PALING YARDS WIND FARM

Shadow Flicker and Blade Glint Assessment

Paling Yards Development Pty Ltd

Report No.: 10277372-AUMEL-R-01, Rev. E
Date: 31 August 2023
Status: FINAL

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Project name:	Paling Yards Wind Farm	
Report title:	Shadow Flicker and Blade Glint Assessment	
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Date of issue:	31 August 2023	
Project No.:	10277372	
Report No.:	10277372-AUMEL-R-01, Rev. E	
Document No.:	E	

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Objective:
Paling Yards Wind Farm Shadow Flicker and Blade Glint Assessment

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Document classification:
Customer's discretion
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Keywords:
Paling Yards Wind Farm, shadow flicker, blade glint

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	8 June 2022	First issue – DRAFT	D Price	N Brammer	T Gilbert
B	24 August 2022	Second issue - DRAFT	V Lau	N Brammer D Price	T Gilbert
C	31 August 2022	FINAL	V Lau	N Brammer D Price	T Gilbert
D	31 August 2022	FINAL – updated in response to Customer comments	V Lau	N Brammer D Price	T Gilbert
E	31 August 2023	FINAL – updated to reflect updated dwelling information	N Brammer	L Anderson	T Gilbert

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EXECUTIVE SUMMARY

DNV has been commissioned by Paling Yards Development Pty Ltd ("the Customer") to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Paling Yards Wind Farm ("PYWF", or "the Project") in New South Wales. 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 NSW Wind Energy Visual Assessment Bulletin (NSW Visual Assessment Bulletin) prepared by the NSW Department of Planning and Infrastructure in December 2016 [1], which is referenced by the Planning Secretary's Environmental Assessment Requirements (SEARs) for the Project [2], and the Draft National Wind Farm Development Guidelines [3] (Draft National Guidelines). The methodology used in this assessment has been informed by these guidelines and various standard industry practices.

The NSW Visual Assessment Bulletin recommends a shadow flicker limit of 30 hours per year at dwellings in the vicinity of a wind farm. Similarly, 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 up to 47 wind turbines with a rotor diameter of 158 m and hub height of 151 m (similar to the GE Cypress 158 turbine type) has been considered. This corresponds to an upper tip height of 230 m (being equal to the turbine hub height plus half the turbine rotor diameter). DNV understands that the Customer is also considering alternative turbine models with a maximum upper tip height of 240 m, but that the turbine dimensions considered here represent the most likely configuration for the Project. For the purposes of this assessment, 13 dwellings in the vicinity of the site have been considered, based on locations provided by the Customer, with nine of these dwellings understood to be stakeholder dwellings "involved" with the Project.

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 been predicted by also estimating the possible reduction in shadow flicker due to turbine orientation and cloud cover.

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.

Assessment results

Based on DNV's modelling, which considers the 47-turbine layout option provided by the Customer, a total of nine dwellings are predicted to experience some high intensity shadow flicker (meaning shadow flicker of at least a moderate level of intensity or above) which is expected to occur up to a distance of around 10 rotor diameters from the wind farm. All of these dwellings are understood to be involved stakeholder dwellings.

For one of the involved stakeholder dwellings, both the theoretical and actual high intensity shadow flicker within 50 m of the dwelling is predicted to be slightly above the proposed limit. For eight of these involved stakeholder dwellings, the theoretical and actual high intensity shadow flicker durations within 50 m of the dwelling are predicted to be very high and exceed the proposed shadow flicker limits by a significant margin (ranging from approximately 2 to 12 times the limits). It is understood that the NSW

Wind Energy Guideline [4] allows for negotiated agreements between the wind farm Proponent and involved stakeholders to manage exceedances of the relevant assessment criteria. Consequently, it is recommended that landholders are informed about the predicted shadow flicker durations that may be experienced, and it is noted that the very high shadow flicker durations may not be acceptable to some involved landholders meaning that some mitigation may be required.

None of the non-involved dwellings are predicted to experience high intensity shadow flicker due to the proposed wind farm, and therefore the shadow flicker limits are not exceeded at these houses.

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

Based on a desktop survey, DNV has investigated whether there are any existing or proposed wind farms (based on data in the public domain) in the vicinity of the Project that could contribute to cumulative shadow flicker at dwellings near the Project. It was determined that currently there are no other wind farm developments sufficiently close to the Project to cause cumulative shadow flicker impacts and that shadow flicker impacts at nearby dwellings will therefore be due to the Project alone.

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

Paling Yards Development Pty Ltd ("the Customer") has commissioned DNV to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Paling Yards Wind Farm ("PYWF", or "the Project") in New South Wales. The results of this work are reported here.

This assessment evaluates the shadow flicker durations in the vicinity of the Project for the specified turbine layout option, in accordance with the NSW Wind Energy Visual Assessment Bulletin (NSW Visual Assessment Bulletin) prepared by the NSW Department of Planning and Infrastructure in December 2016 [1], which is referenced by the Planning Secretary's Environmental Assessment Requirements (SEARs) for the Project [2], and the Draft National Wind Farm Development Guidelines [3] (Draft National Guidelines). The potential for cumulative shadow flicker effects resulting from the combined impact of the Project and neighbouring wind farm projects (existing or proposed) was also investigated as part of the assessment.

This document has been prepared in accordance with DNV proposal L2C-208538-AUME-P-01 Issue B, dated 13 November 2020, and is subject to the terms and conditions in that agreement.

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The site

The Project is located in New South Wales, approximately 30 km north of Taralga and 30 km South of Black Springs, as illustrated in Figure 2.

The terrain within the site boundary is moderately complex with turbine base elevations ranging between approximately 860 m and 1050 m above sea level. Ground cover on site comprises primarily farmland, interspersed with some areas of bushes and small patches of trees. Denser areas of forestry are located in the areas surrounding the Project. A digital elevation model (DEM), extending approximately 10 km from the site, was derived from publicly available SRTM1 data [5], and a map representing the terrain at the Project is included in Figure 3.

2.2 The project

2.2.1 Proposed wind farm layout

The Project is proposed to consist of up to 47 wind turbines [6]. A map of the site with the proposed turbine layout is shown in Figure 3, and the coordinates of the proposed turbine locations are given in Table 1.

DNV has modelled the shadow flicker based on the GE Cypress 158-6.1 MW turbine model with a rotor diameter of 158 m, a hub height of 151 m, and an upper tip height of 230 m (being equal to the turbine hub height plus half the turbine rotor diameter) [6]. DNV understands that the Customer is also considering alternative turbine models with a maximum upper tip height of 240 m, but that the turbine dimensions considered in this assessment represent the most likely configuration for the Project. The maximum blade chord length for this turbine, defined as the dimension through the thickest part of the blade, is 4 m [7].

2.2.2 Shadow receptor locations

Details of dwellings neighbouring the wind farm were provided to DNV by the Customer [8, 9]. The coordinates of 13 dwellings within approximately 2.5 km from the Project are presented in Table 2. Based on the information provided, DNV understands that nine of these dwellings are “involved” stakeholder dwellings.

DNV has modelled all listed dwellings as habitable building structures. Dwellings situated more than 2420 m (15 times the turbine rotor diameter plus 50 m) from turbine locations are considered unlikely to be impacted by shadow flicker, as discussed further in Sections 3.1 and 4.1.

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

2.3 Neighbouring wind farms

Based on a desktop survey, DNV has investigated whether there are any existing or proposed wind farm projects (based on data in the public domain) in the vicinity of the PYWF that could contribute to cumulative shadow flicker at dwellings near the PYWF. It was determined that currently there are no nearby wind farms, existing or proposed, that could result in cumulative shadow flicker impacts.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

The NSW Visual Assessment Bulletin [1] currently states:

> *"…The shadow flicker caused by certain sun angles in relation to the rotation of wind turbine blades on dwellings will be limited to 30 hours per year, and may require mitigation measures such as amended siting and design of turbines to minimise the amount of shadow flicker."*

Although the NSW Visual Assessment Bulletin describes the requirements for assessing and minimising shadow flicker, it does not provide detailed methodologies for these assessments.

The 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) [3]. The Draft National Guidelines cover a range of issues across the different stages of wind farm development.

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.

These limits are assumed to apply to a single dwelling, and it is noted that there is no requirement under either the NSW Visual Assessment Bulletin 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 limited distance from the wind turbines. Beyond this distance 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 distance equivalent to 265 times the maximum blade chord, which corresponds to approximately 1000 m to 1600 m for modern wind turbines (which typically have maximum blade chord lengths of between 4 m to 6 m). However, the UK wind industry considers that a distance limit of around 10 rotor diameters (10D) from a turbine [10, 11], 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 assumed a distance of 10D for determining the maximum distance from turbines that the shadow flicker is considered to be at least of a moderate level of intensity, which DNV considers is more appropriate than a limit of 265 times the maximum blade chord.

For simplicity, in this report shadow flicker of a moderate level of intensity or above is referred to as "high intensity" shadow flicker, and is expected to occur up to a distance of approximately 10D from the wind turbines. Conversely, shadow flicker below a moderate level of intensity is referred to as "low intensity" shadow flicker.

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."*

Similarly, the NSW Visual Assessment Bulletin states:

> *"The direct reflection of the sun from the wind turbine structure (glint) is to be minimised through appropriate turbine treatments (such as the use of low sheen and matte finishes)."*

4 ASSESSMENT METHODOLOGY

4.1 Shadow flicker

4.1.1 Overview

Shadow flicker may occur under certain combinations of geographical position and time of day, when the sun passes behind the rotating blades of a wind turbine and casts a moving shadow over neighbouring areas. When viewed from a stationary position the moving shadows cause periodic flickering of the light from the sun, giving rise to the phenomenon of 'shadow flicker'.

The effect is most noticeable inside buildings, where the flicker appears through a window opening. The likelihood and duration of the effect depends upon a number of factors, including:

- the direction of the property relative to the turbine
- the distance from the turbine (the further the observer is from the turbine, the less pronounced the effect will be)
- the wind direction (the shape of the shadow will be determined by the position of the sun relative to the blades which will be oriented to face the wind)
- the turbine height and rotor diameter
- the time of year and day (the position of the sun in the sky)
- the weather conditions (cloud cover reduces the occurrence of shadow flicker).

Example photographs of wind turbines and associated shadows which have the potential to cause flicker are shown in Figure 1 below.

Figure 1 Examples of wind turbine shadows

4.1.2 Theoretical modelled duration

The theoretical number of hours of shadow flicker experienced annually at a given location can be calculated using a geometrical model which incorporates the sun path, topographic variation over the site area, and wind turbine details such as rotor diameter and hub height.

The wind turbines have been modelled assuming they are spherical objects, which is equivalent to assuming the turbines are always oriented perpendicular to the sun-turbine vector. This assumption will mean the model calculates the maximum duration for which there is potential for shadow flicker to occur, up to a specified distance limit.

In line with the methodology proposed in the Draft National Guidelines, DNV has assessed the shadow flicker at the provided dwellings and has determined the highest shadow flicker duration within 50 m of each of these locations.

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. As noted in Section 3.1, the UK wind industry considers that 10 rotor diameters is appropriate [10, 11], while the Draft National Guidelines suggest a distance equivalent to 265 times the maximum blade chord [3].

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 1580 m for the Project, which DNV considers is more appropriate than a limit of 265 times the maximum blade chord. 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 2370 m for the Project, which should include shadow flicker below a "moderate level of intensity".

As mentioned previously, in this report shadow flicker of a moderate level of intensity or above is referred to as "high intensity" shadow flicker, and is expected to occur up to a distance of approximately 10D from the wind farm. Conversely, shadow flicker below a moderate level of intensity is referred to as "low intensity" shadow flicker, and is expected to occur beyond a distance of 10D and up to a distance of approximately 15D from the wind farm.

The model also makes the following assumptions and simplifications:

- there are clear skies every day of the year
- the 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 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 Bureau of Meteorology (BoM) stations:

- Taralga Post Office (070080), located approximately 30 km from the site [12]
- Oberon (Albion St) (063063), located approximately 50 km from the site [13]
- Goulburn TAFE (070263), located approximately 66 km from the site [14]
- Katoomba (Farnells Rd) (063039), located approximately 68 km from the site [15].

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 51% and 60%, and the average annual cloud cover is approximately 55%. This means that on an average day, 55% of the sky in the vicinity of the wind farm is covered with clouds. Although it is not possible to definitively calculate the effect of cloud cover on shadow flicker duration, a reduction in the shadow flicker duration proportional to the amount of cloud cover is a reasonable assumption.

Similarly, turbine orientation can have an impact on the shadow flicker duration. The shadow flicker duration is greatest when the turbine rotor plane is approximately perpendicular to a line joining the sun and an observer, and a minimum when the rotor plane is approximately parallel to a line joining the sun and an observer. A wind direction frequency distribution derived from publicly available ERA5 meteorological data extracted for the site [16] was used to estimate the reduction in shadow flicker duration due to rotor orientation. The modelled wind rose is shown overlaid on the indicative shadow flicker map in Figure 4. An assessment of the likely reduction in shadow flicker duration due to variation in turbine orientation was conducted on an annual basis.

It should be noted that the method prescribed by the Draft National Guidelines for assessing actual shadow flicker duration recommends that only reductions due to cloud cover, and not turbine orientation, be included. However, DNV considers that the additional reduction due to turbine orientation is appropriate as the projected area of the turbine, and therefore the expected shadow flicker duration, is reduced when the turbine rotor is not perpendicular to the line joining the sun and dwelling. Due to limitations in the availability of suitable cloud cover data, the methodology used in this assessment also deviates somewhat from the method recommended by the Draft National Guidelines for assessing the reduction in shadow flicker due to cloud cover. However, considering the available cloud cover data, the approach described above is deemed 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 Predictions

Shadow flicker assessments were carried out at all provided dwelling locations, or 'receptors', as outlined in Table 2.

The theoretical and predicted actual shadow flicker durations at all considered dwellings identified to be affected by shadow flicker from the 47-turbine layout are presented in Table 4. The maximum predicted shadow flicker durations within 50 m of these receptors are also presented in these tables. Furthermore, the results are shown in the form of shadow flicker maps in Figure 5 and Figure 6. The shadow flicker values presented in these maps represent the worst case between the results at 2 m and 6 m above ground for each modelled grid point.

Based on DNV's modelling, which considers the 47-turbine layout option provided by the Customer, a total of nine dwellings are predicted to experience some high intensity shadow flicker, meaning generally shadow flicker of at least a moderate level of intensity or above, which is expected to occur up to a distance of around 10D from the wind farm. All of these dwellings are understood to be involved stakeholder dwellings.

For one of the involved stakeholder dwellings, the theoretical and actual high intensity shadow flicker within 50 m of the dwelling is predicted to be slightly above the proposed limit. For eight of these involved stakeholder dwellings, the theoretical and actual high intensity shadow flicker durations within 50 m of the dwelling are predicted to be very high and exceed the proposed shadow flicker limits by a significant margin (ranging from approximately 2 to 12 times the limits). It is understood that the NSW Wind Energy Guideline [4] allows for negotiated agreements between the wind farm Proponent and involved stakeholders to manage exceedances of the relevant assessment criteria. Consequently, it is recommended that landholders are informed about the predicted shadow flicker durations that may be experienced, and it is noted that the very high shadow flicker durations may not be acceptable to some involved landholders meaning that some mitigation may be required.

None of the provided non-involved dwellings are predicted to experience high intensity shadow flicker due to the proposed wind farm, and therefore the shadow flicker limits are not exceeded at these houses.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be of low intensity and unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore potentially be affected by low intensity shadow flicker, which is assumed to occur beyond this distance limit. In this case, to inform the potential for this outcome, 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 of low intensity. For the purpose of assessing low intensity shadow flicker, the distance limit has been increased by 50% (to 15D), and the results of this additional assessment are also included in the map presented in Figure 5. These results indicate that two non-involved dwellings may have the potential to be exposed to a small amount of low intensity shadow flicker well below the limits. These dwellings are noted in Table 4.

5.1.2 Mitigation options

The effects of shadow flicker may be reduced through a number of mitigation measures, such as:

- installation of screening structures or planting of trees to block shadows cast by the turbines
- using turbine control strategies to shut down turbines when shadow flicker is likely to occur
- relocation or removal of turbines.

5.1.3 Potential for cumulative shadow flicker impact

As mentioned in Section 2.3, it was determined that there are no wind farm projects in the vicinity of the PYWF (i.e. within a distance of up to 15D from dwelling locations) that could contribute to cumulative shadow flicker at dwellings near the PYWF. As far as DNV is aware, the nearest existing or proposed neighbouring wind farm Project (according to publicly-available information), is the Taralga Wind Farm, approximately 30 km to the south-east of the PYWF. Therefore, it was determined that shadow flicker impacts at nearby dwellings will be due to the PYWF alone.

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 CONCLUSIONS

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

For the purpose of this assessment, DNV has considered a layout consisting of 47 turbines with a rotor diameter of 158 m and a hub height of 151 m. The results of the shadow flicker assessment based on this layout configuration are summarised in Table 4.

Based on DNV's modelling, which considers the 47-turbine layout option provided by the Customer, a total of nine dwellings are predicted to experience some high intensity shadow flicker, meaning shadow flicker of at least a moderate level of intensity or above, which is expected to occur up to a distance of around 10D from the wind farm. All of these dwellings are understood to be involved stakeholder dwellings.

For one of the involved stakeholder dwellings, the theoretical and actual high intensity shadow flicker within 50 m of the dwelling is predicted to be slightly above the proposed limit. For eight of these involved stakeholder dwellings, the theoretical and actual high intensity shadow flicker durations within 50 m of the dwelling are predicted to be very high and exceed the proposed shadow flicker limits by a significant margin (ranging from approximately 2 to 12 times the limits). It is understood that the NSW Wind Energy Guideline [4] allows for negotiated agreements between the wind farm Proponent and involved stakeholders to manage exceedances of the relevant assessment criteria. Consequently, it is recommended that landholders are informed about the predicted shadow flicker durations that may be experienced, and it is noted that the very high shadow flicker durations may not be acceptable to some involved landholders meaning that some mitigation may be required.

None of the non-involved dwellings are predicted to experience high intensity shadow flicker due to the proposed wind farm, and therefore the shadow flicker limits are not exceeded at these houses.

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.

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

Based on a desktop survey, DNV has investigated whether there are any existing or proposed wind farm projects (based on data in the public domain) in the vicinity of the PYWF that could contribute to cumulative shadow flicker at dwellings near the PYWF. It was determined that currently there are no other wind farm developments sufficiently close to the Project to cause cumulative shadow flicker impacts and that shadow flicker impacts at nearby dwellings will be due to the PYWF alone.

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

7 REFERENCES

[1] Department of Planning and Environment, “Wind Energy Visual Assessment Bulletin,” NSW Government, December 2016.

[2] Department of Planning and Environment, “Planning Secretary’s Environmental Assessment Requirements (SEARs), Application Number SSD-29064077,” NSW Government, 9 March 2022.

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

[4] Department of Planning and Environment, “Wind Energy Guideline: For State significant wind energy development,” NSW Government, December 2016.

[5] *SRTM Worldwide Elevation Data (1 arc-second resolution, SRTM Plus V3),* National Aeronautics and Space Administration (NASA), elevation grid downloaded from Global Mapper (v21.0) Online Data interface, 20 April 2022.

[6] “220-0052-00 PY WTG-Coordinates_Tract 12-04-2022.xlsx,” file provided by L Slabbert (Customer) to N Brammer (DNV), 12 April 2022.

[7] GE Renewable Energy, “Technical Documentation - Wind Turbine Generator Systems - Cypress 158 - 50/60Hz - Technical Description and Data,” Report Rev. 08 - Doc-0075288 - EN, 19 November 2021.

[8] “220-0052-00 PY WTG-Coordinates_Tract Update 13-07-2022.xlsx,” file provided by D Stotyn (Customer) to N Brammer (DNV), 22 April 2022.

[9] Email from L Slabbert (Customer) to N Brammer (DNV), 28 August 2023.

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

[11] “Update of UK Shadow Flicker Evidence Base,” Parsons Brinckerhoff, UK, 2011.

[12] Bureau of Meteorology, “Climate statistics for Australian locations - Taralga Post Office,” [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_070080_All.shtml. [Accessed 14 April 2022].

[13] Bureau of Meteorology, “Climate statistics for Australian locations - Oberon (Albion St),” [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_063063_All.shtml. [Accessed 14 April 2022].

[14] Bureau of Meteorology, “Climate statistics for Australian locations - Goulburn TAFE,” [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_070263_All.shtml. [Accessed 14 April 2022].

[15] Bureau of Meteorology, “Climate statistics for Australian locations - Katoomba (Farnells Rd),” [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_063039_All.shtml. [Accessed 14 April 2022].

[16] European Centre for Medium-Range Weather Forecasts (ECMWF), “ERA5,” [Online]. Available: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5. [Accessed 15 April 2022].

Table 1 Proposed turbine layout for the Project site

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]	Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
PY-1	750791	6214083	890	PY-25	753741	6217699	1004
PY-2	751181	6214433	902	PY-26	753904	6218069	1007
PY-3	751425	6214787	922	PY-27	753741	6219320	993
PY-4	751942	6215115	946	PY-28	754162	6219612	1005
PY-5	747801	6214761	892	PY-29	754331	6220009	980
PY-6	748520	6214803	861	PY-30	754518	6220470	981
PY-7	749055	6215129	872	PY-31	754970	6220320	964
PY-8	749638	6214879	869	PY-32	755527	6220446	991
PY-9	750046	6215203	874	PY-33	755988	6220403	1038
PY-10	750521	6215025	912	PY-34	756386	6220593	1050
PY-11	750915	6215238	915	PY-35	757375	6217237	1028
PY-12	751277	6215444	931	PY-36	756992	6217538	1031
PY-13	751743	6215430	944	PY-37	756711	6217870	1035
PY-14	751924	6215913	974	PY-38	757117	6217957	1048
PY-15	752167	6216399	975	PY-39	757375	6218321	1032
PY-16	752655	6216325	984	PY-40	757656	6218768	1019
PY-17	752852	6216863	972	PY-41	757360	6219305	985
PY-18	751295	6216935	938	PY-42	758118	6219898	996
PY-19	751592	6217222	957	PY-43	758168	6220297	1022
PY-20	751942	6217474	976	PY-44	758672	6219951	944
PY-21	751953	6218025	970	PY-45	758948	6220374	1027
PY-22	752264	6217765	994	PY-46	759907	6221290	972
PY-23	753090	6218124	996	PY-47	759979	6221614	983
PY-24	753402	6218432	989				

1. Coordinate system: MGA zone 55, GDA94 datum.

Table 2 Shadow receptor locations (up to approx. 2.5 km from PYWF turbine locations)

Receptor ID	Easting[1] [m]	Northing[1] [m]	Landowner status	Distance to nearest turbine [m] (nearest turbine ID)
3	758075	6222553	Not-Involved	2124 (PY-47)
4	757579	6222366	Not-Involved	2137 (PY-34)
6	758737	6221235	Involved	886 (PY-45)
6A	759167	6220887	Involved	558 (PY-45)
7	755747	6219917	Involved	542 (PY-33)
7A	754860	6219774	Involved	557 (PY-31)
8	752734	6217366	Involved	516 (PY-17)
8A	752774	6217698	Involved	515 (PY-22)
9	752472	6215504	Involved	658 (PY-4)
9A	752296	6215591	Involved	492 (PY-14)
9B	752585	6215759	Involved	570 (PY-16)
10	745867	6215676	Not-Involved	2139 (PY-5)
115	761552	6220096	Not-Involved	2032 (PY-46)

1. Coordinate system: MGA zone 55, GDA94 datum.

Table 3 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1580 m
Year of calculation	2034
Minimum elevation of the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere (disc for turbine orientation reduction calculation)
Sun modelled as	Disc
Offset between rotor and tower	None
Receptor height (single storey)	2 m
Receptor height (double storey)	6 m
Locations used for determining maximum shadow flicker within 50 m of each dwelling	8 points evenly spaced (every 45°) on 25 m and 50 m radius circles centred on the provided house location

Table 4 Theoretical and predicted actual annual duration for high intensity shadow flicker (to 10D distance)

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
3 [4]	Non-Involved	758075	6222553	PY-47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Involved	758737	6221235	PY-46 PY-47	26.1	25.2	**30.1**	29.2	9.3	8.9	**10.7**	**10.3**
6A	Involved	759167	6220887	PY-46	**63.0**	**61.5**	**70.5**	**69.0**	**19.3**	**18.8**	**21.2**	**20.8**
7	Involved	755747	6219917	PY-29 PY-30 PY-31 PY-33 PY-34	**61.1**	**60.1**	**120.8**	**113.5**	**21.6**	**21.2**	**32.8**	**31.8**
7A	Involved	754860	6219774	PY-27 PY-28 PY-29 PY-33	**205.9**	**208.5**	**233.8**	**236.8**	**72.9**	**73.7**	**80.0**	**80.7**
8	Involved	752734	6217366	PY-18 PY-19 PY-20 PY-21 PY-22 PY-25 PY-26	**253.8**	**251.8**	**275.5**	**274.4**	**81.4**	**80.9**	**88.1**	**87.7**
8A	Involved	752774	6217698	PY-19 PY-20 PY-21 PY-22 PY-23 PY-25 PY-26	**322.9**	**319.8**	**356.4**	**354.1**	**104.5**	**103.6**	**115.3**	**115.0**
9	Involved	752472	6215504	PY-11 PY-12 PY-13 PY-14	**162.1**	**163.7**	**185.8**	**186.6**	**52.0**	**52.7**	**60.0**	**60.2**
9A	Involved	752296	6215591	PY-11 PY-12 PY-13 PY-14	**276.6**	**281.1**	**284.9**	**293.1**	**93.2**	**95.1**	**95.2**	**96.6**
9B	Involved	752585	6215759	PY-12 PY-13 PY-14	**109.4**	**109.9**	**122.1**	**123.2**	**38.9**	**39.3**	**44.8**	**45.0**
10 [4]	Non-Involved	745867	6215676	PY-5	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 no theoretical shadow flicker has been calculated to a distance of 15 times the rotor diameter are excluded from this table.
2. Coordinate system: MGA zone 55, 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 high intensity shadow flicker, but may experience some low intensity shadow flicker.

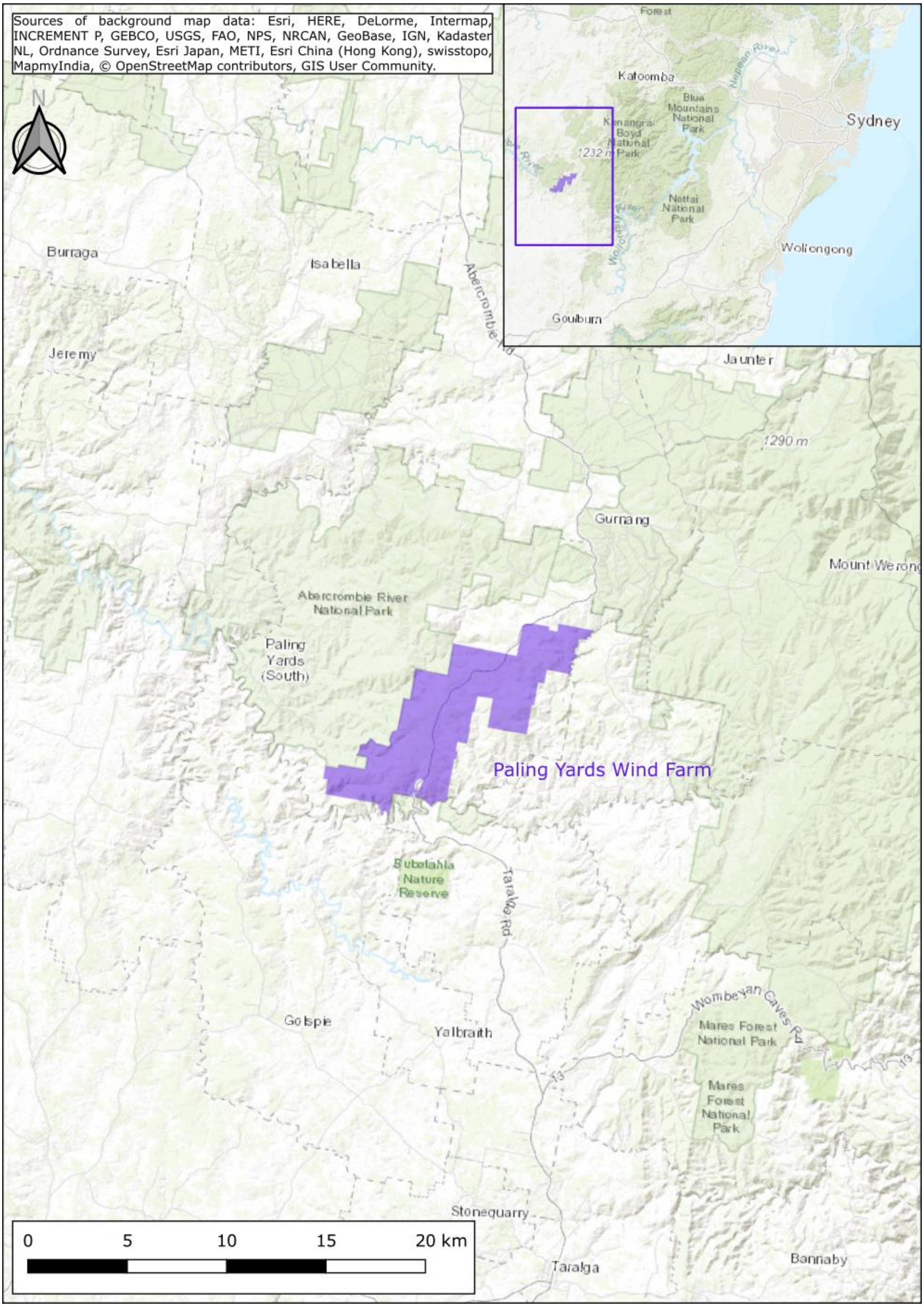


Figure 2   Location of the Project

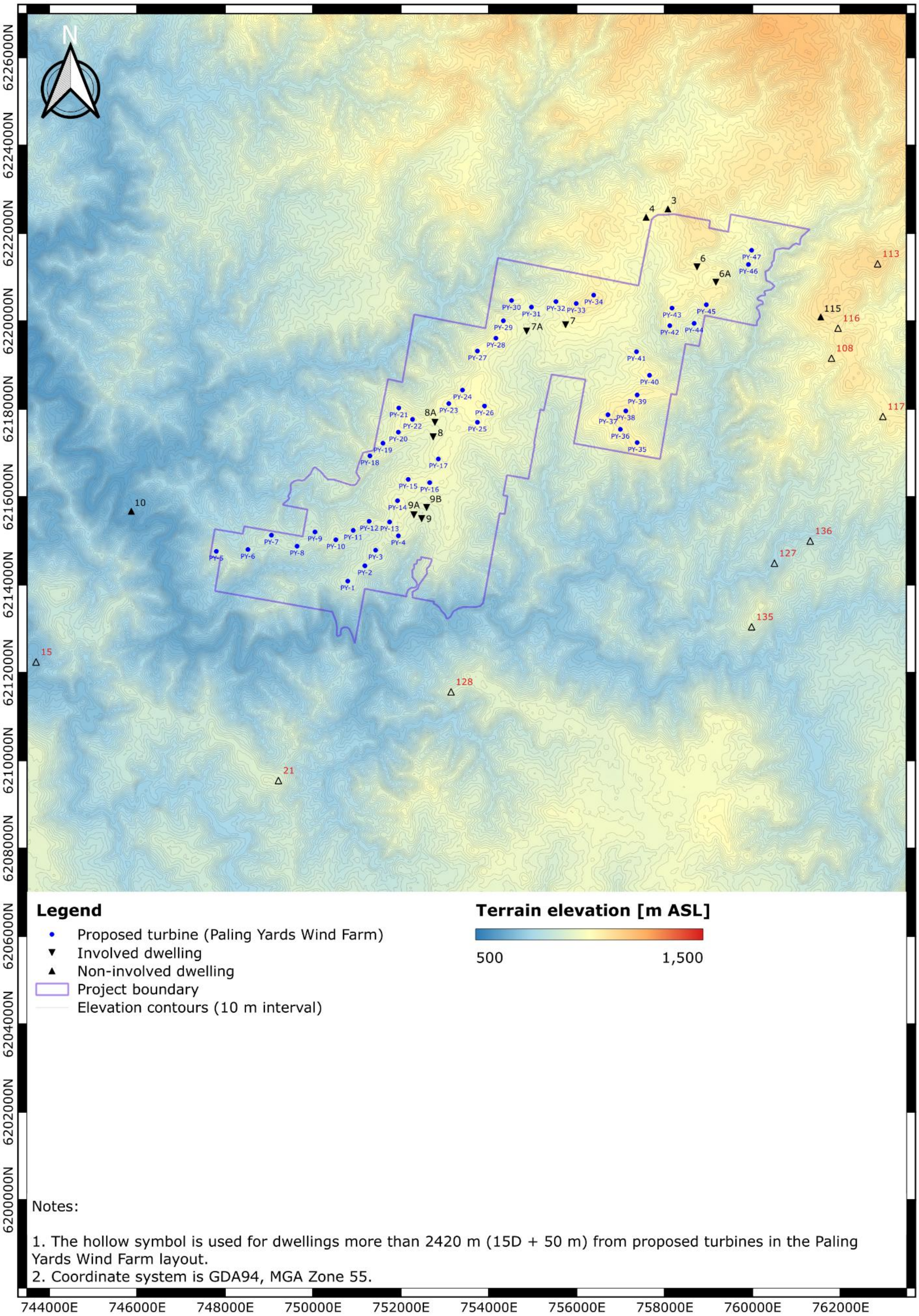


Figure 3 Elevation map of the Project

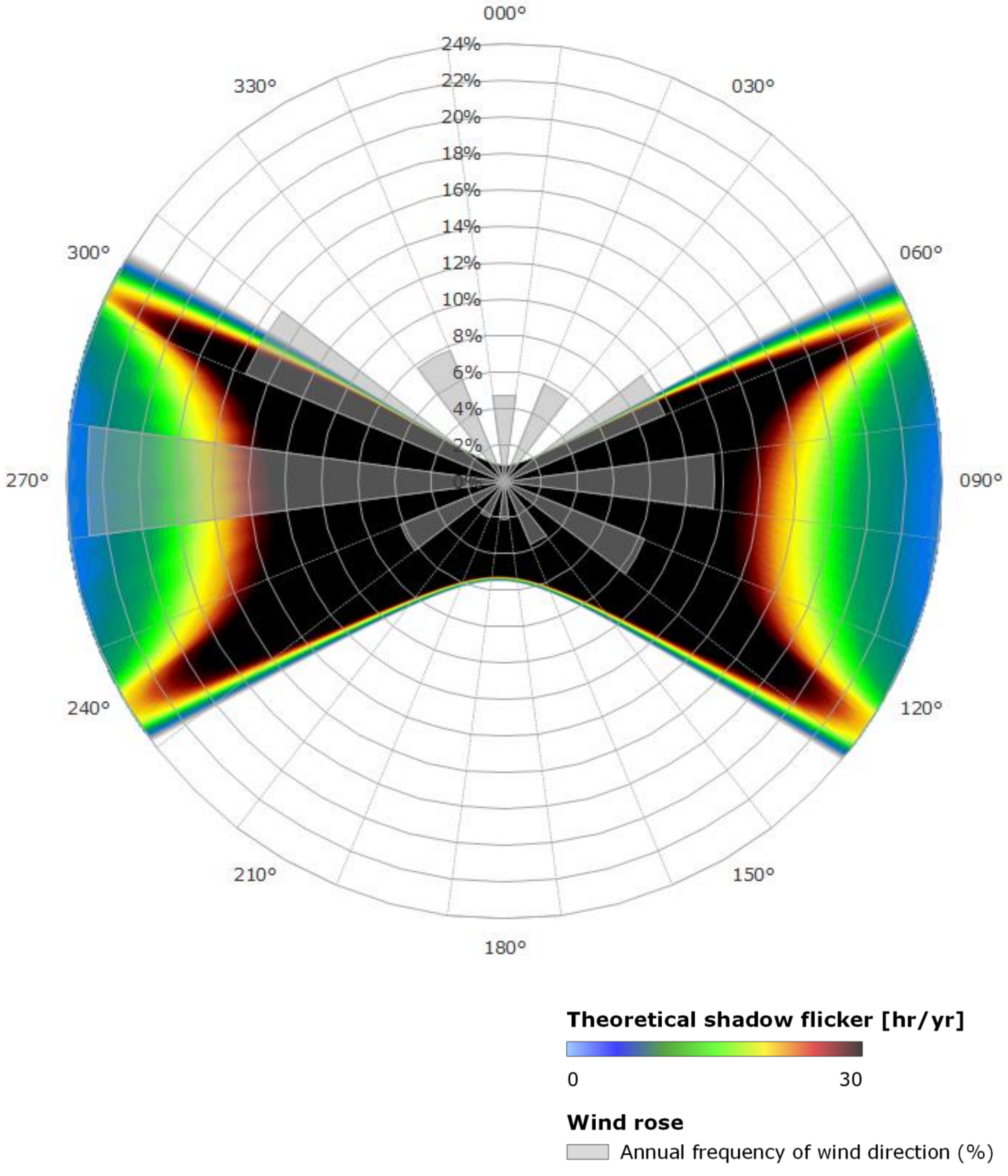


Figure 4 Indicative shadow flicker map and wind direction frequency distribution

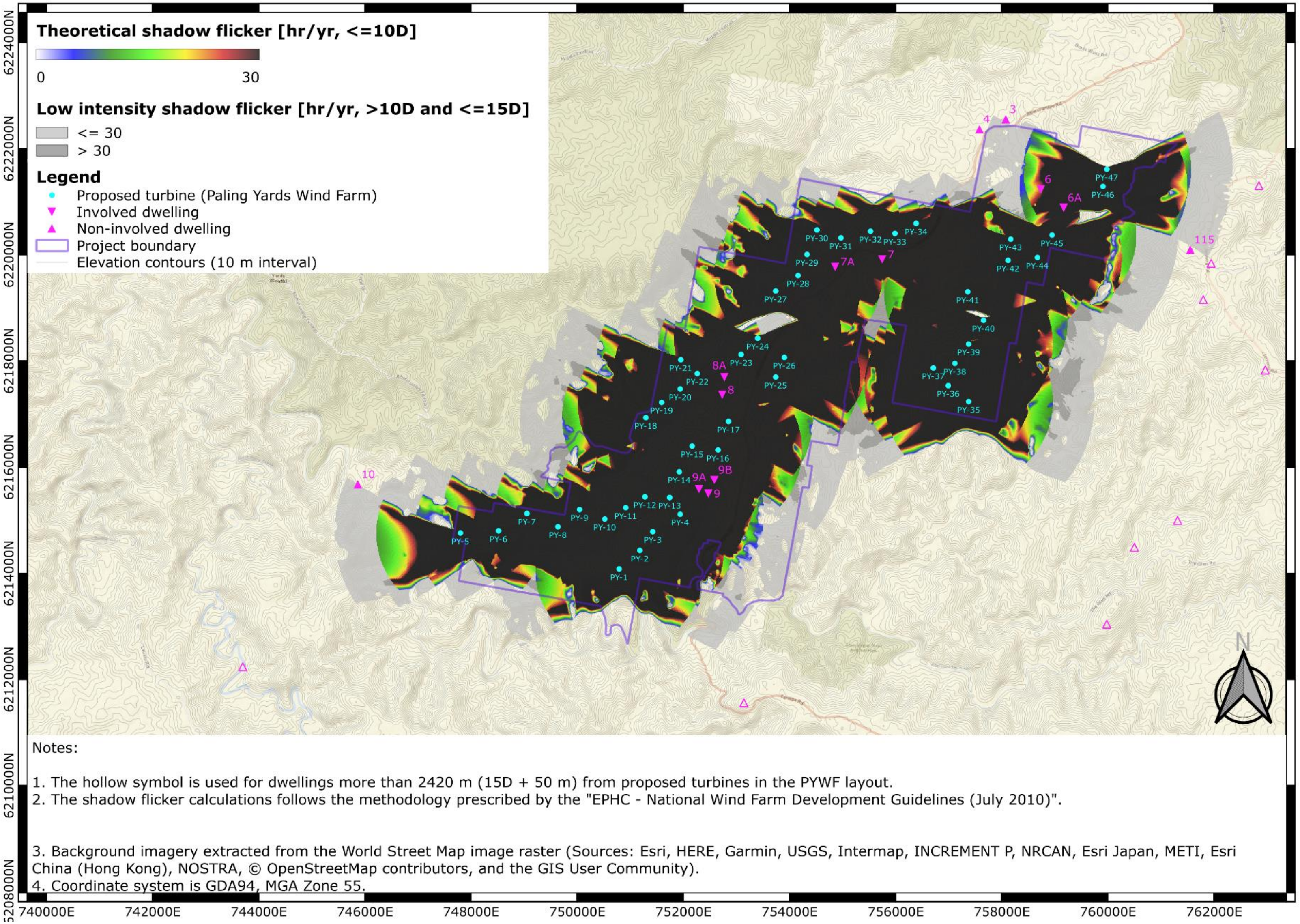
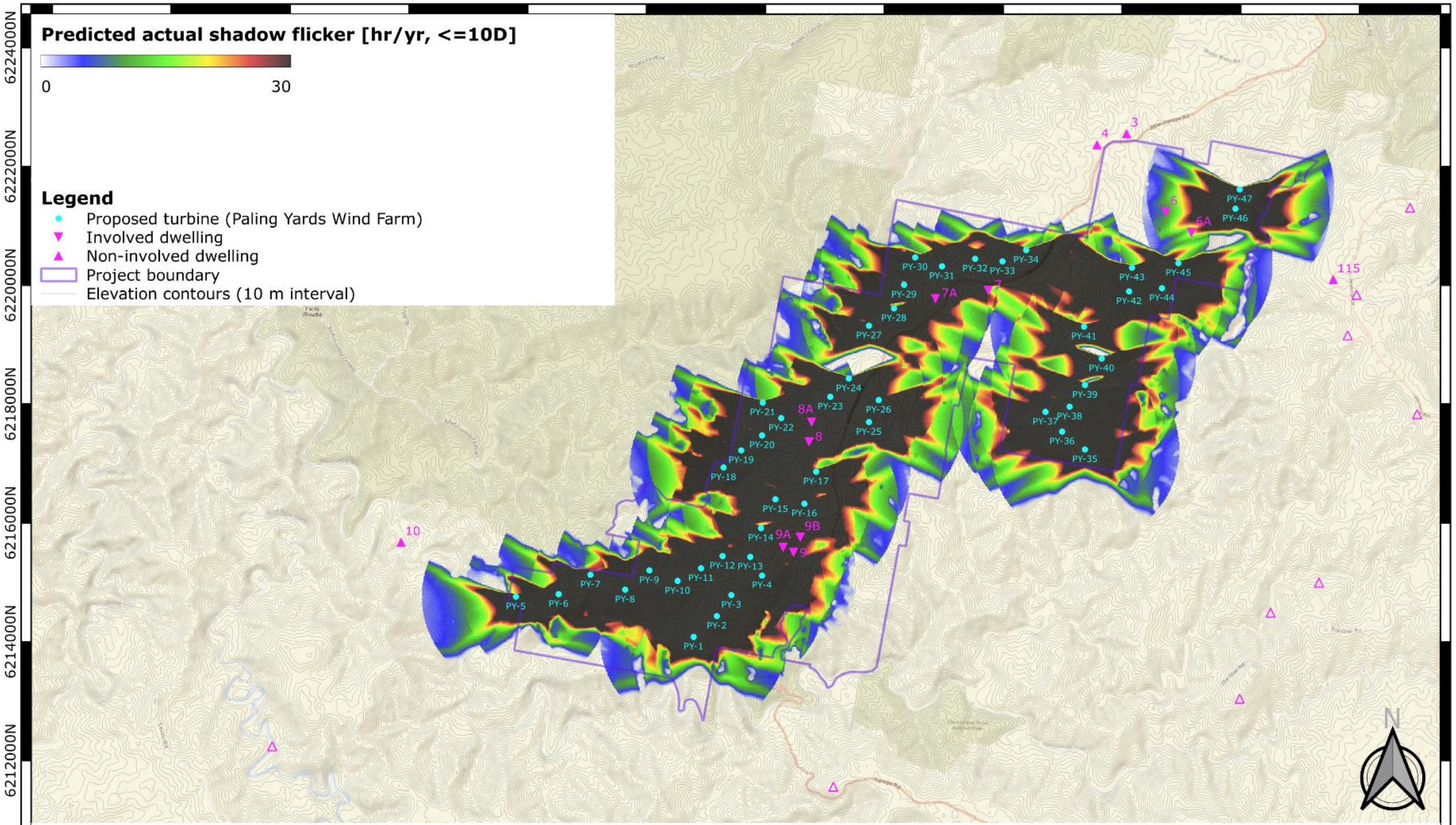


Figure 5 Theoretical annual shadow flicker duration map



Notes:

1. The hollow symbol is used for dwellings more than 2420 m (15D + 50 m) from proposed turbines in the PYWF layout.
2. The shadow flicker calculations follows the methodology prescribed by the "EPHC - National Wind Farm Development Guidelines (July 2010)".
3. The predicted actual shadow flicker duration considers reduction derived from cloud coverage, obtained from surrounding Bureau of Meteorology stations, and rotor orientation, defined by the site monitoring masts wind direction distribution.
4. Background imagery extracted from the World Street Map image raster (Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCAN, Esri Japan, METI, Esri China (Hong Kong), NOSTRA, © OpenStreetMap contributors, and the GIS User Community).
5. Coordinate system is GDA94, MGA Zone 55.

Figure 6 Predicted actual annual shadow flicker duration map

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.

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