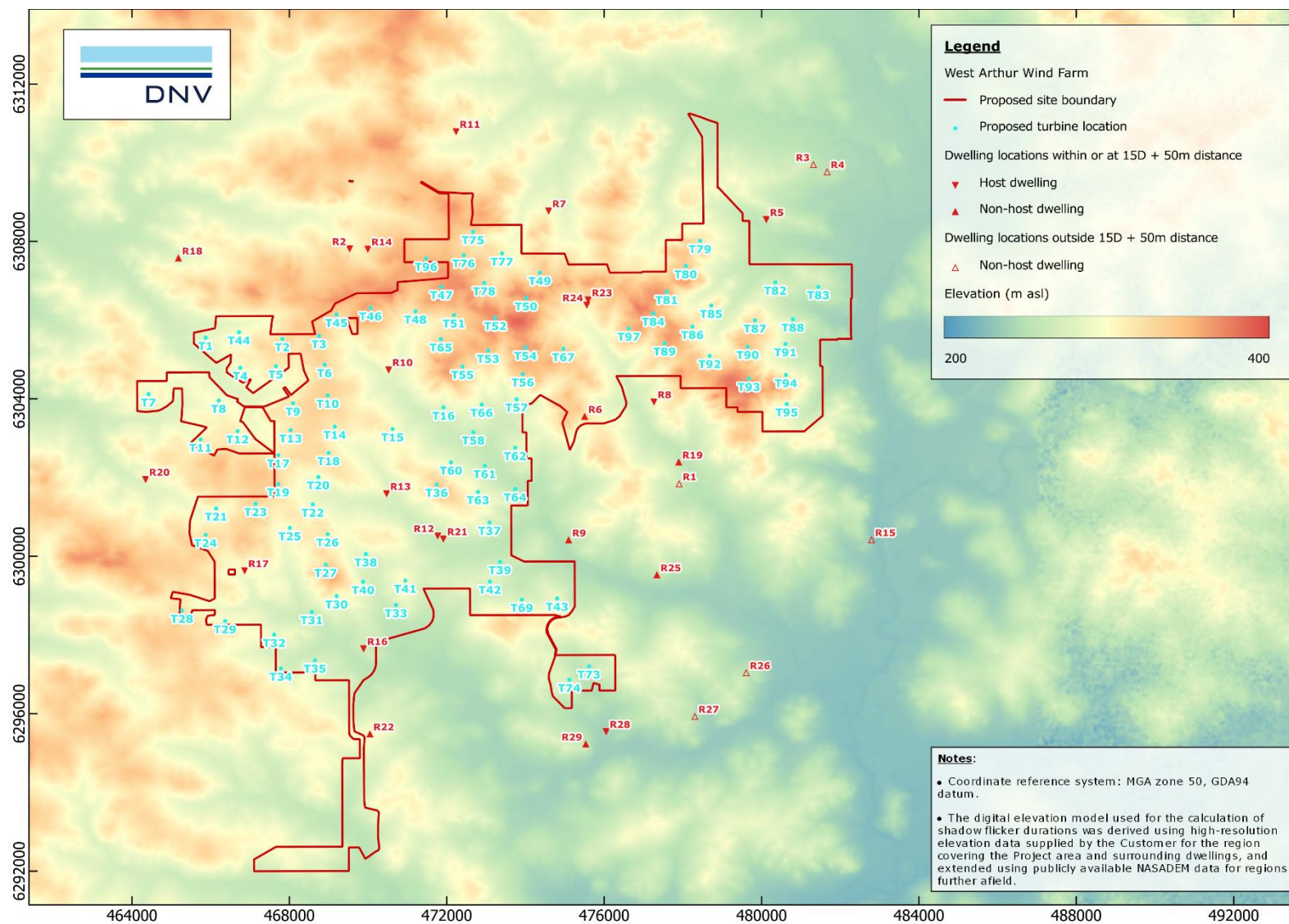


Figure 3 Map of the proposed Project, showing proposed turbine locations, nearby dwellings, and terrain elevation

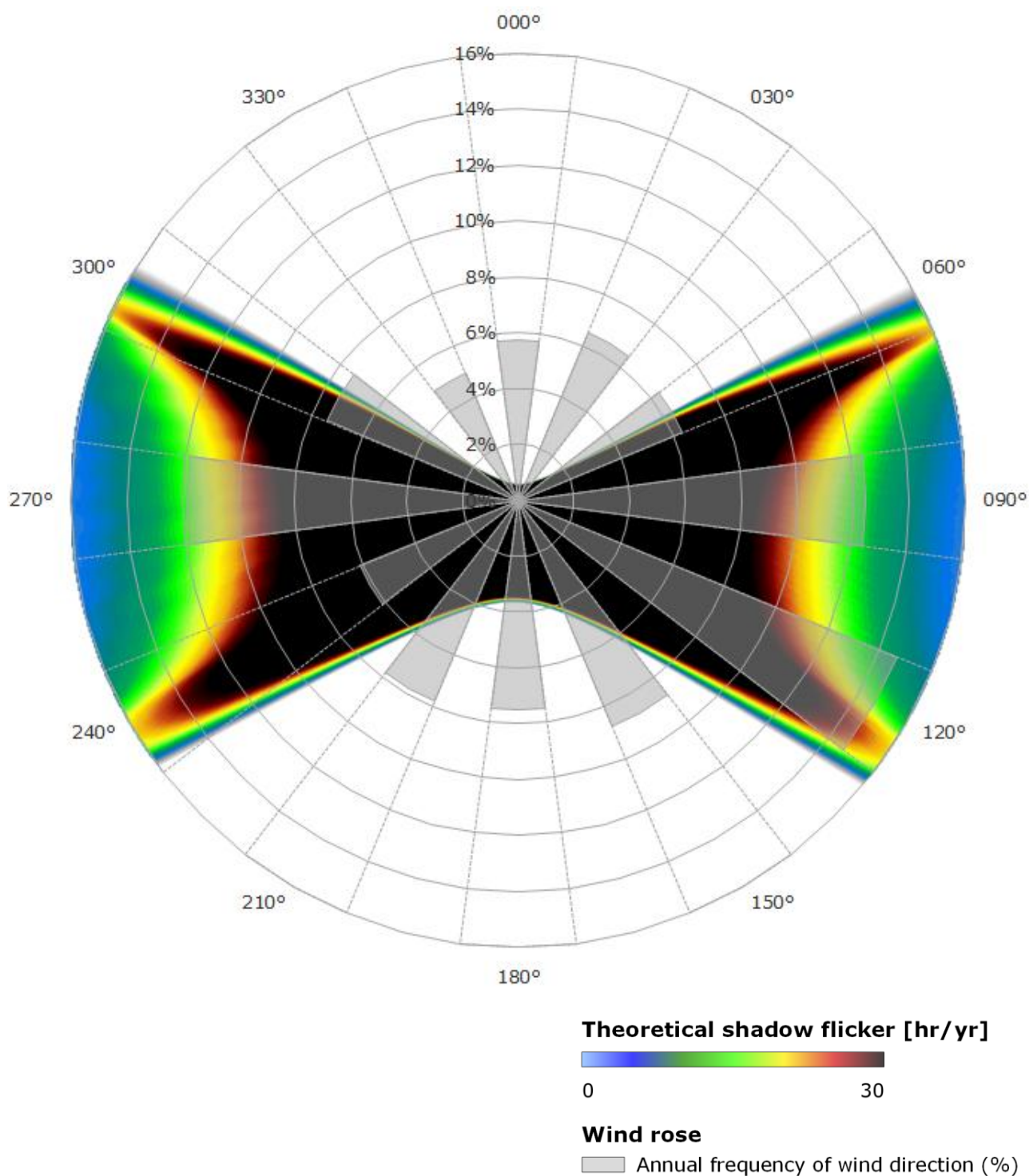


Figure 4 Indicative shadow flicker map (assuming a 10D distance limit) and wind direction frequency distribution

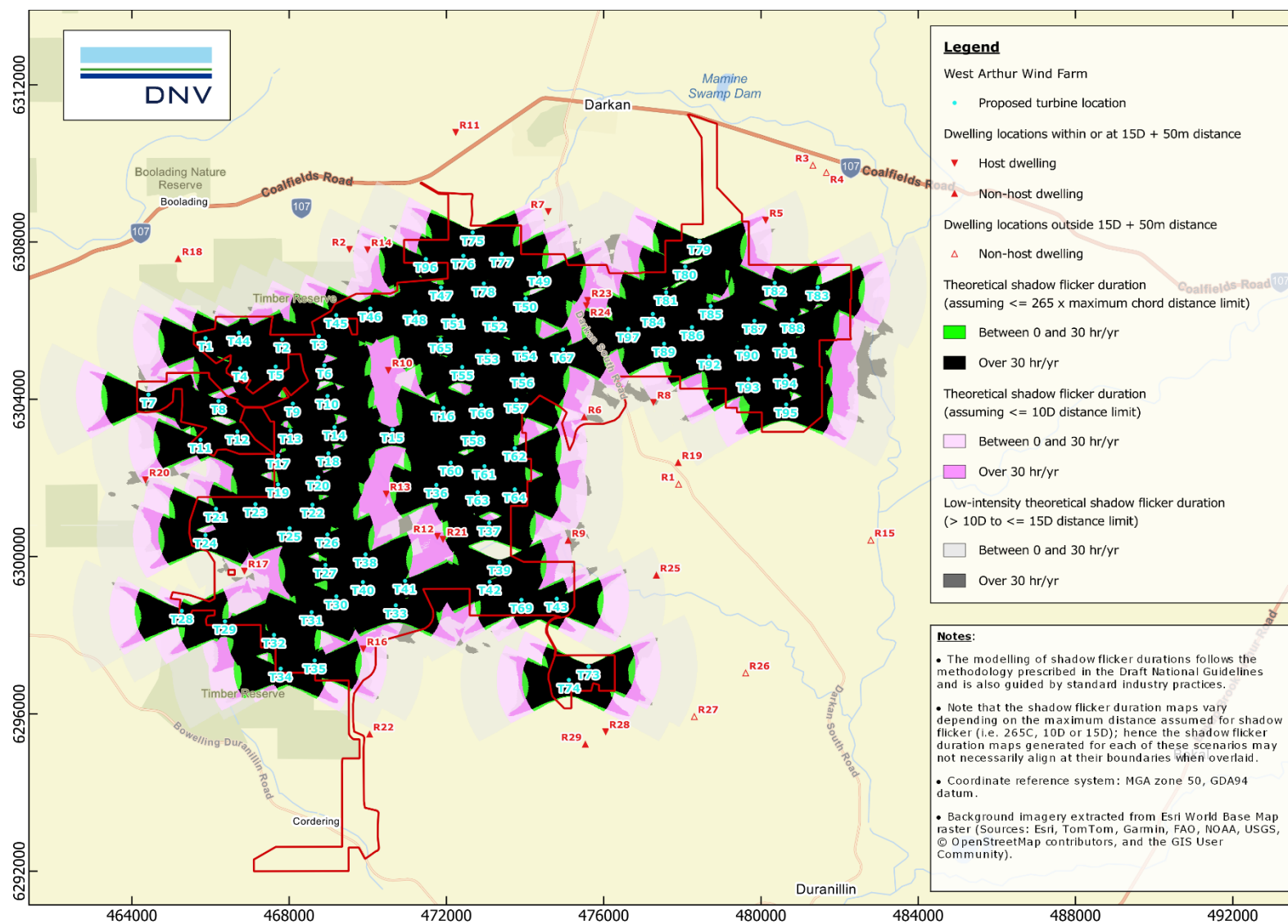


Figure 5 Theoretical annual shadow flicker duration map for the Project

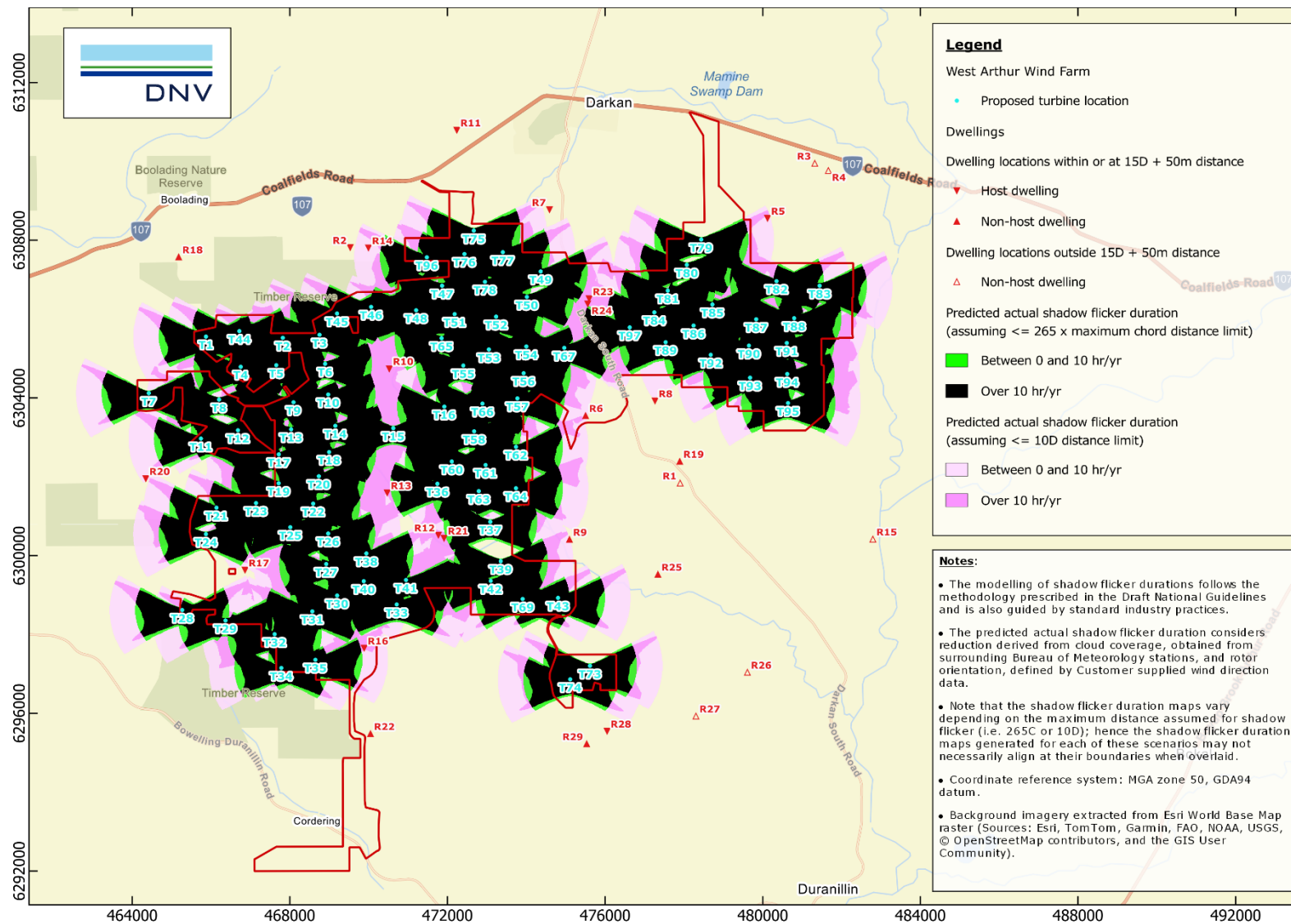


Figure 6 Predicted actual annual shadow flicker duration map for the Project



About DNV

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

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

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.