WATTA WELLA RENEWABLE ENERGY PROJECT

Shadow Flicker Assessment

Umwelt (Australia) Pty Ltd

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Umwelt Subconsultant Terms of Engagement between Umwelt (Australia) Pty Ltd and DNV Australia Pty Ltd, dated 11 April 2023

Objective: Watta Wella Renewable Energy Project Shadow Flicker Assessment

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EXECUTIVE SUMMARY

DNV has been commissioned by Umwelt (Australia) Pty Ltd ("Umwelt" or "the Customer") on behalf of RES Australia Pty Ltd ("RES" or "the Proponent") to independently assess the expected annual shadow flicker durations associated with the development and operation of the wind farm component of the proposed Watta Wella Renewable Energy Project ("WWREP" or "the Project"). The Project is located approximately 16 km northeast of Stawell and 30 km north of Ararat on land with an area of approximately 4,850 hectares (the "Project Area"). The results of the 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 Victorian Planning Guidelines [1] and Draft National Wind Farm Development Guidelines [2] (Draft National Guidelines). The methodology used in this study has been informed by these guidelines and various standard industry practices.

The Victorian Planning Guidelines require that shadow in the area immediately surrounding a dwelling must not exceed the limit of 30 hours per year. In addition, the Draft National Guidelines recommend limits of 30 hours per year on the theoretical shadow flicker duration, and 10 hours per year on the actual shadow flicker duration.

A Project layout consisting of 45 wind turbines with a rotor diameter of 178 m and a hub height of 166 m, giving a tip height of 255 m above ground level (AGL), has been considered. These dimensions represent the maximum overall tip height for the maximum rotor and tower hub height dimensions considered for the Project.

There are 76 dwellings that have been identified within 5 km of the Project Area, 9 of which are involved dwellings belonging to wind farm host landowners.

Outcomes of the assessment

The results of the shadow flicker assessment are summarised in Table 6, which is located at the end of this document.

Based on DNV's modelling, seven dwellings are expected to experience some shadow flicker above a moderate level of intensity (meaning shadow flicker at a level of intensity that is likely to cause annoyance for most people), which for the purposes of this assessment is assumed to occur up to a distance of 10 times the rotor diameter from the wind turbines. All discussions of shadow flicker in this report, except when explicitly stated, refers to shadow flicker above a moderate level of intensity. Three of the dwellings are involved dwellings and four are non-involved dwellings.

Out of the seven dwellings predicted to experience shadow flicker, one is predicted to experience theoretical shadow flicker durations above the Draft National Guidelines recommended limit of 30 hours per year within 50 m of the dwelling (involved dwelling 2). The theoretical shadow flicker durations at dwelling 2 exceed the recommended limit by more than 30 hours per year. When considering the likely reduction in shadow flicker due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of dwelling 2 remain above the Draft National Guidelines recommended limit of 10 hours per year.

The calculation of the predicted actual shadow flicker duration does not take into account other potential reductions due to low wind speed, vegetation, or other shielding effects around each dwelling.

Considering the above results, some form of mitigation is likely to be required to manage the shadow flicker impacts at dwelling 2 where the shadow flicker limits are exceeded.

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. Shadow flicker exceedances can also be managed through establishing agreements with potentially affected landholders. The proponent has advised that the turbines predicted to cause shadow flicker at dwelling 2 are located on the landowner’s property [3].

A cumulative shadow flicker assessment was also carried out for the Project considering the combined impacts of WWREP and Bulgana Wind Farm turbines which are in close proximity to the south of the Project. When considering shadow flicker above a moderate level of intensity, it was found that no dwellings were impacted from the WWREP and Bulgana turbines acting cumulatively.

Blade glint is not expected to be an issue for the Project provided a non-reflective finish is applied to the wind turbine blades.

1 INTRODUCTION

Umwelt (Australia) Pty Ltd ("Umwelt" or "the Customer") on behalf of RES Australia Pty Ltd ("RES" or "the Proponent") has commissioned DNV to independently assess the expected annual shadow flicker durations involved with the proposed Watta Wella Renewable Energy Project ("WWREP" or "the Project") in western Victoria. The results of this work are reported here.

This assessment evaluates the shadow flicker durations in the vicinity of the Project for the current proposed turbine layout and configuration in accordance with the Planning Guidelines for Development of Wind Energy Facilities (Victorian Planning Guidelines) prepared by the Victorian Government Department of Transport and Planning in September 2023 [1], and the National Wind Farm Development Guidelines – Draft (Draft National Guidelines) prepared by the Environment Protection and Heritage Council (EPHC) in July 2010 [2].

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The Project Area

The Project is located in the Northern Grampians Shire Council local government area in western Victoria, approximately 16 km northeast of Stawell and 30 km north of Ararat on land with an area of approximately 4,850 hectares (the "Project Area"). An overview of the Project Area is presented in Figure 1. The Project Area is characterised by open farmland on gently undulating terrain, interspersed with wind breaks and some areas of trees. The Joel Joel Nature Conservation Reserve lies in the centre of the site and the Wimmera River lies to the east.

High resolution digital elevation data was supplied for the Project Area by the Proponent [4], which was included in the site model. Areas outside of this map region were covered using publicly available SRTM-1 data [5].

2.2 Proposed wind farm layout

The Project is proposed to consist of 45 wind turbines [6]. A map of the Project Area with the proposed turbine layout is shown in Figure 2, and the coordinates of the proposed turbine locations are presented in Table 3.

The Project was modelled assuming turbines with a rotor diameter of 178 m and a hub height of 166 m, for a total tip height of 255 m AGL, based on data supplied by the Customer [7]. DNV understands that these dimensions represent the maximum overall tip height for the maximum rotor and tower hub height dimensions considered for the Project.

2.3 Dwelling locations

The locations of dwellings in the vicinity of the Project Area have been provided by the Customer [8, 9]. There are 76 dwellings located within 5 km of the Project Area boundaries, 9 of which belong to landowners who are involved with the Project.

For the purposes of this assessment, DNV has considered all identified dwellings up to 2720 m from Project turbines (which corresponds to 15 times the rotor diameter, or 15D, plus 50 m). Dwellings situated more than 2720 m from turbine locations are considered unlikely to be impacted by shadow flicker, as discussed further in Sections 3.1 and 4.1. The coordinates of the dwellings included in the assessment are presented in Table 4, and also presented in Figure 2. DNV has assumed that all listed dwellings are inhabited.

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

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

The Victorian Planning Guidelines [1] currently state:

> *"The shadow flicker experienced immediately surrounding the area of a dwelling (garden-fenced area) must not exceed 30 hours per year as a result of the operation of the wind energy facility."*

In addition, the Draft National Guidelines [2] include recommendations for shadow flicker limits relevant to wind farms in Australia.

The Draft National Guidelines recommend that the modelled theoretical shadow flicker duration should not exceed 30 hours per year, and that the actual or measured shadow flicker duration should not exceed 10 hours per year. The guidelines also recommend that the shadow flicker duration at a dwelling be assessed by calculating the maximum shadow flicker occurring within 50 m of the centre of a dwelling.

As details of the 'garden fenced area' for a dwelling are not readily available, DNV assumes that the evaluation of the maximum shadow flicker duration within 50 m of a dwelling (as required by the Draft National Guidelines) is similar to assessing shadow flicker durations within the 'garden fenced area'. In most cases this approach is expected to be adequate, however it is acknowledged that, in rural areas, the 'garden fenced area' may extend beyond 50 m from a dwelling.

These limits are assumed to apply to a single dwelling, and it is noted that there is no requirement under either the Victorian Planning Guidelines or the Draft National Guidelines to assess shadow flicker durations at locations other than in the vicinity of dwellings.

The Draft National Guidelines also provide background information, a proposed methodology, and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm.

The impact of shadow flicker is typically only significant up to a distance of around 10 rotor diameters from a turbine [10] or approximately 1200 m to 1700 m for modern wind turbines (which typically have rotor diameters of 120 m to 170 m). Shadow flicker may still be experienced beyond this distance although the shadow will be diffused such that the variation in light levels is not likely to be significant. 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 term "shadow flicker above a moderate level of intensity" is used in the Draft National Guidelines and in this report to refer to shadow flicker at a level of intensity that is likely to cause annoyance for most people, although it is acknowledged that this is subjective and can vary from person to person.

The shadow flicker duration limits in the Draft National Guidelines are intended to apply only to shadow flicker above a moderate level of intensity. Therefore, when calculating shadow flicker durations, only those occurrences meeting or exceeding this intensity threshold should be considered. To help define this threshold spatially, the Draft National Guidelines suggest a distance equivalent to 265 times the maximum blade chord as an appropriate limit, which corresponds to approximately 1000 m to 1600 m for modern wind turbines (which typically have maximum blade chord lengths of 4 m to 6 m). All discussions of shadow flicker in this report, except when explicitly stated, refers to shadow flicker above a moderate level of intensity.

3.2 Blade glint

The Draft National Guidelines [2] 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."*

The Victorian Guidelines [1] provide the requirement that:

> *"Blade glint can result from the sun reflecting from turbine blades.*
>
> *Blades should be finished with a surface treatment of low reflectivity to minimise glint."*

4 ASSESSMENT METHODOLOGY

4.1 Shadow flicker

4.1.1 Overview

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

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

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

4.1.2 Theoretical modelled duration

The theoretical number of hours of shadow flicker experienced annually at a given location can be calculated using a geometrical model which incorporates the sun path, topographic variation over the Project 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 dwelling locations and has determined the highest shadow flicker duration within 50 m of each of the provided dwelling location.

Shadow flicker has been calculated at dwellings at heights of 2 m, to represent ground floor windows, and 6 m, to represent second floor windows. The shadow receptors are simulated as fixed points, representing the worst-case scenario, as real windows could be facing a particular direction less affected by shadows cast from the turbines. The shadow flicker calculations for dwelling locations have been carried out with a temporal resolution of 1 minute. The shadow flicker map was generated using a temporal resolution of 5 minutes and a spatial resolution of 10 m to reduce computational requirements to acceptable levels.

As part of the shadow flicker assessment, it is necessary to make an assumption regarding the maximum length of a shadow cast by a wind turbine that is likely to cause annoyance due to shadow flicker. The UK wind industry considers that 10 rotor diameters is appropriate [10], while the Draft National Guidelines suggest a distance equivalent to 265 times the maximum blade chord as an appropriate limit.

For the current assessment, DNV has applied a maximum shadow length of 10 times the rotor diameter (10D), which corresponds to a distance limit of 1780 m. Under the Draft National Guidelines, this may be conservative for any turbine with a maximum blade chord of less than 6.7 m. Beyond this distance limit, it is assumed that any shadow flicker experienced will be below a "moderate level of intensity" and unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by shadow flicker intensities below the "moderate level of intensity" assumed by this distance limit. To account for this possibility, DNV has also assessed the shadow flicker for an increased distance limit of 15 times the rotor diameter (15D), or 2670 m, which should include shadow flicker below a "moderate level of intensity".

The model also makes the following assumptions and simplifications:

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

The first two of these items are addressed in the calculation of the predicted actual shadow flicker duration as described in Section 4.1.4. The third item is not considered but is unlikely to have a significant impact on the results. The settings used to execute the model can be seen in Table 5.

To illustrate typical results, an indicative shadow flicker map for a turbine located in a flat area is shown in Figure 3. The geometry of the shadow flicker map can be characterised as a butterfly shape, with the four protruding lobes corresponding to slowing of solar north-south travel around the summer and winter solstices for morning and evening. The lobes to the north of the indicative turbine location result from the summer months and conversely the lobes to the south result from the winter months. The lobes to the west result from morning sun while the lobes to the east result from evening sun. When the sun is low in the sky, the length of shadows cast by the turbine increases, increasing the area around the turbine affected by shadow flicker.

4.1.3 Factors affecting duration

Shadow flicker duration calculated in this manner overestimates the annual number of hours of shadow flicker experienced at a specified location for several reasons, including:

1. The wind turbine will not always be oriented such that its rotor is in the worst-case position (i.e., perpendicular to the sun-turbine vector). Any other rotor orientation will reduce the area of the projected shadow and hence the shadow flicker duration.

   The wind speed frequency distribution or wind rose at the Project Area 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 Bureau of Meteorology stations summarised in Table 1.

Table 1 Sources of cloud data used in the assessment

Weather station	Station ID	Distance to Project Area [approx. km]
Stawell [11]	079080	15.6
Ararat Prison [12]	089085	29.6
Maryborough [13]	088043	69.2
Ballarat Aerodrome [14]	089002	92.6

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 43% and 71%, and the average annual cloud cover is approximately 60%. This means that on an average day, 60% of the sky in the vicinity of the wind farm is covered with clouds. Although it is not possible to definitively calculate the effect of cloud cover on shadow flicker duration, a reduction in the shadow flicker duration proportional to the amount of cloud cover is a reasonable assumption.

Similarly, turbine orientation can have an impact on the shadow flicker duration. The shadow flicker duration is greatest when the turbine rotor plane is approximately perpendicular to a line joining the sun and an observer, and a minimum when the rotor plane is approximately parallel to a line joining the sun and an observer. Wind direction frequency distributions for the Project were derived from wind measurements at the Project Area, which were provided by the Proponent [15] and used to estimate the reduction in shadow flicker duration due to rotor orientation. The measured wind rose is shown overlaid on the indicative shadow flicker map in Figure 3. An assessment of the likely reduction in shadow flicker duration due to variation in turbine orientation was conducted on an annual basis.

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

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in calculating the shadow flicker duration. Similarly, turbine shutdown has not been considered.

4.1.5 Cumulative impact assessment

DNV notes that the Project Area is located in an area of high wind farm development activity, with multiple operational wind farms nearby. Consequently, it is possible that some dwellings near the Project Area could experience cumulative impacts from neighbouring wind farms.

The nearest wind farm development to the Project Area is summarised in Table 2 below, based on information provided by the Proponent [16] and publicly available sources [17] [18] [19].

Table 2 Other wind farm developments located in the vicinity of the Project Area

Wind farm	Status	Location
Bulgana Wind Farm	Operating	Adjacent to the WWREP southern boundary (with the nearest Bulgana turbine < 1000 m from WWREP turbines)

At typical distances from the Project Area that shadow flicker could potentially be an issue, turbines from the Bulgana Wind Farm are close enough to potentially cause cumulative shadow flicker impacts in combination with WWREP turbines at nearby dwellings. The Bulgana turbines nearest to the Project Area are shown in Figure 2. Based on publicly available sources of data, it is understood that the Bulgana turbines consist of Siemens Gamesa SG 3.4-132 turbines with a rotor diameter of 132 m [20] and hub height of 114 m [21], giving a tip height of 180 m AGL.

For the purposes of this assessment, if it is conservatively assumed that Bulgana turbines generate shadow flicker at similar distances to WWREP turbines (up to the 10D and 15D distance limits), up to two dwellings could potentially be affected by cumulative shadow flicker (dwellings 8 and 44). The shadow flicker areas which could potentially lead to cumulative impacts are shown in Figure 6.

Neither of these dwellings will be affected by shadow flicker generated from turbines at both wind farms if only shadow flicker above a moderate levels of intensity is considered. However these dwellings could potentially be subject to shadow flicker from both wind farms if shadow flicker above *and* below a moderate level of intensity is considered, depending on the distance of each dwelling from specific WWREP and Bulgana turbines.

The potential for cumulative impacts have been assessed using distance thresholds of up to 1780 m (i.e., 10 times the rotor diameter of WWREP turbines, plus 50 m) from all WWREP and Bulgana turbines when considering shadow flicker above a moderate level of intensity only, and up to 2720 m (i.e. 15 times the rotor diameter of WWREP turbines, plus 50 m) when considering shadow flicker above and below a moderate level of intensity.

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 Considering WWREP turbines only

Shadow flicker assessments were carried out at the dwelling locations, as outlined in Table 4.

The theoretical and predicted actual shadow flicker durations at all dwelling locations identified to be affected by shadow flicker considering WWREP turbines only are presented in Table 6. The maximum shadow flicker durations within 50 m of the dwellings are also presented in this table. Furthermore, the results are shown in the form of shadow flicker maps in Figure 4 and Figure 5. The shadow flicker values presented in these maps represent the maximum between the results at 2 m and 6 m above ground for each modelled grid point.

Based on DNV's modelling of up to a distance of around 10 rotor diameters from the wind turbines, seven dwellings are expected to experience some shadow flicker, within 50 m of the dwelling. Of these seven dwellings, two are involved dwellings.

Out of the seven dwellings predicted to experience shadow flicker, one is predicted to experience shadow flicker durations above the recommended limit of 30 hours per year (involved dwelling 2). The theoretical shadow flicker durations at dwelling 2 exceed the recommended limit by more than 30 hours per year. When considering the likely reduction in shadow flicker due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of dwelling 2 remain above the recommended limit of 10 hours per year.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be below a "moderate level of intensity" and unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by shadow flicker intensities below the intensity assumed by this distance limit. To account for this possibility, and although not part of the methodology outlined in the Draft National Guidelines, DNV has also assessed the shadow flicker impacts for the Project for an increased distance limit that is intended to include shadow flicker below a "moderate level of intensity". For the purpose of this assessment, the distance limit has been increased by 50% (to 15D), and the results of this additional assessment are illustrated in the map presented in Figure 4. These results indicate that 15 dwellings have the potential to be exposed to shadow flicker below a "moderate level of intensity", in addition to the seven dwellings above which have been predicted to experience shadow flicker above a moderate level of intensity. These dwellings are noted in Table 6.

At all the assessed dwelling locations, the turbine configuration parameters (namely maximum hub height and rotor diameter) used in the modelling will generally be representative of a "conservative case" scenario for the wind farm, based on the turbine options that DNV understands the Proponent is considering for the wind farm.

If a turbine with smaller rotor dimensions is selected but the hub height is unchanged, the shadow flicker durations will reduce from the reported results.

5.1.2 Cumulative impact assessment

A cumulative shadow flicker impact assessment was carried out for potential shadow flicker from WWREP and Bulgana Wind Farm (BWF), where two dwelling locations (dwellings 8 and 44) were identified as potential candidates for cumulative shadow flicker based on turbine distances.

The theoretical and predicted actual cumulative shadow flicker durations at the affected dwelling locations, are presented in Table 7. The maximum shadow flicker durations within 50 m of the dwellings are also presented in this table.

Based on these results:

- Dwelling 8 is not predicted to experience shadow flicker from WWREP or BWF turbines, but may experience some shadow flicker below a moderate level of intensity from the BWF turbines.
- Dwelling 44 is not predicted to experience shadow flicker from WWREP turbines, but may experience some shadow flicker from BWF turbines.

Therefore, when considering shadow flicker above a moderate level of intensity, it was found that there were no dwellings where the shadow flicker impacts from the WWREP and BWF turbines were acting cumulatively.

5.1.3 Mitigation

Considering the above results, some form of mitigation is likely to be required to manage the shadow flicker impacts at affected neighbouring dwellings where the shadow flicker limits are exceeded.

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 (rotor) 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.

Another option to manage shadow flicker restrictions is for the Proponent to establish agreements with the landowners of dwellings where shadow flicker is predicted to occur above the recommended limits which include an agreed acceptable shadow flicker duration. Such agreements can be used to manage the acceptable shadow flicker durations at these locations. It is also recommended that as part of this process the landowners are made aware of the shadow flicker durations that may be experienced at their dwellings without mitigation. The Proponent has advised that the turbines predicted to cause shadow flicker at dwelling 2 are located on the landowner’s property [3].

5.2 Blade glint

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

6 CONCLUSIONS

A shadow flicker assessment was carried out at all dwelling locations in the vicinity of the Project Area. For the purpose of this assessment, DNV has considered a layout consisting of 45 turbines with a rotor diameter of 178 m and hub height of 166 m for a total tip height of 255 m AGL. The results of the shadow flicker assessment based on this layout configuration are summarised in Table 6.

Based on DNV's modelling, seven dwellings are expected to experience some shadow flicker (meaning shadow flicker at a level of intensity that is likely to cause annoyance for most people), which for the purposes of this assessment is assumed to occur up to a distance of 10 times the rotor diameter from the wind turbines. Of these, three are involved dwellings and four are non-involved dwellings.

Out of the seven dwellings predicted to experience shadow flicker, one is predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling (involved dwelling 2). The theoretical shadow flicker durations at dwelling 2 exceeds the Draft National Guidelines recommended limits by more than 30 hours per year. When considering the likely reduction in shadow flicker due to cloud cover and rotor orientation, the predicted actual shadow flicker durations within 50 m of dwelling 2 remain above the recommended limit of 10 hours per year.

The calculation of the predicted actual shadow flicker duration does not take into account other potential reductions due to low wind speed, vegetation, or other shielding effects around each dwelling.

A cumulative shadow flicker assessment was also carried out for the Project considering the combined impacts of WWREP and Bulgana Wind Farm turbines. When considering shadow flicker above a moderate level of intensity, it was found that there were no dwellings where the shadow flicker impacts from the WWREP and Bulgana turbines were acting cumulatively.

Considering the above results, some form of mitigation is likely to be required to manage the shadow flicker impacts at dwelling 2 where the shadow flicker limits are exceeded. The Proponent has advised that the turbines predicted to cause shadow flicker at dwelling 2 are located on the landowner's property [3].

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. Shadow flicker exceedances can also be managed through establishing agreements with potentially affected landholders.

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

7 REFERENCES

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Table 3 Proposed turbine layout for the Project Area [6]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]	Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
T1	675123	5897322	247	T24	674611	5902203	221
T2	674306	5898338	257	T25	670723	5902511	226
T3	674628	5898023	245	T26	673784	5902287	227
T4	675250	5898000	245	T27	672082	5902497	213
T5	675746	5898411	225	T28	670731	5900805	237
T6	674199	5902231	219	T29	673268	5903336	226
T7	672769	5899273	244	T30	673656	5902866	223
T8	673127	5899182	245	T31	674027	5903733	210
T9	671555	5899832	222	T32	671571	5902822	211
T10	671291	5906540	204	T33	672551	5903527	228
T11	670789	5899847	248	T36	672086	5904266	227
T12	671331	5900081	232	T37	673305	5904230	218
T13	670358	5899945	258	T38	672940	5904620	216
T14	670946	5903181	217	T39	672571	5905101	213
T15	672980	5900212	241	T40	671711	5905318	210
T16	677150	5900399	219	T41	670229	5905409	203
T17	677588	5900404	229	T42	672181	5905700	211
T18	678125	5900408	219	T43	669407	5905806	209
T19	669672	5900497	265	T44	669814	5905753	202
T20	670041	5900881	256	T45	671321	5905775	211
T21	671283	5901486	237	T46	670848	5906297	212
T22	674135	5902785	220	T47	670475	5906718	205
T23	669462	5900980	254				

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

Table 4 Dwellings within 2720 m of turbines at the Project Area [9, 8]

Dwelling ID	Easting[1] [m]	Northing[1] [m]	Landowner status	Nearest WWREP turbine Distance [km]	Nearest WWREP turbine Turbine ID
0	*678361*	*5898558*	*Involved*	*1.9*	*T18*
2	*669749*	*5902271*	*Involved*	*1.0*	*T25*
8	676986	5895734	Not involved	2.4	T1
9	678868	5902527	Not involved	2.2	T18
11	668313	5903395	Not involved	2.6	T25
12	676342	5901674	Not involved	1.5	T16
15	677143	5902053	Not involved	1.7	T16
23	677004	5902378	Not involved	2.0	T16
25	679220	5898513	Not involved	2.2	T18
30	675006	5900351	Not involved	1.9	T24
31	676188	5903025	Not involved	1.8	T24
38	*673777*	*5907538*	*Involved*	*2.4*	*T42*
41	668258	5902216	Not involved	1.7	T23
44	670957	5897209	Not involved	2.6	T11
46	*672062*	*5908384*	*Involved*	*2.0*	*T10*
47	*676129*	*5901656*	*Involved*	*1.6*	*T24*
51	668065	5904350	Not involved	2.0	T43
54	*669101*	*5907464*	*Involved*	*1.6*	*T47*
61	667826	5905316	Not involved	1.7	T43
62	667940	5903147	Not involved	2.6	T23
64	668055	5903838	Not involved	2.4	T43
65	668126	5907406	Not involved	2.1	T43
66	668403	5904581	Not involved	1.6	T43
68	668109	5904886	Not involved	1.6	T43
69	668509	5904147	Not involved	1.9	T43
70	667892	5902284	Not involved	2.0	T23
72	668401	5903959	Not involved	2.1	T43
74	667117	5904419	Not involved	2.7	T43
75	667600	5906574	Not involved	2.0	T43
76	*677235*	*5902833*	*Involved*	*2.4*	*T16*

1. Coordinate system: MGA zone 54, GDA94 datum.
2. Involved dwellings are indicated by *underlined italic text*.

Table 5 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1780 m
Year of calculation	2035
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 6 Theoretical and predicted actual annual shadow flicker duration to 10D distance (WWREP turbines only)

Dwelling ID[1]	Easting[2] [m]	Northing[2] [m]	Landowner status	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
0[4]	678361	5898558	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	669749	5902271	Involved	T14 T21 T25	**64.6**	**63.9**	**69.4**	**68.8**	**13.8**	**13.6**	**15.3**	**15.2**
11[4]	668313	5903395	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	676342	5901674	Not involved	T24	0.0	0.0	11.4	11.1	0.0	0.0	2.4	2.3
15[4]	677143	5902053	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23[4]	677004	5902378	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30[4]	675006	5900351	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	676188	5903025	Not involved	T24	3.6	3.9	11.4	11.5	0.4	0.4	2.4	2.4
38[4]	673777	5907538	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41[4]	668258	5902216	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	676129	5901656	Involved	T24	14.1	14.0	15.4	15.2	3.0	3.0	3.2	3.2
51[4]	668065	5904350	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	669101	5907464	Involved	T47	12.6	12.7	22.5	22.4	2.8	2.9	6.4	6.5
61	667826	5905316	Not involved	T43	11.7	11.6	12.9	12.6	2.3	2.3	2.5	2.5
65[4]	668126	5907406	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
66[4]	668403	5904581	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
68	668109	5904886	Not involved	T43	18.9	18.1	27.5	26.8	3.1	2.9	4.9	4.8
69[4]	668509	5904147	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
72[4]	668401	5903959	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
74[4]	667117	5904419	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
75[4]	667600	5906574	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76[4]	677235	5902833	Involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Recommended duration limits (hr/yr)					***30***	***30***	***30***	***30***	***10***	***10***	***10***	***10***

1. Dwellings identified in Table 4 for which there is no theoretical shadow flicker occurrence up to a distance limit of 15 times the rotor diameter have been omitted from this table.
2. Coordinate system: MGA zone 54, GDA94 datum.
3. Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.
4. Dwelling is not predicted to experience any shadow flicker above a moderate level of intensity, but may experience some shadow flicker below a moderate level of intensity.

Table 7 Theoretical and predicted actual annual shadow flicker duration to 10D distance (cumulative impacts)

Dwelling ID	Easting[1] [m]	Northing[1] [m]	Landowner status	Contributing turbines	Theoretical annual: At dwelling [hr/yr] 2 m	Theoretical annual: At dwelling [hr/yr] 6 m	Theoretical annual: Max within 50 m [hr/yr] 2 m	Theoretical annual: Max within 50 m [hr/yr] 6 m	Predicted actual annual[2]: At dwelling [hr/yr] 2 m	Predicted actual annual[2]: At dwelling [hr/yr] 6 m	Predicted actual annual[2]: Max within 50 m [hr/yr] 2 m	Predicted actual annual[2]: Max within 50 m [hr/yr] 6 m
8[3]	676986	5895734	Not involved	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44[3]	670957	5897209	Not involved	BU01 BU02	13.6	13.1	15.2	14.6	3.3	3.1	3.6	3.5
Recommended duration limits (hr/yr)					***30***	***30***	***30***	***30***	***10***	***10***	***10***	***10***

1. Coordinate system: MGA zone 54, GDA94 datum.
2. Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.
3. Dwelling is not predicted to experience shadow flicker above or below a moderate level of intensity from WWREP turbines, but may experience some shadow flicker above a moderate level of intensity from Bulgana turbines.

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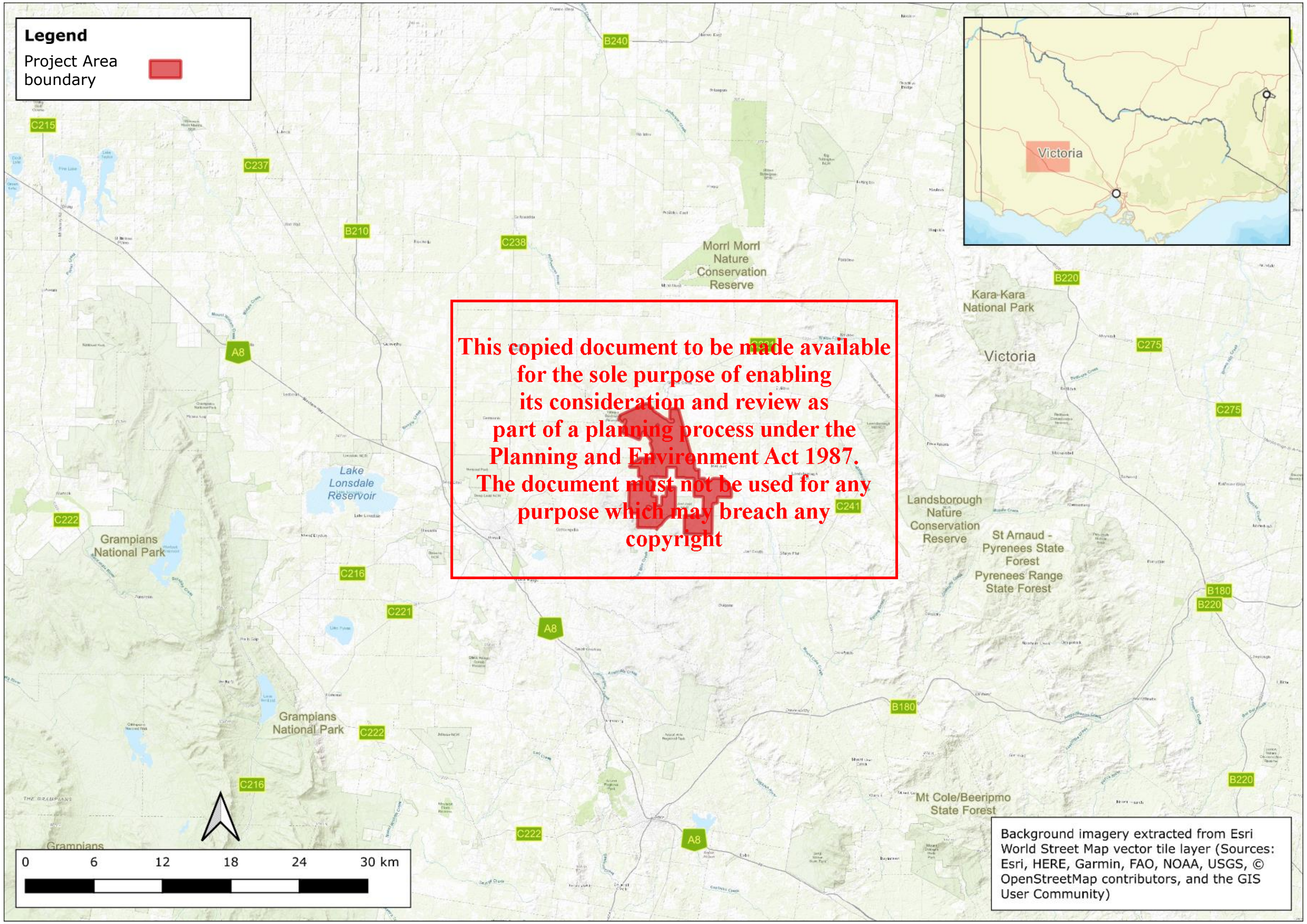
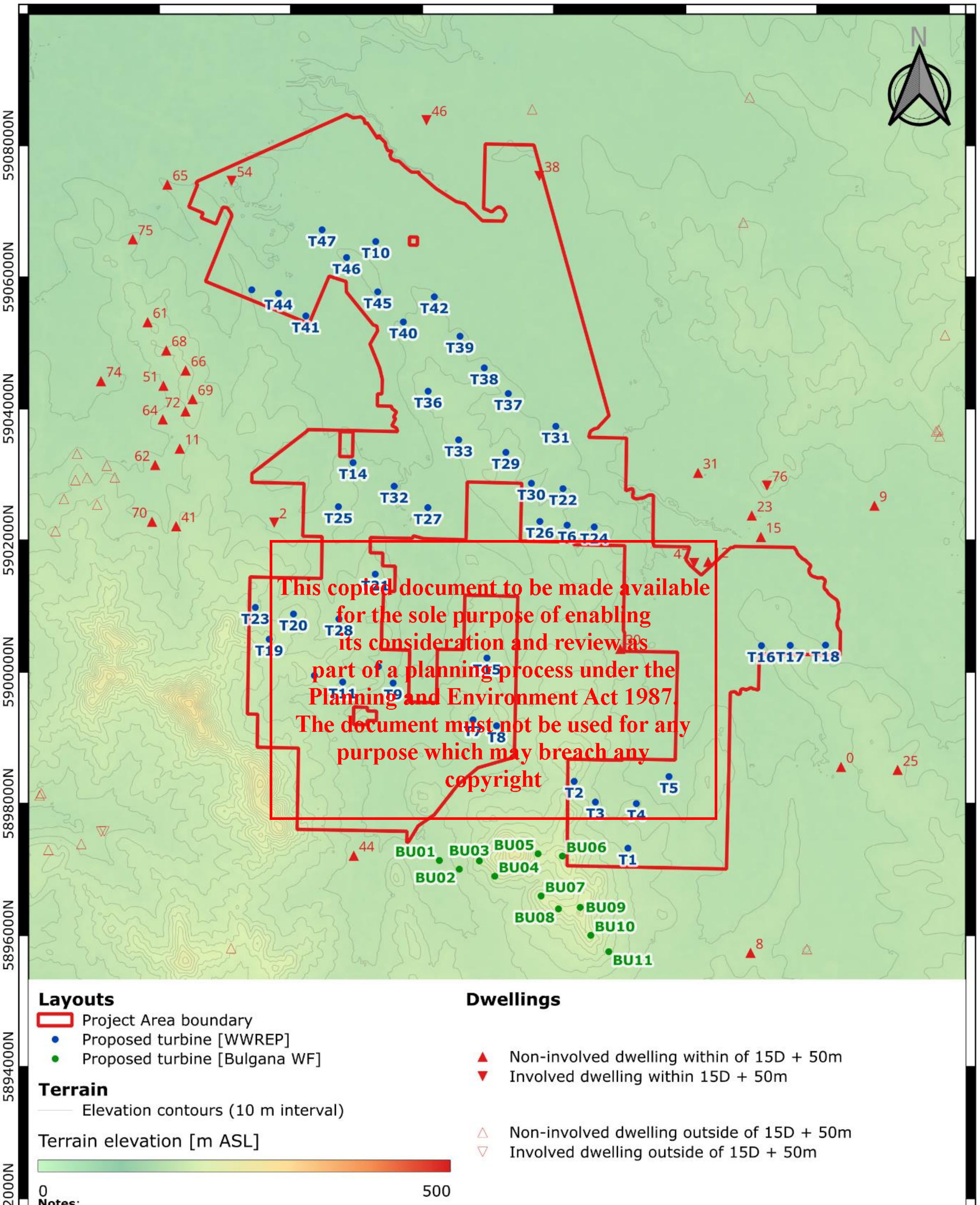


Figure 1 Location of the Project Area



Notes:

- The modelling of shadow flicker durations follows the methodology prescribed in the Draft National Guidelines and is also guided by standard industry practices.
- 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 mast wind direction distribution.
- Coordinate reference system: MGA zone 54, GDA94 datum.
- Background imagery extracted from Esri World Street Map raster (Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community).

Figure 2 Project Area, showing wind turbines, dwellings and elevations

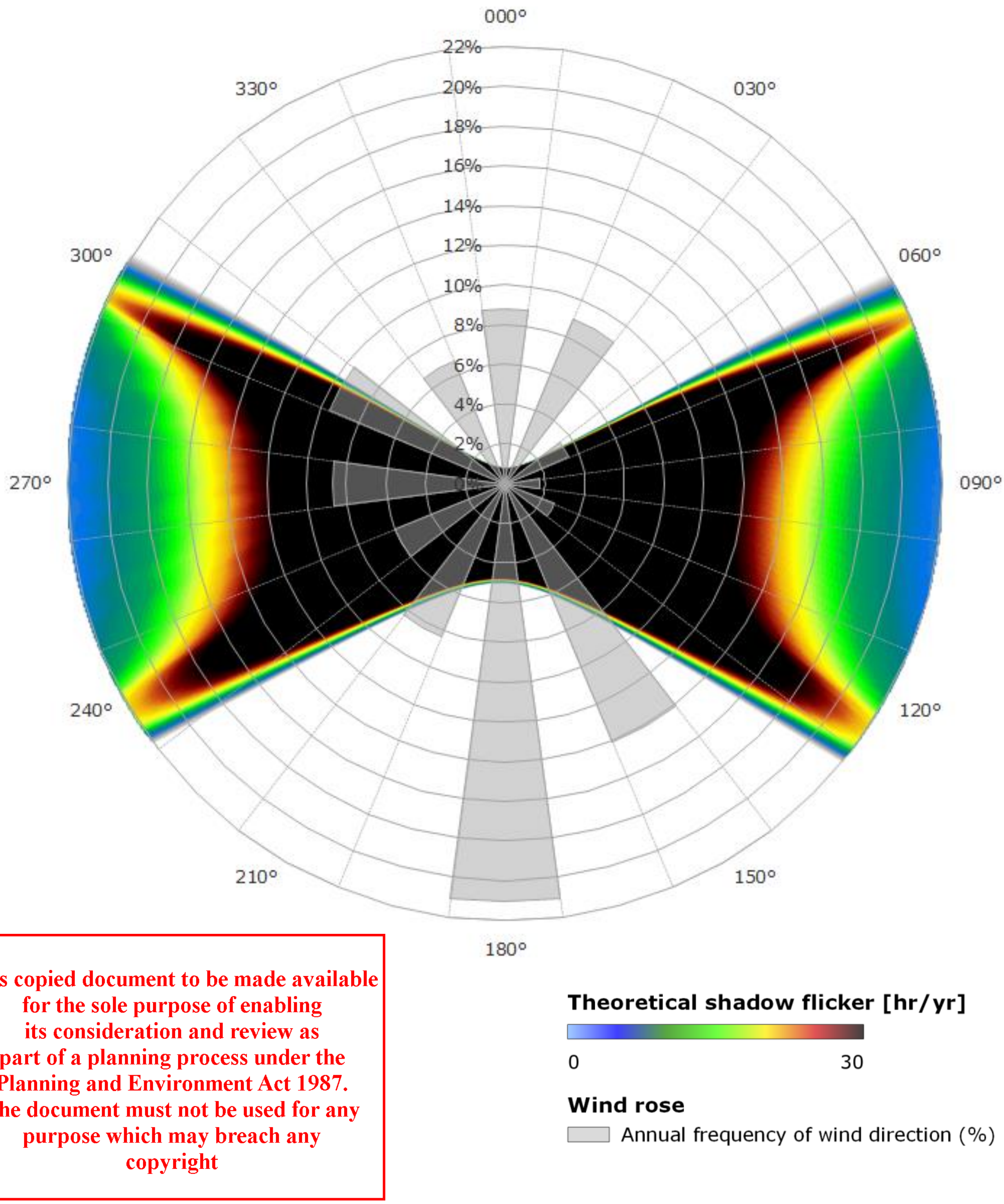


Figure 3 Indicative shadow flicker map and wind direction frequency distribution

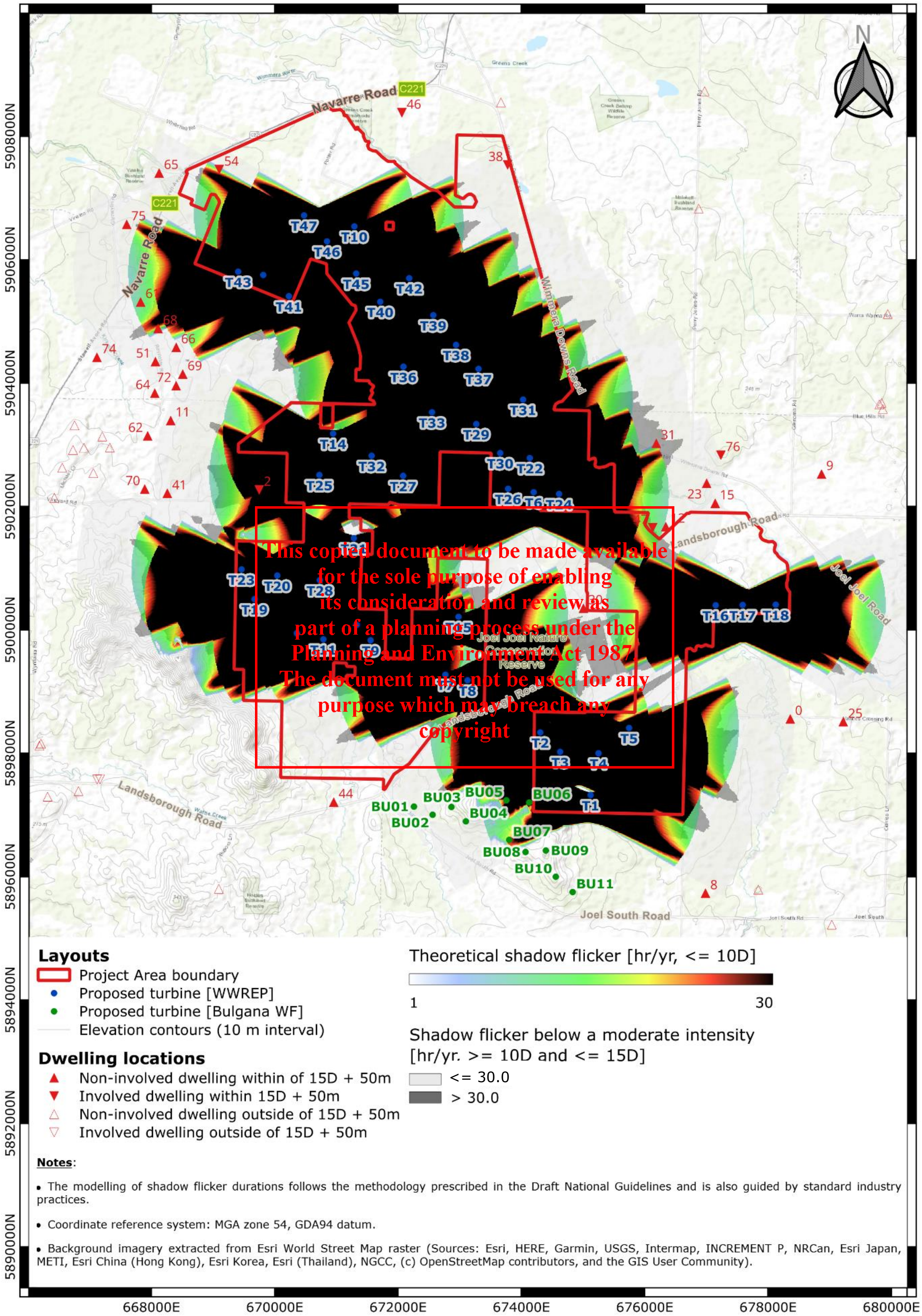


Figure 4 Theoretical annual shadow flicker duration map

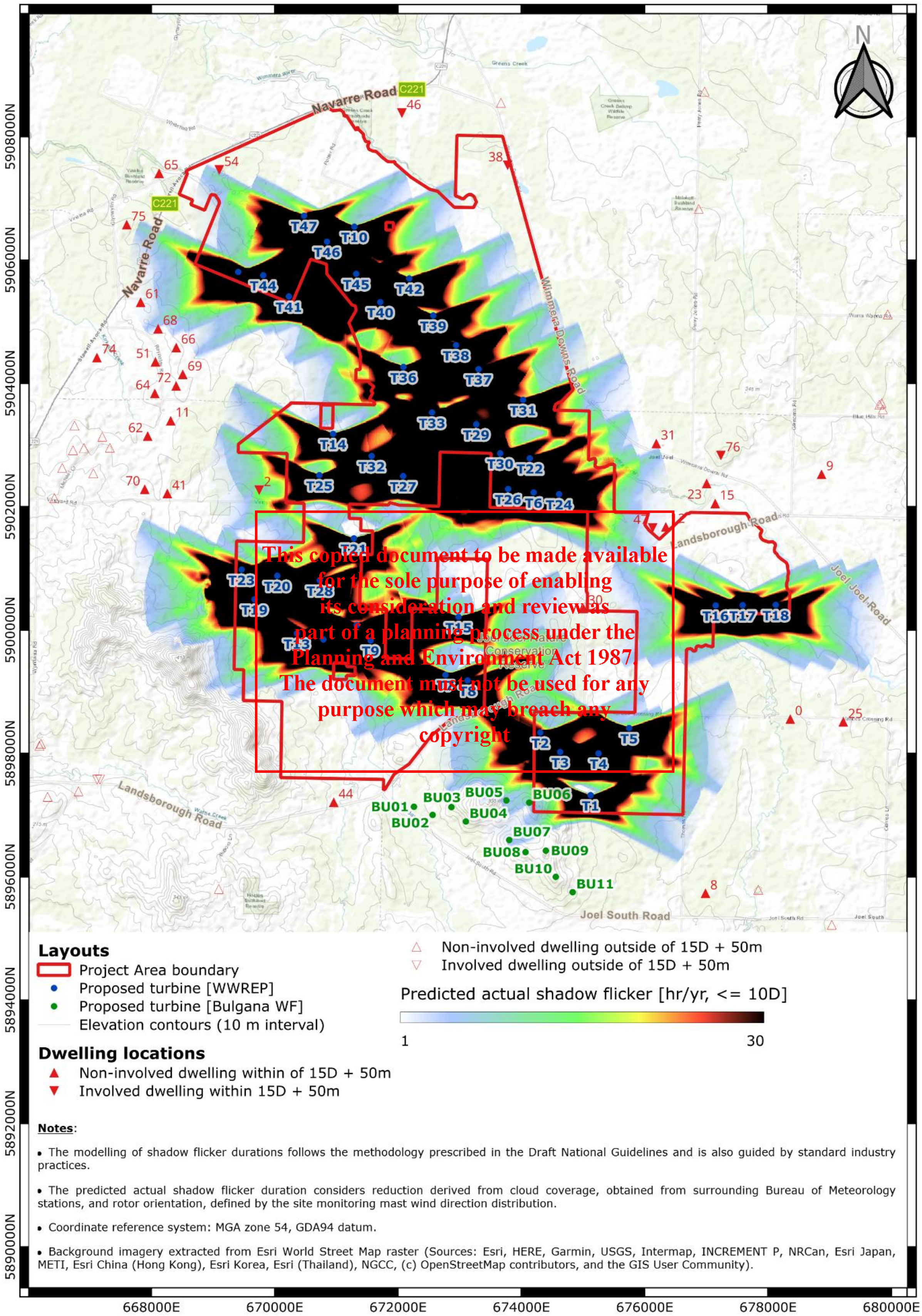


Figure 5 Predicted actual annual shadow flicker duration map

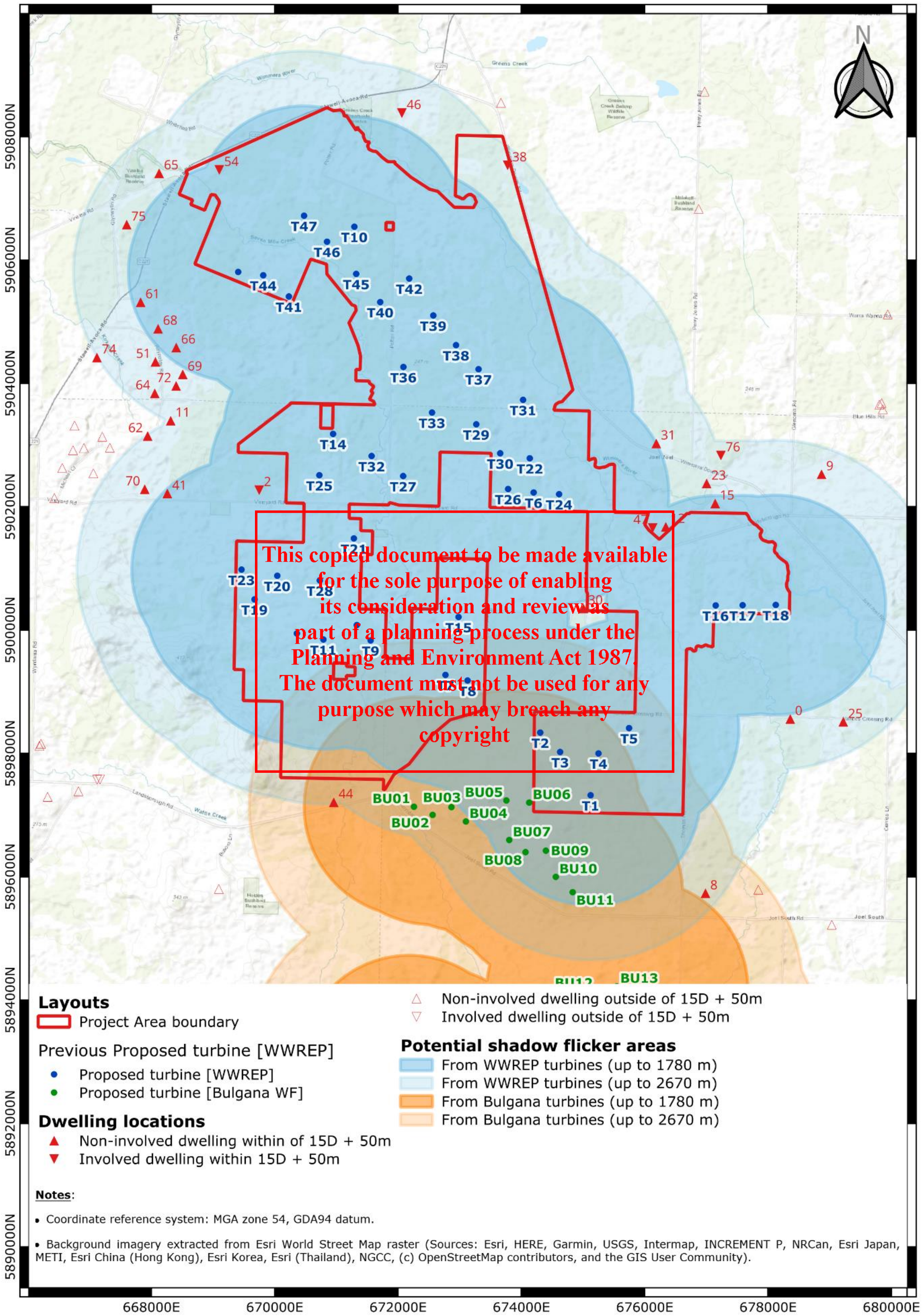


Figure 6 Potential areas for shadow flicker (cumulative impacts)

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