G.2 SHADOW FLICKER AND BLADE GLINT

RYE PARK WIND FARM

Shadow Flicker and Blade Glint Assessment

Rye Park Renewable Energy Pty Ltd

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EXECUTIVE SUMMARY

DNV GL has been commissioned by Rye Park Renewables Energy Pty Ltd ("Rye Park Renewable Energy" or "the Customer") to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Rye Park Wind Farm ("the Project") in south-eastern New South Wales. The results of the shadow flicker assessment are described in this document.

Background and methodology

Development consent for the Project was issued by the NSW Planning Assessment Commission on 22 May 2017 [1] ("the Development Consent"). A shadow flicker assessment to support the submission of the development application was prepared by another consultant in 2016 [2] ("the previous shadow flicker assessment").

DNV GL understands that the Customer is now seeking a modification to the Development Consent, which will include changes to the turbine layout and tip height ("Mod-1"). This document is intended to support that modification and presents the anticipated differences in the expected annual shadow flicker durations in the vicinity of the Project arising from the proposed changes in turbine configuration.

DNV GL has assessed the expected annual shadow flicker durations for the Project in accordance with the requirements of the Development Consent, the Director-General's Requirements for the Rye Park Wind Farm [3], NSW Wind Energy Visual Assessment Bulletin [4] (NSW Visual Assessment Bulletin), and Draft National Wind Farm Development Guidelines [5] (Draft National Guidelines). The methodology used in this study has been informed by these guidelines and standard industry practices based on guidelines adopted in the UK.

Condition 6 of the Development Consent requires that the shadow flicker from the Project at any non-associated dwelling must not exceed 30 hours per year. Similarly, the NSW Visual Assessment Bulletin recommends a shadow flicker limit of 30 hours per year at dwellings in the vicinity of a wind farm. 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.

Three turbine configurations have been considered.

- **Configuration 1** represents the 109-turbine layout presented in the previous shadow flicker assessment for the Project [2].
- **Configuration 2** represents the 92-turbine layout subsequently approved during the Planning Assessment Commission process.
- **Configuration 3** represents the 80-turbine layout and increased turbine tip height in the proposed modification to the Development Consent for the Project.

The theoretical shadow flicker durations at dwellings in the vicinity of the Project have been determined using a purely geometric analysis. The calculation of the theoretical shadow flicker durations does not take into account any reduction due to cloud cover, turbine rotor orientation, low wind speed, vegetation, or other shielding effects around each dwelling in calculating the number of shadow flicker hours. Therefore, the values presented here are likely to be conservative.

Assessment results

The results of the shadow flicker assessment for Configuration 3, and the expected changes in impact compared to Configurations 1 and 2, are summarised in the table below.

In accordance with Condition 6 of the Development Consent, the predicted theoretical shadow flicker impact does not exceed 30 hours per year at any non-associated residences for all three configurations.

Summary of shadow flicker assessment results for the proposed Project

Predicted theoretical shadow flicker within 50 m of dwelling	Number of dwellings affected for Configuration 3 (proposed by Mod-1)	Anticipated change in impact	
		Relative to Configuration 1 (development application)	Relative to Configuration 2 (consented)
Above 0 hours/year	7 (R001, R002, R014, R016, R044, R056, R128)	3 additional dwellings affected (R044, R056, R128) 3 dwellings no longer affected (R025, R031, R046)	3 additional dwellings affected (R044, R056, R128)
Above Development Consent limit of 30 hours/year	3 (R002, R014, R016)	1 additional dwelling affected (R014) 1 dwelling no longer affected (R046)	1 additional dwelling affected (R014)

DNV GL notes that the shadow flicker durations at some associated dwellings are high, with theoretical durations of up to approximately 100 hours per year for Configuration 3. It is recommended that, through the development of the final layout and once a turbine model is selected, further assessment is undertaken to determine the shadow flicker durations at these dwellings. The purpose of this assessment would be to inform discussions with landowners and obtain confirmation that the predicted durations are accepted.

Given the simplifications in the calculation of the theoretical shadow flicker duration noted above, the values presented here are likely to be conservative. Moreover, if the turbine selected for the site has smaller dimensions than those considered here shadow flicker durations are likely to be lower than those predicted. The effects of shadow flicker can also be reduced through a number of mitigation measures.

Since a non-reflective finish is proposed for the wind turbine blades, as required by Condition 4(b) of the Development Consent, blade glint is not expected to be an issue for any configuration.

1 INTRODUCTION

Rye Park Renewable Energy Pty Ltd ("Rye Park Renewable Energy" or "the Customer") has commissioned DNV GL to independently assess the expected annual shadow flicker durations in the vicinity of the proposed Rye Park Wind Farm ("the Project") in south-eastern New South Wales. The results of this work are reported here. This document has been prepared in accordance with DNV GL proposal L2C-178647-AUME-P-01 Issue C, dated 27 February 2019, and is subject to the terms and conditions in that agreement.

Development consent for the Project was issued by the NSW Planning Assessment Commission on behalf of the Minister for Planning on 22 May 2017 [1] ("the Development Consent"). A shadow flicker assessment to support the submission of the development application was prepared by another consultant in 2016 [2] ("the previous shadow flicker assessment").

DNV GL understands that the Customer is now seeking a modification to the Development Consent, which will include changes to the turbine layout and tip height ("Mod-1"). The current shadow flicker assessment is intended to support that modification. This document presents the anticipated differences in the expected annual shadow flicker durations in the vicinity of the Project arising from the proposed changes in turbine configuration compared to the turbine layout and dimensions presented in the previous shadow flicker assessment for the Project and those subsequently approved during the Planning Assessment Commission process.

This assessment evaluates the shadow flicker durations in the vicinity of the project in accordance with the Director-General's Requirements for the Rye Park Wind Farm [3], the NSW Wind Energy Visual Assessment Bulletin (NSW Visual Assessment Bulletin) prepared by the NSW Department of Planning and Infrastructure in December 2016 [4], and the National Wind Farm Development Guidelines – Draft (Draft National Guidelines) prepared by the Environment Protection and Heritage Council (EPHC) in July 2010 [5].

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The site

The proposed Project site is located in the Hilltops, Yass Valley, and Upper Lachlan Local Government Areas (LGAs) in New South Wales, approximately 4 km east of the township of Rye Park and 250 km southwest of Sydney.

Two digital elevation models, one with a horizontal resolution of 1 m in the immediate vicinity of the turbines [6] and one with a horizontal resolution of 5 m to a distance of approximately 4 km from the Project boundary [7], were provided by the Customer. The elevation coverage was extended by DNV GL to approximately 9 km from the boundary using publicly-available elevation data [8].

2.2 The project

2.2.1 Proposed wind farm layout

The wind farm layout for the proposed modification to the Development Consent for the Project consists of 80 turbines with a maximum tip height of 200 m. An indicative rotor diameter of 170 m has been considered in this assessment. Turbine base elevations for this layout range from approximately 660 m to 770 m (Australian Height Datum, AHD).

For the purpose of this assessment, the Customer has asked DNV GL to consider three configurations, as summarised in Table 1 [9, 10, 11, 12, 13].

- **Configuration 1** represents the 109-turbine layout that was presented in the previous shadow flicker assessment for the Project that supported the original development application.
- **Configuration 2** represents the 92-turbine layout that was subsequently approved during the Planning Assessment Commission process. DNV GL understands that the 17 turbine locations removed between Configuration 1 and Configuration 2 were omitted from the layout to reduce visual impacts.
- **Configuration 3** represents the 80-turbine layout and increased turbine tip height proposed in this modification.

The shadow flicker results generated based on the indicative turbine dimensions shown in Table 1 will be conservative for turbines with dimensions that are within the indicative turbine envelope, assuming the same turbine layout is adopted.

Table 1 Turbine configurations for the proposed Project considered in this assessment [9, 10, 11, 12, 13]

Configuration	Number of turbines	Indicative rotor diameter [m]	Maximum upper tip height [m]
Configuration 1	109	130	157
Configuration 2	92	130	157
Configuration 3	80	170	200

An elevation map of the site presenting the layout from which the three configurations are derived is shown in Figure 4 and Figure 5. The coordinates of the turbine locations are presented in Table 2, Table 3, and Table 4.

2.2.2 Shadow receptor locations

A list of dwellings, or 'shadow receptors', within approximately 5 km of the Project was given to DNV GL by the Customer [14]. The coordinates of those receptors within 3 km of proposed turbine locations are presented in Table 5.

DNV GL has modelled all listed receptors as habitable building structures. DNV GL has not carried out a detailed and comprehensive survey of sensitive land uses and building locations in the area and is relying on information provided by the Customer.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

3.1.1 Relevant shadow flicker duration limits

In relation to shadow flicker, Condition 6 in the Development Consent for the Project specifies the following requirement:

> *"The Applicant must ensure that shadow flicker from operational wind turbines does not exceed 30 hours per year at any non-associated residence."*

This limit is consistent with the advice given in the NSW Visual Assessment Bulletin [4], which 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."*

In addition, the Director-General's Requirements for the Rye Park Wind Farm [3] outline the need to assess the expected shadow flicker impacts for the Project as follows:

> *"…the EA must… assess the impact of shadow 'flicker'… from the wind farm."*

Although the Development Consent specifies a limit on the shadow flicker duration at non-associated dwellings and the Director-General's Requirements and NSW Visual Assessment Bulletin describe the requirements for assessing and minimising shadow flicker impacts, they do 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) [5]. The Draft National Guidelines cover a range of issues across the different stages of wind farm development and provide background information, a proposed methodology, and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm.

In relation to shadow flicker, the Draft National Guidelines recommend that the modelled theoretical shadow flicker duration should not exceed 30 hours per year at any dwelling. 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 the 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.

3.1.2 Defining the maximum shadow length

The impact of shadow flicker is typically only significant up to a limited distance from the wind turbine. Beyond this distance limit the shadow is diffused such that the variation in light levels is not likely to be sufficient to cause annoyance. This issue is discussed in the Draft National Guidelines where it is stated that:

> *"Shadow flicker can theoretically extend many kilometres from a wind turbine. However the intensity of the shadows decreases with distance. While acknowledging that different individuals have different levels of sensitivity and may be annoyed by different levels of shadow intensity, these guidelines limit assessment to moderate levels of intensity (i.e., well above the minimum*

theoretically detectable threshold) commensurate with the nature of the impact and the environment in which it is experienced."

The Draft National Guidelines suggest a distance limit equal to 265 times the maximum blade chord length, 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). In situations where the blade chord length is not known, however, a distance limit based on the turbine rotor diameter is more convenient. Research and computer modelling conducted in the UK suggests that shadow flicker effects are unlikely to be significant beyond a distance limit equal to 10 times the turbine rotor diameter [15, 16]. For modern wind turbines, which typically have rotor diameters of 100 m to 170 m, this corresponds to a distance limit of approximately 1000 m to 1700 m.

According to the Draft National Guidelines, the recommended distance limit of 265 times the maximum blade chord length was chosen to maintain some consistency with previous work based on a distance limit of 10 times the rotor diameter. Therefore, in the absence of information about the blade chord length, the maximum shadow length of 10 times the rotor diameter proposed in the UK guidelines may be considered an appropriate distance limit for shadow flicker impacts.

3.2 Blade glint

In relation to blade glint, Condition 4(b) in the Development Consent for the Project specifies the following requirement:

"The Applicant must:

g. ensure the wind turbines are:

- *painted off white/grey, unless otherwise agreed by the Secretary; and*
- *finished with a surface treatment that minimises the potential for glare and reflection…"*

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)."

The Draft National Guidelines provide further guidance on blade glint and state that:

"The sun's light may be reflected from the surface of wind turbine blades. Blade Glint has the potential to annoy people. All major wind turbine manufacturers currently finish their blades with a low reflectivity treatment. This prevents a potentially annoying reflective glint from the surface of the blades and the possibility of a strobing reflection when the turbine blades are spinning. Therefore the risk of blade glint from a new development is considered to be very low."

4 ASSESSMENT METHODOLOGY

4.1 Shadow flicker

4.1.1 Overview

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

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

1. the direction of the property relative to the turbine
2. the distance from the turbine (the further the observer is from the turbine, the less pronounced the effect will be)
3. the turbine height and rotor diameter
4. the time of year and day (the position of the sun in the sky)
5. the weather conditions (cloud cover reduces the occurrence of shadow flicker)
6. 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 theoretical shadow flicker duration at any given location can be calculated using an idealised geometrical model that considers only items 1 to 4 above. As discussed further in Sections 4.1.2 and 4.1.5, the assumptions involved in this approach will produce a conservative estimate of the actual shadow flicker duration that will be experienced at that location. If required, the expected actual or measured shadow flicker duration can be more accurately predicted by considering the potential reductions in modelled shadow flicker impact due to factors such as weather conditions and wind direction.

4.1.2 Theoretical modelled shadow flicker duration

The theoretical number of hours of shadow flicker experienced annually at a given location was calculated using a geometrical model within the DNV GL WindFarmer - Analyst software package that incorporates the sun path, topographic variation over the site area, and wind turbine details such as rotor diameter and hub height.

The WindFarmer model has been validated against shadow flicker measurements for a wind turbine operating under clear-sky conditions, and was found to predict the occurrence and duration of shadow flicker at the measurement locations with appropriate accuracy [17]. In situations where the turbine rotor was angled away from the observer, the theoretical calculation was found to overpredict the measured shadow flicker duration, and more accurate results were obtained by taking the actual rotor orientation into account [18].

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 GL has assessed the shadow flicker at the surveyed dwelling locations and has determined the highest shadow flicker duration within 50 m of each of the provided dwelling 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 would be facing a particular direction. The shadow flicker calculations for dwelling locations have been carried out with a temporal resolution of 1 minute; if shadow flicker is predicted to occur in any 1-minute period, the model records this as 1 minute of shadow flicker. 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 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
- there is no vegetation or other physical obstructions located between the turbines and the shadow receptor locations that could shield the view of the wind turbines and therefore reduce the incidence of shadow flicker at those locations.

The settings used to execute the model can be seen in Table 6.

As discussed in Section 4.1.5, there are a number of factors which may reduce the incidence of shadow flicker that are not considered in the calculation of the theoretical shadow flicker duration. Exclusion of these factors means that the theoretical calculation is likely to be conservative. To account for this, DNV GL has also attempted to predict the actual shadow flicker impacts for the Project considering potential reductions in shadow flicker due to cloud cover and turbine orientation (items 1 and 2 in Section 4.1.5). The results of this additional assessment are described in Appendix A.

4.1.3 Assumed maximum shadow length

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.

For the current assessment, only indicative turbine dimensions have been considered and the maximum blade chord lengths are not known. DNV GL has therefore applied a maximum shadow length of 10 times the indicative turbine rotor diameter for each turbine layout configuration, based on the distance limit proposed in the UK guidelines as discussed in Section 3.1.2. The resulting maximum shadow lengths are 1300 m for Configurations 1 and 2, and 1700 m for Configuration 3, as shown in Table 6. Based on the maximum shadow length of 265 times the maximum blade chord recommended in the Draft National Guidelines, these distance limits will be conservative for turbine with maximum blade chord lengths of up to 4.9 m for Configurations 1 and 2, and 6.4 m for Configuration 3.

Beyond the applied distance limits, 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 GL has also assessed the shadow flicker impacts for the Project for an increased distance limit that includes shadow flicker below a "moderate level of intensity". The results of this additional assessment are described in Appendix B.

4.1.4 Typical modelled shadow flicker results

To illustrate typical results, an indicative shadow flicker map for a turbine located in a relatively flat area is shown in Figure 6. 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 solstice and conversely the lobes to the south result from the winter solstice. The lobes to the west result from morning sun while the lobes to the east result from afternoon or 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.

4.1.5 Sources of conservatism in the theoretical model

The theoretical shadow flicker duration calculated as described in Section 4.1.2 overestimates the annual number of hours of actual shadow flicker that will be experienced at a specified location for several reasons. The following factors have not been considered in the calculation of the theoretical shadow flicker durations presented here.

1. The occurrence of cloud cover has the potential to significantly reduce the number of hours of shadow flicker.

2. 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.

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 have a non-uniform thickness with the thickest part of the blade (maximum chord length) close to the hub and the thinnest part (minimum chord length) at the tip. As discussed in Section 3.1.2, the human threshold for perception of variations in light intensity limits the maximum distance at which an observer will experience a shadow cast by a turbine blade. The intensity of the shadow, and therefore the maximum distance at which it will be perceived, also depends on the thickness of the part of the turbine blade causing it.

Because the sun is not a point light source, a shadow produced by the obstruction of sunlight consists of three parts, the umbra, penumbra, and antumbra, as shown in Figure 1. The umbra is the dark central region of the shadow where all the incident sunlight is blocked by the object. In both the penumbra and the antumbra, only a portion of the sun is obscured and enough light passes around the object to reduce the shadow intensity relative to the umbra. The further an observer moves from the object casting the shadow, the smaller the portion of the sun obscured by the object and the lower the intensity of the shadow. This effect is amplified by the diffusion of sunlight from dispersants in the atmosphere, as discussed in item 3 above and illustrated in Figure 2.

For a modern wind turbine, the umbra of the shadow cast by the thickest part of the blade ends approximately 4-5 rotor diameters from the turbine while the umbra from thinner parts of the blade will end closer to the turbine. As the observer moves away from the umbra and into the penumbra or antumbra, light passing around the turbine blade reduces the intensity of the shadow until it is below the human threshold of perception. Therefore, the maximum distance at which shadow flicker caused by the blade tip is likely to cause annoyance is shorter than the corresponding distance limit for shadow flicker caused by the thickest part of the blade.

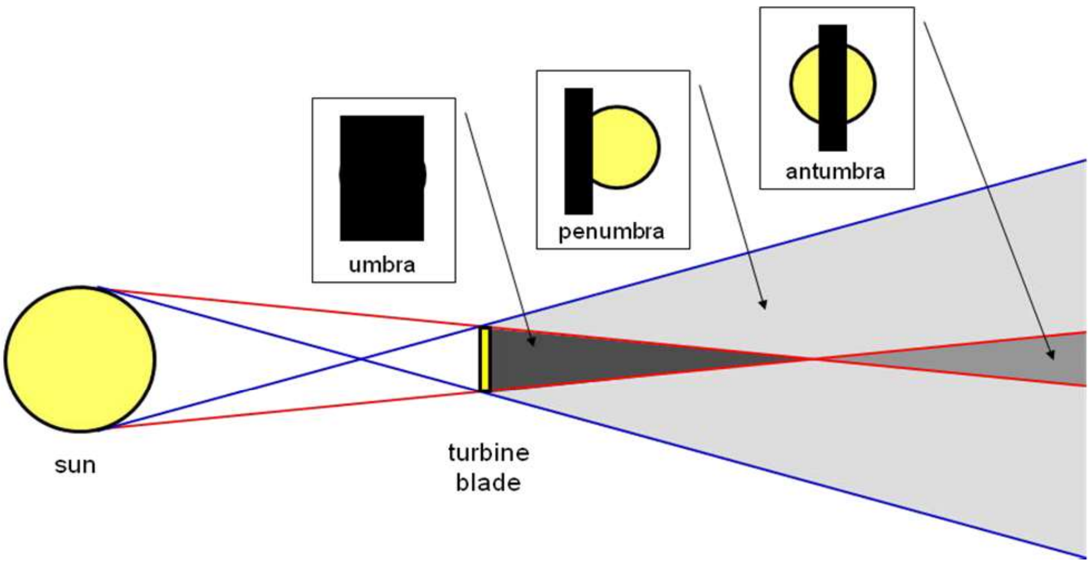

Figure 1 Parts of a shadow cast by a turbine blade

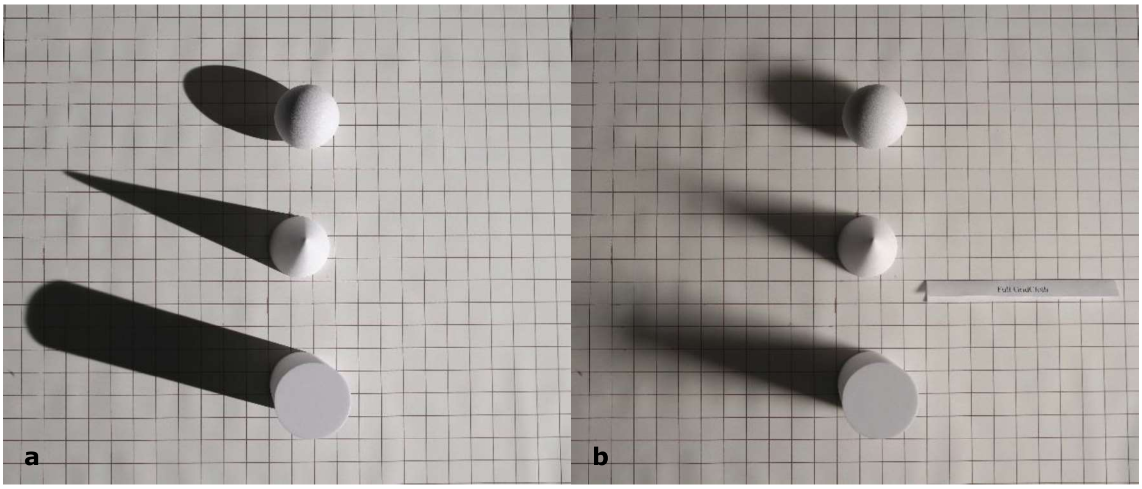

Figure 2 Shadows cast by various shapes for (a) light with no artificial diffusion and (b) light with significant diffusion [19]

5. When the sun is positioned directly behind the stationary wind turbine nacelle when viewed from the receptor location, rather than behind the rotating turbine blades, the shadow cast at the receptor will also be stationary. There will be no shadow flicker experienced at the receptor under these conditions, and so the shadow flicker duration at that location will be reduced.
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.

4.2 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 Overview

Shadow flicker assessments were carried out at all provided habitable dwelling locations, or 'receptors', as outlined in Table 5 for the three turbine configurations considered. The number of dwellings that are predicted to experience shadow flicker for each configuration, and the expected changes in shadow flicker impact for Configuration 3 (80 turbine layout proposed by the modification application) compared to Configuration 1 (109 turbine layout – original development application) and Configuration 2 (92 turbine layout – existing development consent), are summarised in Table 7.

The theoretical shadow flicker durations at all dwellings identified to be affected by shadow flicker are presented in Table 8, Table 9, and Table 10 for Configurations 1, 2, and 3 respectively. The maximum predicted shadow flicker durations within 50 m of these receptors are also presented in these tables. The results are shown in the form of shadow flicker maps in Figure 7 to Figure 12. 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. Figure 13 to Figure 16 show the difference in theoretical shadow flicker durations at each modelled grid point for Configuration 3 compared to Configurations 1 and 2.

5.1.2 Discussion of shadow flicker results

For Configuration 1, seven associated dwellings (R001, R002, R014, R016, R025, R031, and R046) are predicted to experience some theoretical shadow flicker based on the methodology recommended by the Draft National Guidelines, for an assumed maximum shadow length of 10 times the turbine rotor diameter.

For Configuration 2, four associated dwellings (R001, R002, R014, and R016) are predicted to experience some theoretical shadow flicker.

For Configuration 3, seven associated dwellings are also predicted to experience some theoretical shadow flicker (R001, R002, R014, R016, R044, R056, and R128), although the affected dwellings are different to those affected by Configuration 1.

For Configuration 1, three associated dwellings (R002, R016, and R046) are predicted to experience theoretical shadow flicker durations that exceed the 30 hour per year limit recommended by the Draft National Guidelines and required by Condition 6 of the Development Consent. For Configurations 2 and 3, two associated dwellings (R002 and R016) and three associated dwellings (R002, R014, and R016) respectively are predicted to experience theoretical shadow flicker durations that exceed 30 hours per year.

For all three configurations, no non-associated dwellings are predicted to experience theoretical shadow flicker durations above the 30 hours per year limit required by the Development Consent and recommended by the Draft National Guidelines.

DNV GL notes that the theoretical shadow flicker durations at some associated dwellings are high for Configurations 1 and 3, with theoretical annual durations reaching approximately 99 hours for Configuration 1 and approximately 101 hours for Configuration 3.

It is recommended that, through the development of the final wind turbine layout and once a turbine model is selected, further assessment is undertaken to determine the shadow flicker durations at the affected dwellings. The purpose of this assessment would be to inform discussions with landowners and obtain confirmation that the predicted durations are accepted.

If shadow flicker presents a problem, its effects can be reduced through a number of measures. These include the 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 relocation of turbines.

5.1.3 Comparison to the previous shadow flicker assessment

The previous shadow flicker assessment [2], which was prepared to support the submission of the development application, considered the expected annual shadow flicker durations in the vicinity of the Project for Configuration 1. The results of the previous assessment are summarised and compared to the results obtained in the current assessment for Configuration 1 in Table 11.

The methodology used in the previous assessment modelled the shadow flicker durations for two maximum shadow lengths: 1060 m (which is 240 m less than the distance limit applied for Configuration 1 in the current assessment) and 2000 m (which is 700 m more than the distance limit applied for Configuration 1 in the current assessment). The distance limits used in the previous assessment were based on the draft wind farm planning guidelines for South Australia [20] and NSW [21] available at the time, which proposed different limits on the distance at which shadow flicker was likely to cause annoyance compared to the Draft National Guidelines considered in the current assessment.

Using a maximum shadow length of 1060 m, the previous shadow flicker assessment predicted that three currently habitable dwellings would experience some theoretical shadow flicker. Two of those dwellings were predicted to experience theoretical shadow flicker durations that would exceed the 30 hours per year shadow flicker limit recommended by the Draft National Guidelines and required by Condition 6 of the Development Consent. This is less than the three dwellings that are predicted to experience theoretical shadow flicker above the 30 hours per year limit for Configuration 1 in the current shadow flicker assessment. This is due to the smaller maximum shadow length applied in the previous assessment (1060 m) compared to the maximum shadow length applied in the current assessment (1300 m).

Using a maximum shadow length of 2000 m, the previous shadow flicker assessment predicted that 27 currently habitable dwellings would experience some theoretical shadow flicker. Six of those dwellings were predicted to experience theoretical shadow flicker durations that would exceed the 30 hours per year shadow flicker limit recommended by the Draft National Guidelines and required by Condition 6 of the Development Consent. This is more than the three dwellings predicted to experience theoretical shadow flicker above the 30 hours per year limit for Configuration 1 in the current shadow flicker assessment. This is due to the larger maximum shadow length applied in the previous assessment (2000 m) compared to the maximum shadow length applied in the current assessment (1300 m).

5.2 Blade glint

As discussed in Section 4.2, blade glint is not generally a problem for modern wind turbines, provided that the blades are coated with a non-reflective paint.

Condition 4(b) of the Development Consent required that wind turbines at the Project are painted off-white or grey with a surface finish that minimises the potential for glare and reflection. The Customer has confirmed that a standard requirement is included in contracts with turbine suppliers that the turbines are painted in an industry-standard grey colour with a non-reflective finish that complies with the requirements of the Development Approval. Therefore, DNV GL does not expect blade glint to be a problem for any of the three turbine configurations.

5.3 Comments on relevant conditions of consent

In addition to the shadow flicker modelling, the Customer has requested that DNV GL comment on the impact of the changes proposed for Configuration 3 on the conditions of consent detailed below.

5.3.1 Condition 4(b)

The condition listed in the Development Consent states the following:

> *"The Applicant must:*
>
> *g. ensure the wind turbines are:*
>
> - *painted off white/grey, unless otherwise agreed by the Secretary; and*
> - *finished with a surface treatment that minimises the potential for glare and reflection…"*

The proposed changes in the turbine layout and tip height for Configuration 3 are not expected to influence the fulfilment of this condition. As discussed in Section 5.2, the Customer has confirmed that a non-reflective finish in an industry-standard grey colour is proposed for the wind turbine blades and therefore blade glint is not expected to be a problem for any configuration.

5.3.2 Condition 6

The condition listed in the Development Consent states the following:

> *"The Applicant must ensure that shadow flicker from operational wind turbines does not exceed 30 hours per year at any non-associated residence."*

The proposed changes in the turbine layout and tip height for Configuration 3 are not expected to influence the fulfilment of this condition. Based on the methodology recommended by the Draft National Guidelines, for an assumed maximum shadow length of 10 times the turbine rotor diameter, no non-associated dwellings are expected to experience theoretical shadow flicker durations above 30 hours per year for any of the three turbine configurations considered in this assessment.

6 CONCLUSION

A shadow flicker assessment was carried out at all dwelling locations in the vicinity of the Project. For the purpose of this assessment, DNV GL has considered three turbine configurations.

- **Configuration 1** represents the 109-turbine layout presented in the previous shadow flicker assessment for the Project.
- **Configuration 2** represents the 92-turbine layout subsequently approved during the Planning Assessment Commission process.
- **Configuration 3** represents the 80-turbine layout and increased turbine tip height in the proposed modification to the Development Consent for the Project. The shadow flicker modelling for Configuration 3 has been based on a hypothetical turbine with a rotor diameter of 170 m and an upper tip height of 200 m.

The results of the shadow flicker assessment for Configuration 3, and the expected changes in impact compared to Configurations 1 and 2, are summarised in the table below.

For Configuration 3, seven associated dwellings are predicted to experience some shadow flicker. Of those, three dwellings are predicted to experience theoretical shadow flicker durations that exceed the 30 hour per year limit required by Condition 6 of the Development Consent and recommended by the Draft National Guidelines. This includes one additional dwelling that was not expected to experience theoretical shadow flicker durations above the relevant limits for Configurations 1 and 2.

In accordance with Condition 6 of the Development Consent, the predicted theoretical shadow flicker impact does not exceed 30 hours per year at any non-associated residences for all three configurations considered in this assessment.

Summary of shadow flicker assessment results for the proposed Project

Predicted theoretical shadow flicker within 50 m of dwelling	Number of dwellings affected for Configuration 3 (proposed by Mod-1)	Anticipated change in impact	
		Relative to Configuration 1 (development application)	Relative to Configuration 2 (consented)
Above 0 hours/year	7 (R001, R002, R014, R016, R044, R056, R128)	3 additional dwellings affected (R044, R056, R128) 3 dwellings no longer affected (R025, R031, R046)	3 additional dwellings affected (R044, R056, R128)
Above Development Consent limit of 30 hours/year	3 (R002, R014, R016)	1 additional dwelling affected (R014) 1 dwelling no longer affected (R046)	1 additional dwelling affected (R014)

DNV GL notes that the shadow flicker durations at some associated dwellings are very high, with theoretical durations of up to approximately 100 hours per year for Configuration 3. It is recommended that, through the development of the final layout and once a turbine model is selected, further assessment is undertaken to determine the shadow flicker durations at these dwellings. The purpose of this assessment would be to inform discussions with landowners and obtain confirmation that the predicted durations are accepted.

In accordance with the Draft National Guidelines, the calculation of the theoretical shadow flicker durations presented here does not take into account any reduction due to cloud cover, turbine rotor orientation, low wind speed, vegetation, or other shielding effects around each receptor in calculating the number of shadow flicker hours. Therefore, the values presented are likely to be conservative. The effects of shadow flicker may also be reduced through a number of mitigation measures such as the 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 relocation of turbines.

The results presented have been generated based on hypothetical turbine models. If the turbine selected for the site has dimensions smaller than those considered, but within the indicative turbine envelope, then shadow flicker durations are likely to be lower than those predicted here.

Since a non-reflective finish is proposed for the wind turbine blades, as required by Condition 4(b) of the Development Consent, blade glint is not expected to be an issue for any configuration.

7 REFERENCES

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LIST OF TABLES

Table 2 Proposed turbine layout for Configuration 1 [10]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
1	676629	6186672	723
2	676471	6186291	716
3	676320	6185897	706
4	676320	6185509	684
5	677805	6185279	716
6	676377	6185158	667
7	677490	6184967	727
9	677384	6184591	720
11	677266	6184203	735
12	677322	6183750	727
16	677936	6182318	717
17	681368	6182678	728
18	678502	6182471	705
20	681054	6182312	748
21	678588	6181965	695
22	679549	6181989	693
25	679389	6181591	710
26	678511	6181575	704
28	678484	6181184	734
29	678385	6180840	756
30	679009	6180754	742
31	680367	6180463	761
32	678570	6180428	738
34	678899	6180032	730
35	679581	6180032	742
36	680242	6180109	741
37	678987	6179642	713
38	679645	6179648	745
39	680098	6179394	719
41	680008	6179119	711
42	680994	6179015	702
43	679027	6179114	714
44	678960	6178706	687
45	678438	6178498	669
47	678190	6178066	699
48	681515	6177825	763
49	681955	6177678	725
50	681372	6177446	776
51	681355	6177078	743
52	681625	6176824	724
53	681153	6176713	751
56	681509	6176441	722
58	682400	6176161	724
61	680965	6176347	752
62	680830	6175999	747
63	682309	6175645	713
64	683431	6175508	700

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
65	684812	6175374	663
66	682384	6175319	709
67	680267	6175231	699
68	684506	6175044	671
69	682302	6174979	719
71	682195	6173075	731
72	682099	6172655	734
73	681120	6172346	711
74	681358	6172003	725
75	681388	6171634	737
76	680446	6171508	715
77	681464	6171283	737
78	680782	6171250	709
79	680673	6170767	703
80	682014	6170267	760
82	682004	6169806	745
83	681810	6169398	737
84	681373	6167591	761
85	681917	6167300	727
86	681730	6166773	749
87	681536	6166404	734
90	681137	6165157	736
93	681045	6164377	739
94	680716	6163813	707
95	681550	6163639	747
96	682288	6163400	738
97	682410	6162959	716
98	682319	6162534	730
99	682358	6162122	720
101	682364	6161546	702
102	686233	6156685	745
103	685997	6156377	747
104	686150	6156084	743
119	683654	6152722	743
120	684987	6152789	747
122	683572	6152343	732
124	685103	6152217	731
125	684396	6152175	742
127	684307	6151723	726
128	683138	6151393	703
129	684402	6151298	727
130	683127	6151016	701
131	683001	6150684	706
133	678003	6181399	703
134	677946	6181062	715
135	679301	6180383	743
136	680809	6181821	739

Table 2 Proposed turbine layout for Configuration 1 [10] (continued)

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
137	680652	6181414	727
138	680607	6181022	734
139	680934	6177688	773
140	680771	6177337	726
141	680488	6175710	742
142	684592	6152523	736
143	681415	6167988	758
144	678465	6177749	680
145	686104	6154215	720
146	684178	6174388	693
147	684451	6173978	717
148	684474	6173545	713
149	683804	6173875	718
150	682052	6170803	757
151	677325	6185689	696

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

Table 3 Proposed turbine layout for Configuration 2 [11]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]	Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
1	676629	6186672	723	69	682302	6174979	719
2	676471	6186291	716	71	682195	6173075	731
3	676320	6185897	706	72	682099	6172655	734
4	676320	6185509	684	73	681120	6172346	711
5	677805	6185279	716	74	681358	6172003	725
6	676377	6185158	667	75	681388	6171634	737
7	677490	6184967	727	76	680446	6171508	715
9	677384	6184591	720	77	681464	6171283	737
11	677266	6184203	735	78	680782	6171250	709
12	677322	6183750	727	79	680673	6170767	703
17	681368	6182678	728	80	682014	6170267	760
18	678502	6182471	705	82	682004	6169806	745
20	681054	6182312	748	83	681810	6169398	737
21	678588	6181965	695	84	681373	6167591	761
22	679549	6181989	693	85	681917	6167300	727
25	679389	6181591	710	86	681730	6166773	749
26	678511	6181575	704	87	681536	6166404	734
28	678484	6181184	734	102	686233	6156685	745
30	679009	6180754	742	103	685997	6156377	747
31	680367	6180463	761	104	686150	6156084	743
32	678570	6180428	738	119	683654	6152722	743
34	678899	6180032	730	120	684987	6152789	747
35	679581	6180032	742	122	683572	6152343	732
36	680242	6180109	741	124	685103	6152217	731
37	678987	6179642	713	125	684396	6152175	742
38	679645	6179648	745	127	684307	6151723	726
39	680098	6179394	719	128	683138	6151393	703
41	680008	6179119	711	129	684402	6151298	727
42	680994	6179015	702	130	683127	6151016	701
43	679027	6179114	714	131	683001	6150684	706
48	681515	6177825	763	135	679301	6180383	743
49	681955	6177678	725	136	680809	6181821	739
50	681372	6177446	776	137	680652	6181414	727
51	681355	6177078	743	138	680607	6181022	734
52	681625	6176824	724	139	680934	6177688	773
53	681153	6176713	751	140	680771	6177337	726
56	681509	6176441	722	141	680488	6175710	742
58	682400	6176161	724	142	684592	6152523	736
61	680965	6176347	752	143	681415	6167988	758
62	680830	6175999	747	145	686104	6154215	720
63	682309	6175645	713	146	684178	6174388	693
64	683431	6175508	700	147	684451	6173978	717
65	684812	6175374	663	148	684474	6173545	713
66	682384	6175319	709	149	683804	6173875	718
67	680267	6175231	699	150	682052	6170803	757
68	684506	6175044	671	151	677325	6185689	696

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

Table 4 Proposed turbine layout for Configuration 3 [12]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]	Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
1	676629	6186672	723	69	682302	6174979	719
2	676471	6186291	716	71	682195	6173075	731
3	676320	6185897	706	72	682099	6172655	734
4	676320	6185509	684	73	681120	6172346	711
5	677805	6185279	716	74	681358	6172003	725
7	677490	6184967	727	75	681388	6171634	737
9	677384	6184591	720	76	680446	6171508	715
11	677266	6184203	735	78	680782	6171250	709
12	677322	6183750	727	79	680673	6170767	703
17	681368	6182678	728	80	682014	6170267	760
18	678502	6182471	705	82	682004	6169806	745
20	681054	6182312	748	83	681810	6169398	737
21	678588	6181965	695	84	681373	6167591	761
22	679549	6181989	693	85	681917	6167300	727
25	679389	6181591	710	86	681730	6166773	749
26	678511	6181575	704	87	681536	6166404	734
28	678484	6181184	734	119	683654	6152722	743
30	679009	6180754	742	120	684987	6152789	747
31	680367	6180463	761	122	683572	6152343	732
32	678570	6180428	738	124	685103	6152217	731
34	678899	6180032	730	125	684396	6152175	742
36	680242	6180109	741	127	684307	6151723	726
37	678987	6179642	713	128	683138	6151393	703
39	680098	6179394	719	129	684402	6151298	727
41	680008	6179119	711	130	683127	6151016	701
42	680994	6179015	702	131	683001	6150684	706
43	679027	6179114	714	135	679301	6180383	743
48	681515	6177825	763	136	680809	6181821	739
49	681955	6177678	725	137	680652	6181414	727
50	681372	6177446	776	138	680607	6181022	734
51	681355	6177078	743	139	680934	6177688	773
58	682400	6176161	724	141	680488	6175710	742
61	680965	6176347	752	142	684592	6152523	736
62	680830	6175999	747	143	681415	6167988	758
63	682309	6175645	713	145	686104	6154215	720
64	683431	6175508	700	146	684178	6174388	693
65	684812	6175374	663	147	684451	6173978	717
66	682384	6175319	709	148	684474	6173545	713
67	680267	6175231	699	150	682052	6170803	757
68	684506	6175044	671	151	677325	6185689	696

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

Table 5 Shadow receptor locations within 3000 m of turbines at the Project

Receptor ID	Landowner status	Easting[1] [m]	Northing[1] [m]	Distance to nearest turbine [m] (and nearest turbine ID)		
				Configuration 1	Configuration 2	Configuration 3
R001	Associated	677418	6187127	910 (1)	910 (1)	910 (1)
R002	Associated	678095	6185733	539 (5)	539 (5)	539 (5)
R004	Non-associated	680436	6185190	2627 (5)	2627 (5)	2627 (5)
R006	Non-associated	681484	6184020	1350 (17)	1350 (17)	1350 (17)
R007	Non-associated	681917	6183967	1403 (17)	1403 (17)	1403 (17)
R008	Non-associated	682339	6183864	1534 (17)	1534 (17)	1534 (17)
R009	Non-associated	682517	6183838	1633 (17)	1633 (17)	1633 (17)
R010	Non-associated	682842	6183767	1832 (17)	1832 (17)	1832 (17)
R011	Non-associated	679650	6183618	1623 (18)	1623 (18)	1623 (18)
R014	Associated	677807	6183115	800 (12)	800 (12)	800 (12)
R015	Associated	675095	6182805	2416 (12)	2416 (12)	2416 (12)
R016	Associated	677297	6181991	717 (16)	1281 (26)	1281 (26)
R017	Non-associated	676127	6181740	1896 (16)	2341 (12)	2341 (12)
R018	Non-associated	676024	6181739	1994 (16)	2396 (12)	2396 (12)
R019	Non-associated	676412	6181665	1610 (133)	2096 (26)	2096 (26)
R020	Associated	676130	6181544	1875 (133)	2376 (26)	2376 (26)
R022	Non-associated	676095	6181037	1847 (134)	2388 (28)	2388 (28)
R024	Non-associated	683597	6178847	2014 (49)	2014 (49)	2014 (49)
R025	Associated	677075	6178323	1142 (47)	2103 (43)	2103 (43)
R026	Non-associated	676523	6178178	1667 (47)	2669 (43)	2669 (43)
R028	Non-associated	684090	6177918	2144 (49)	2144 (49)	2144 (49)
R029	Non-associated	676434	6177903	1760 (47)	2858 (43)	2858 (43)
R031	Associated	679304	6177019	1112 (144)	1498 (140)	1759 (139)
R034	Associated	681817	6174338	804 (69)	804 (69)	804 (69)
R036	Associated	679988	6173811	1450 (67)	1450 (67)	1450 (67)
R038[3]	Non-associated	679623	6173620	1738 (67)	1738 (67)	1738 (67)
R040	Associated	678605	6171136	1874 (76)	1874 (76)	1874 (76)
R041	Associated	681870	6168503	688 (143)	688 (143)	688 (143)
R042	Associated	683370	6168206	1711 (85)	1711 (85)	1711 (85)
R044	Associated	679986	6166322	1549 (87)	1549 (87)	1549 (87)
R045	Non-associated	682847	6165279	1711 (90)	1727 (87)	1727 (87)
R046	Associated	681835	6164679	844 (93)	1755 (87)	1755 (87)
R047	Non-associated	680155	6162689	1258 (94)	3971 (87)	3971 (87)
R048	Non-associated	679834	6162662	1451 (94)	4118 (87)	4118 (87)
R049	Associated	680667	6162540	1277 (94)	3969 (87)	3969 (87)
R050	Non-associated	680701	6161784	1676 (101)	4705 (87)	4705 (87)
R051	Associated	680970	6161588	1392 (101)	4860 (87)	4860 (87)
R052	Associated	684135	6161246	1792 (101)	5028 (102)	5784 (87)
R053	Non-associated	680877	6160875	1629 (101)	5581 (87)	5581 (87)
R054	Associated	683514	6155819	2540 (103)	2540 (103)	3043 (145)
R056	Associated	686567	6153140	1172 (145)	1172 (145)	1172 (145)
R059	Associated	684670	6149654	1669 (129)	1669 (129)	1669 (129)

Table 5 Shadow receptor locations within 3000 m of turbines at the Project (continued)

Receptor ID	Landowner status	Easting[1] [m]	Northing[1] [m]	Distance to nearest turbine [m] (and nearest turbine ID)		
				Configuration 1	Configuration 2	Configuration 3
R060	Associated	684244	6149529	1696 (131)	1696 (131)	1696 (131)
R061	Associated	684489	6149335	1969 (129)	1969 (129)	1969 (129)
R063	Non-associated	683875	6148991	1908 (131)	1908 (131)	1908 (131)
R064	Associated	676239	6180502	1793 (134)	2327 (32)	2327 (32)
R065	Non-associated	676668	6179644	1910 (134)	2054 (32)	2054 (32)
R066	Associated	683628	6159544	2370 (101)	3868 (102)	5885 (145)
R067	Non-associated	683606	6159059	2784 (101)	3540 (102)	5457 (145)
R068	Non-associated	684235	6160336	2226 (101)	4167 (102)	6412 (145)
R072	Associated	677635	6173854	2967 (67)	2967 (67)	2967 (67)
R073	Associated	677725	6173856	2887 (67)	2887 (67)	2887 (67)
R075	Non-associated	677851	6172291	2706 (76)	2706 (76)	2706 (76)
R080	Associated	679215	6168709	2311 (143)	2311 (143)	2311 (143)
R083	Non-associated	678818	6162988	2067 (94)	4368 (87)	4368 (87)
R085	Non-associated	680217	6161078	2193 (77)	5499 (87)	5499 (87)
R086	Non-associated	680739	6159422	2676 (101)	6069 (103)	7044 (87)
R090	Non-associated	680583	6151407	2519 (131)	2519 (131)	2519 (131)
R098	Non-associated	684400	6148461	2629 (131)	2629 (131)	2629 (131)
R100	Non-associated	684738	6148432	2846 (131)	2846 (131)	2846 (131)
R101	Non-associated	688189	6154931	2201 (145)	2201 (145)	2201 (145)
R102	Non-associated	685395	6158972	2440 (102)	2440 (102)	4820 (145)
R110	Non-associated	684391	6165083	2693 (96)	3141 (87)	3141 (87)
R111	Non-associated	684234	6167383	2313 (85)	2313 (85)	2313 (85)
R112	Non-associated	686151	6177467	2487 (65)	2487 (65)	2487 (65)
R113	Associated	684054	6179129	2550 (49)	2550 (49)	2550 (49)
R114	Associated	683962	6183346	2674 (17)	2674 (17)	2674 (17)
R128	Associated	678848	6183498	1086 (18)	1086 (18)	1086 (18)
R131	Associated	674633	6183862	2172 (6)	2172 (6)	2358 (4)
R132	Associated	675005	6182884	2470 (12)	2470 (12)	2470 (12)
R153	Non-associated	689004	6153469	2988 (145)	2988 (145)	2988 (145)
R170	Non-associated	683284	6165017	1901 (96)	2230 (87)	2230 (87)
R203	Non-associated	676049	6179500	2457 (134)	2682 (32)	2682 (32)
R204	Non-associated	675863	6179390	2670 (134)	2895 (32)	2895 (32)
R266	Non-associated	676126	6178067	2060 (47)	3079 (43)	3079 (43)
R267	Non-associated	675619	6180141	2499 (134)	2959 (32)	2959 (32)
R268	Non-associated	675798	6179747	2516 (134)	2849 (32)	2849 (32)
R269	Non-associated	675542	6178459	2671 (47)	3539 (43)	3539 (43)
R270	Non-associated	675545	6178651	2703 (47)	3505 (32)	3505 (32)
R271	Non-associated	675812	6176676	2752 (47)	4033 (43)	4033 (43)
R286	Non-associated	683162	6184437	2513 (17)	2513 (17)	2513 (17)
R294	Non-associated	681540	6148503	2628 (131)	2628 (131)	2628 (131)
R315	Non-associated	686718	6158805	2179 (102)	2179 (102)	4641 (145)
R324	Non-associated	680449	6161468	1912 (101)	5065 (87)	5065 (87)

Table 5 Shadow receptor locations within 3000 m of turbines at the Project (continued)

Receptor ID	Landowner status	Easting[1] [m]	Northing[1] [m]	Distance to nearest turbine [m] (and nearest turbine ID)		
				Configuration 1	Configuration 2	Configuration 3
R329	Non-associated	673626	6185507	2688 (4)	2688 (4)	2688 (4)
R330	Non-associated	675185	6183010	2258 (10)	2258 (12)	2258 (12)

1. Coordinate system: MGA zone 55, GDA94 datum.
2. Dwelling subject to acquisition on request.

Table 6 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	Configuration 1	Configuration 2	Configuration 3
Turbine rotor diameter (D)	130 m	130 m	170 m
Turbine upper tip height	157 m	157 m	200 m
Shadow distance limit (10D)	1300 m	1300 m	1700 m
Year of calculation		2031	
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 7 Summary of shadow flicker assessment results for the Project – theoretical shadow flicker

Predicted theoretical shadow flicker within 50 m of dwelling	Number of dwellings affected						Anticipated change in impact for Configuration 3	
	Configuration 1 (development application)		Configuration 2 (consented)		Configuration 3 (proposed by Mod-1)			
	Total	Non-associated dwellings	Total	Non-associated dwellings	Total	Non-associated dwellings	Relative to Configuration 1	Relative to Configuration 2
Above 0 hours/year	7 (R001, R002, R014, R016, R025, R031, R046)	0	4 (R001, R002, R014, R016)	0	7 (R001, R002, R014, R016, R044, R056, R128)	0	3 additional dwellings affected (R044, R056, R128) 3 dwellings no longer affected (R025, R031, R046)	3 additional dwellings affected (R044, R056, R128)
Above Development Consent limit of 30 hours/year	3 (R002, R016, R046)	0	2 (R002, R016)	0	3 (R002, R014, R016)	0	1 additional dwelling affected (R014) 1 dwelling no longer affected (R046)	1 additional dwelling affected (R014)

Table 8 Theoretical annual shadow flicker duration – Configuration 1

Dwelling ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Theoretical annual shadow flicker At dwelling [hr/yr] 2 m	At dwelling [hr/yr] 6 m	Max within 50 m of dwelling [hr/yr] 2 m	Max within 50 m of dwelling [hr/yr] 6 m
R001	Associated	677418	6187127	1	0.0	0.0	6.7	8.0
R002	Associated	678095	6185733	151	29.3	29.3	**33.8**	**33.7**
R014	Associated	677807	6183115	12	0.0	0.0	9.0	6.3
R016	Associated	677297	6181991	16 21 26	**62.2**	**63.2**	**73.7**	**74.2**
R025	Associated	677075	6178323	47	17.4	17.4	20.9	20.8
R031	Associated	679304	6177019	144	8.6	7.3	16.3	15.2
R046	Associated	681835	6164679	90 93	**95.4**	**96.0**	**98.5**	**98.8**
				Development Consent limit	***30 hr/yr***			

1. Dwellings identified in Table 5 with no theoretical shadow flicker occurrence for a distance limit of 10 times the rotor diameter, have been omitted from this table.
2. Coordinate system: UTM Zone 55, WGS84 datum.

Table 9 Theoretical annual shadow flicker duration – Configuration 2

Dwelling ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Theoretical annual shadow flicker At dwelling [hr/yr] 2 m	At dwelling [hr/yr] 6 m	Max within 50 m of dwelling [hr/yr] 2 m	Max within 50 m of dwelling [hr/yr] 6 m
R001	Associated	677418	6187127	1	0.0	0.0	6.7	8.0
R002	Associated	678095	6185733	151	29.3	29.3	**33.8**	**33.7**
R014	Associated	677807	6183115	12	0	0	9.0	6.3
R016	Associated	677297	6181991	21 26	25.7	26.4	**31.8**	**32.4**
				Development Consent limit	***30 hr/yr***			

1. Dwellings identified in Table 5 with no theoretical shadow flicker occurrence for a distance limit of 10 times the rotor diameter, have been omitted from this table.
2. Coordinate system: UTM Zone 55, WGS84 datum.

Table 10 Theoretical annual shadow flicker duration – Configuration 3

Dwelling ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Theoretical annual shadow flicker At dwelling [hr/yr] 2 m	At dwelling [hr/yr] 6 m	Max within 50 m of dwelling [hr/yr] 2 m	Max within 50 m of dwelling [hr/yr] 6 m
R001	Associated	677418	6187127	1	0.0	0.0	12.3	13.9
R002	Associated	678095	6185733	1 2 151	**49.9**	**49.7**	**100.7**	**100.2**
R014	Associated	677807	6183115	12	16.2	13.5	**44.0**	**41.6**
R016	Associated	677297	6181991	18 21 26	**56.3**	**57.3**	**56.7**	**58.1**
R044	Associated	679986	6166322	87	12.3	12.3	13.1	13.0
R056	Associated	686567	6153140	120	14.7	14.5	16.2	16.1
R128	Associated	678848	6183498	11 12	12.1	12.5	27.2	27.7
				Development Consent limit	***30 hr/yr***			

1. Dwellings identified in Table 5 with no theoretical shadow flicker occurrence for a distance limit of 10 times the rotor diameter, have been omitted from this table.
2. Coordinate system: UTM Zone 55, WGS84 datum.

Table 11 Comparison of shadow flicker assessment results for Configuration 1 with the results of the previous shadow flicker assessment for the Project – theoretical shadow flicker

Predicted theoretical shadow flicker within 50 m of dwelling	Number of dwellings affected		
	Previous shadow flicker assessment		Current shadow flicker assessment
	Maximum shadow length of 1060 m	Maximum shadow length of 2000 m	Maximum shadow length of 1300 m
Above 0 hours/year	4 (3 currently habitable) (R002, R016, R030[1], R046)	28 (27 currently habitable) (R002, R016, R018, R019, R020, R022, R025, R026, R029, R030[1], R031, R034, R042, R044, R045, R046, R047, R048, R049, R050, R051, R052, R053, R056, R059, R064, R128, R324)	7 (R001, R002, R014, R016, R025, R031, R046)
Above Development Consent limit of 30 hours/year	3 (2 currently habitable) (R016, R030[1], R046)	7 (6 currently habitable) (R002, R016, R019, R025, R030[1], R031, R046)	3 (R002, R016, R046)

1. Dwelling has been identified as uninhabitable [22] and excluded from the current shadow flicker assessment.

LIST OF FIGURES

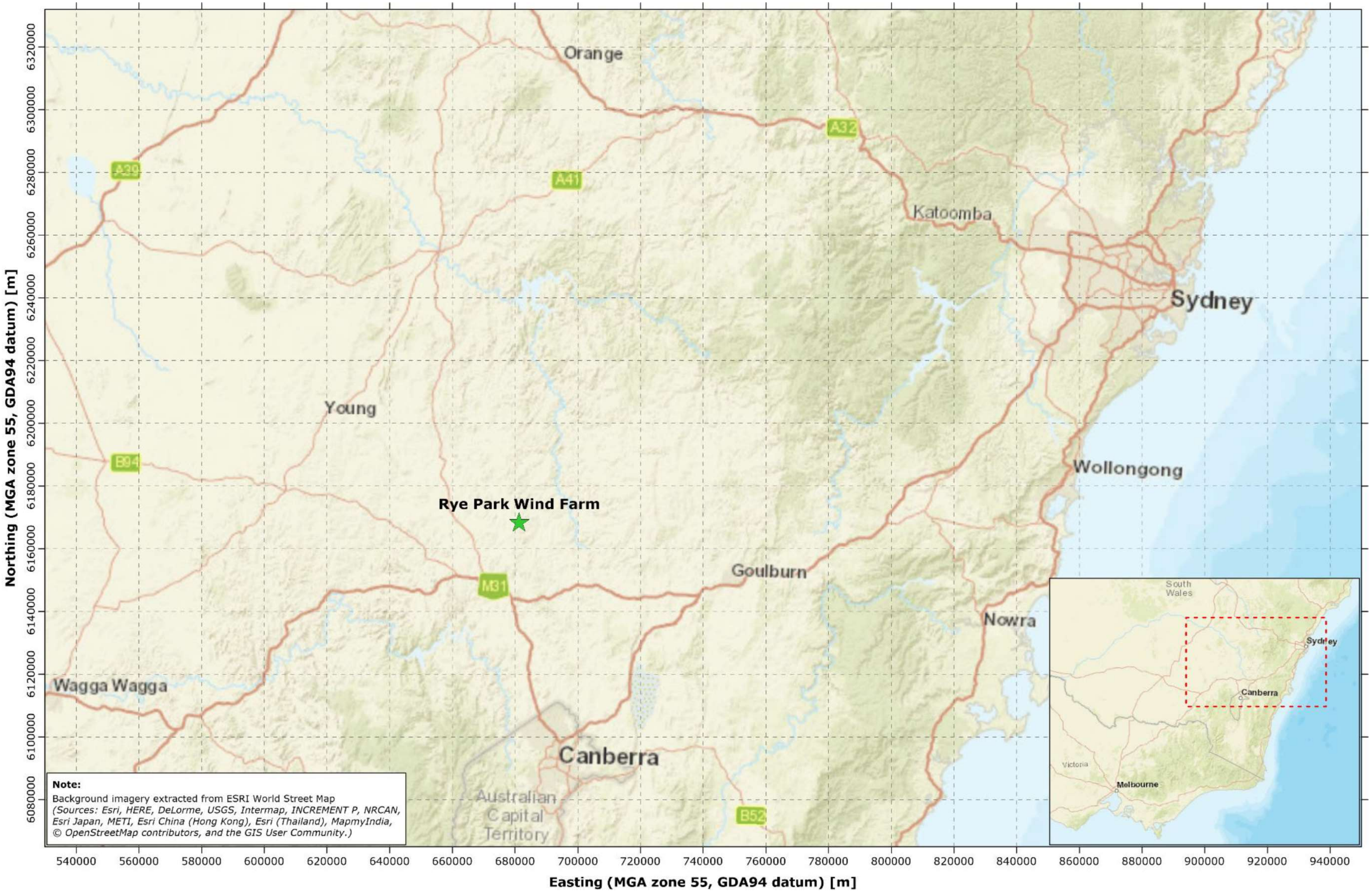

Figure 3 Location of the Project

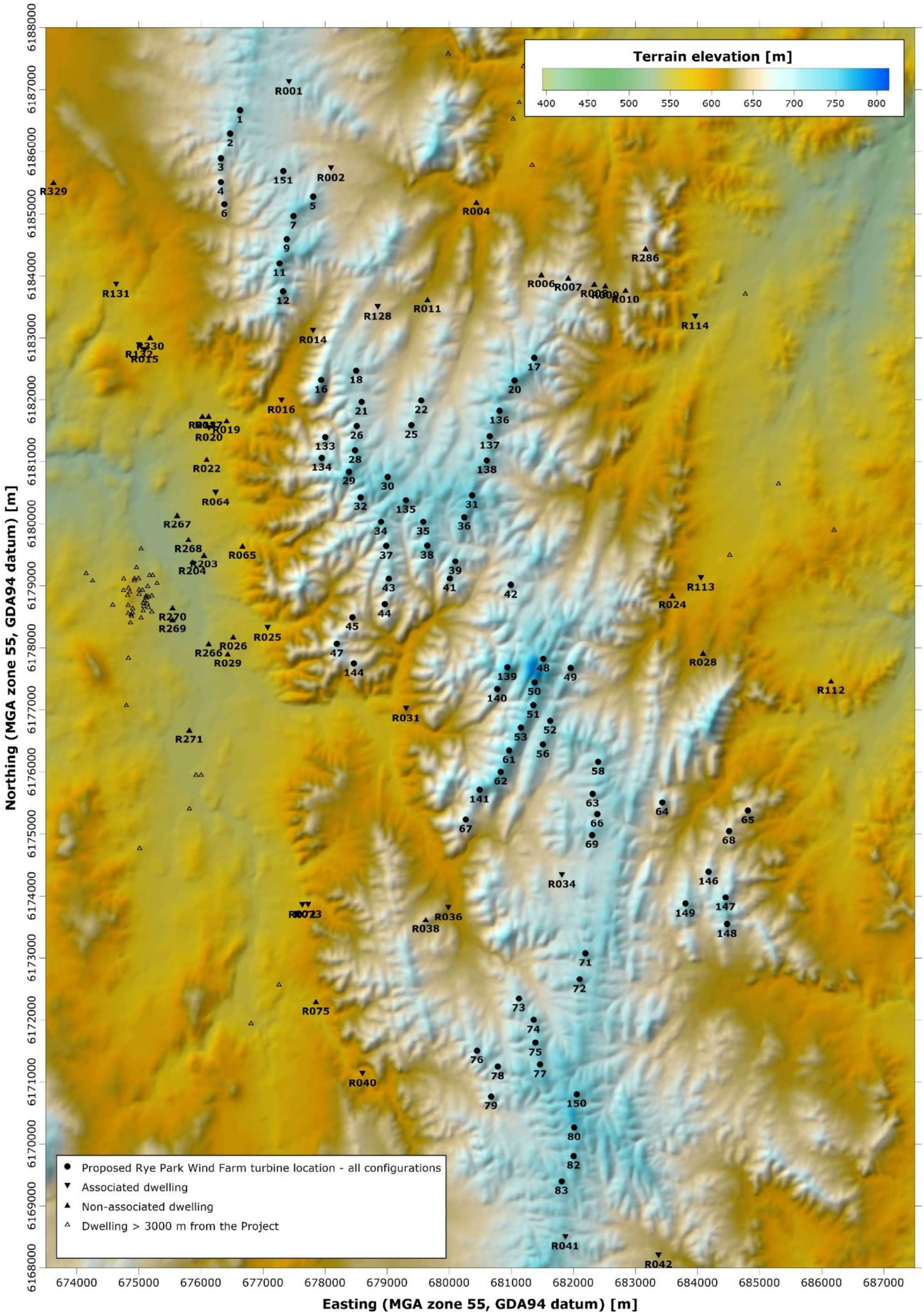

Figure 4 Elevation map of the Project (north)

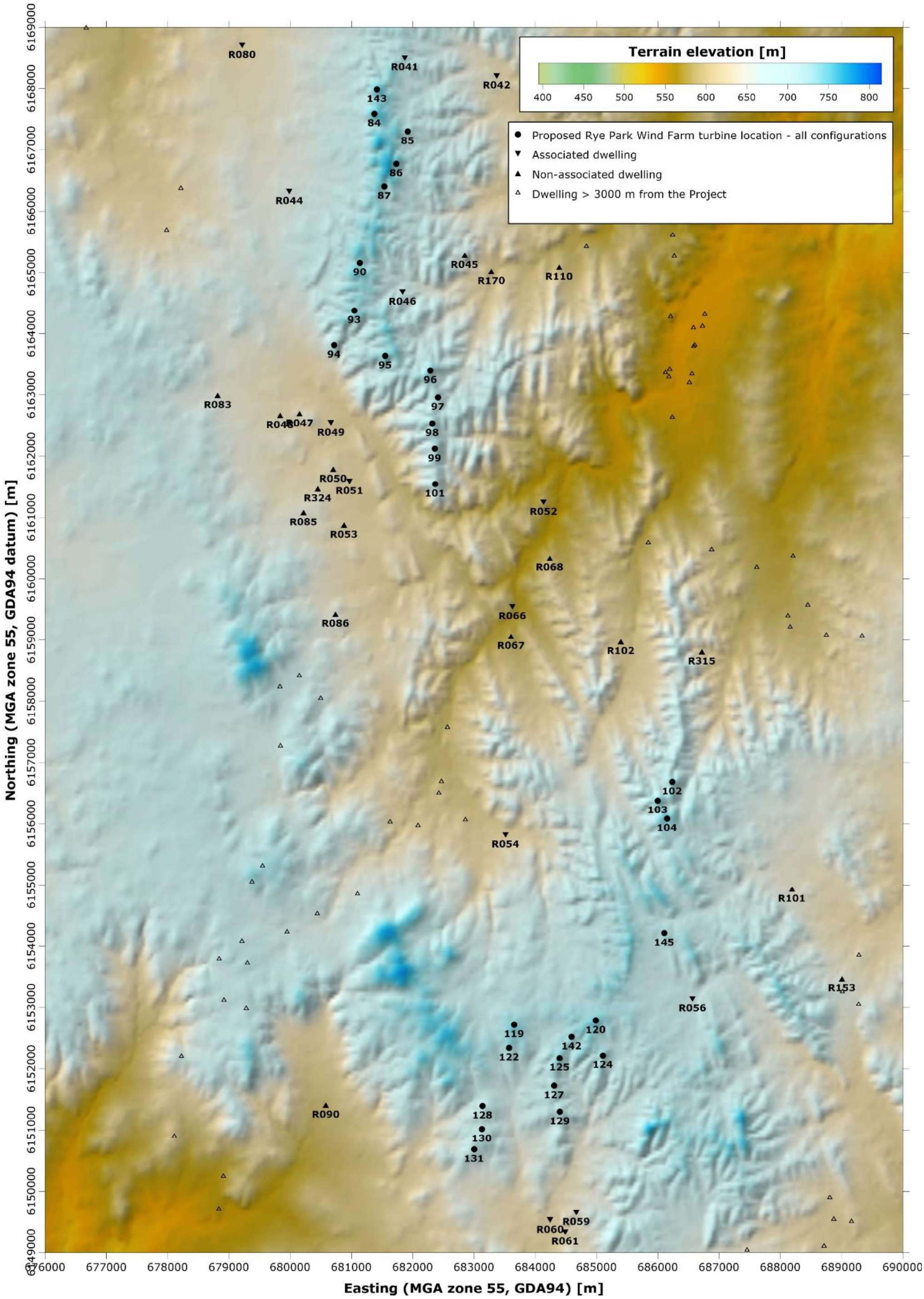

Figure 5 Elevation map of the Project (south)

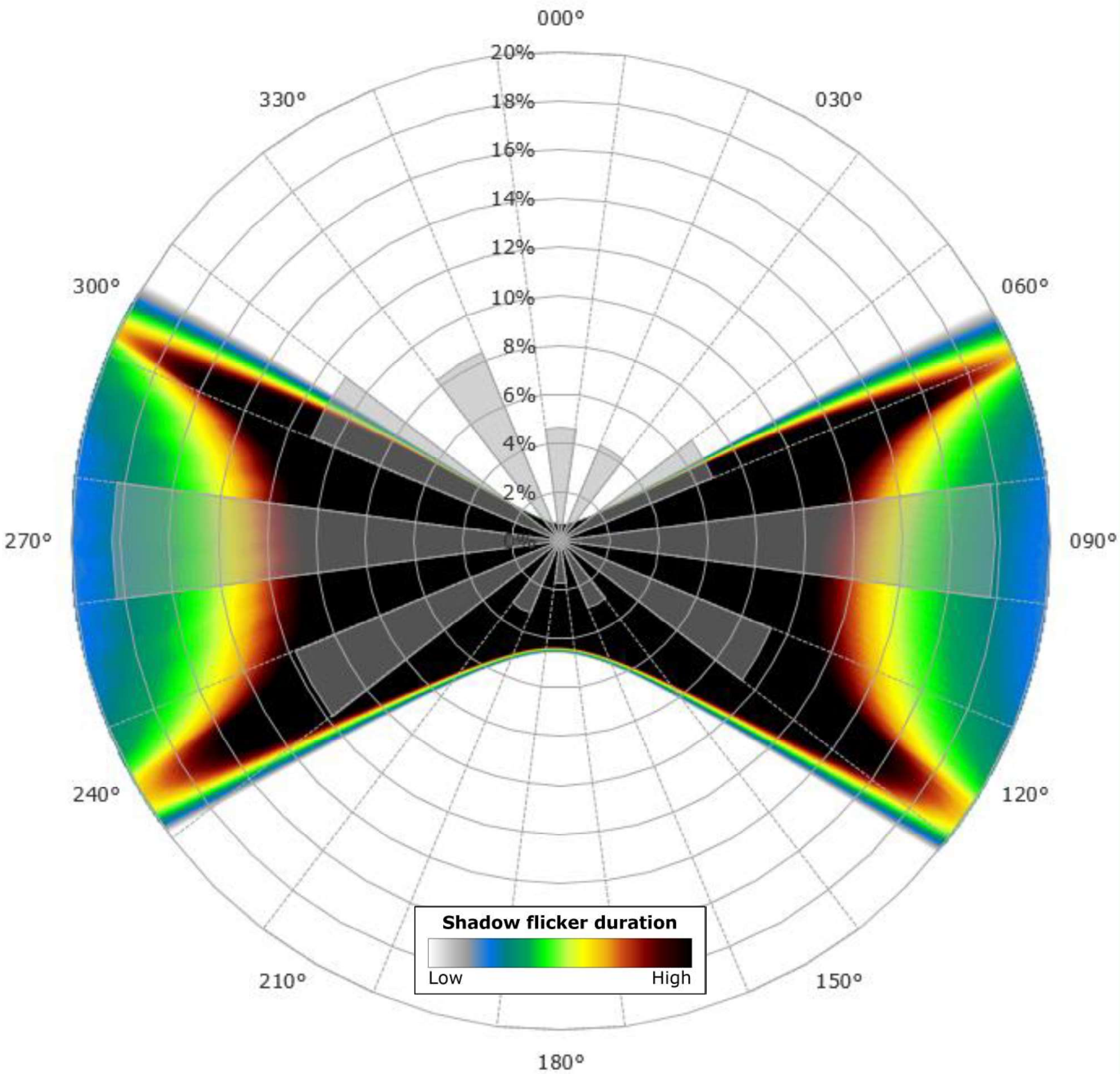

Figure 6 Indicative shadow flicker map and wind direction frequency distribution

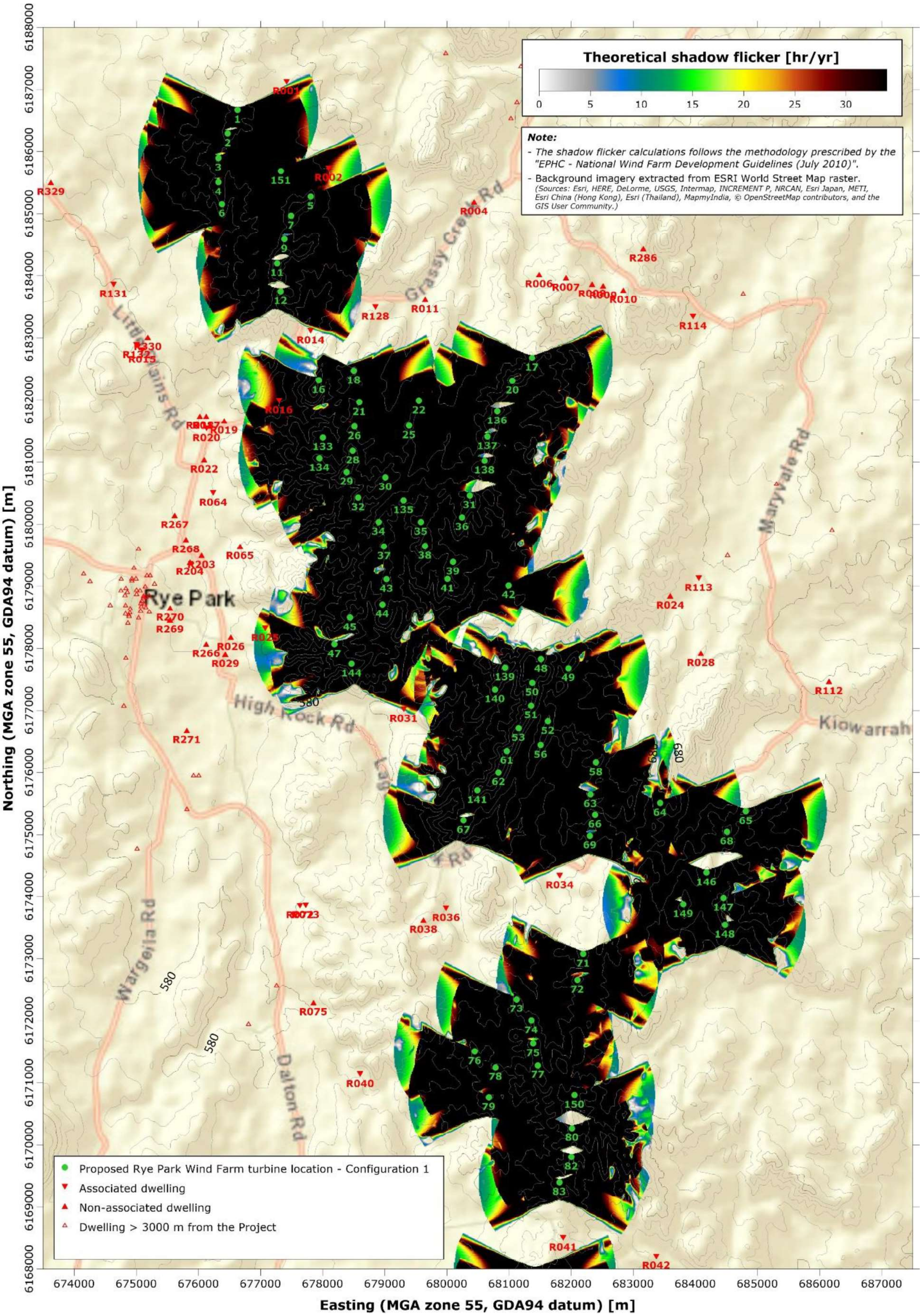

Figure 7 Theoretical annual shadow flicker duration map – Configuration 1 (north)

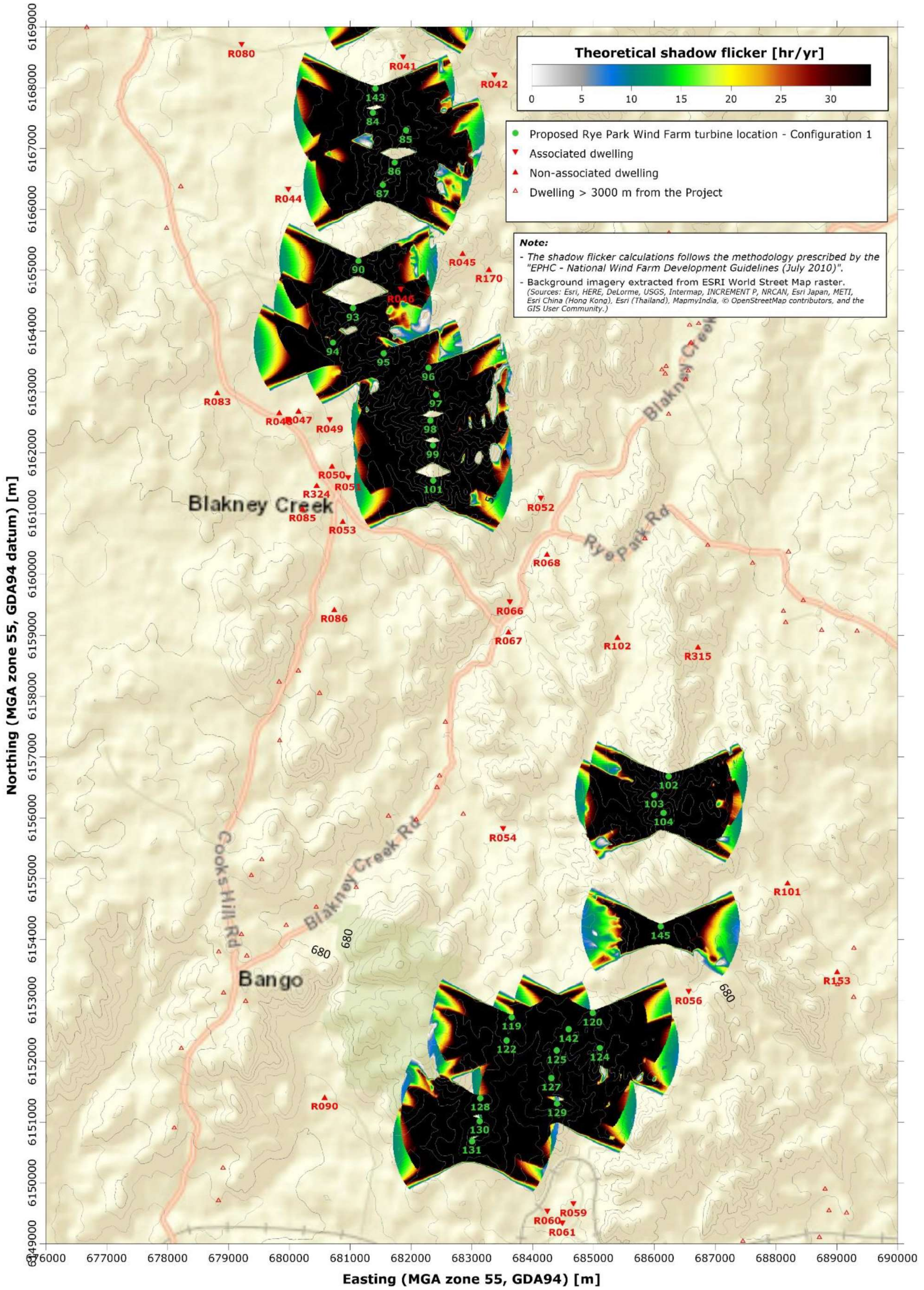

Figure 8 Theoretical annual shadow flicker duration map – Configuration 1 (south)

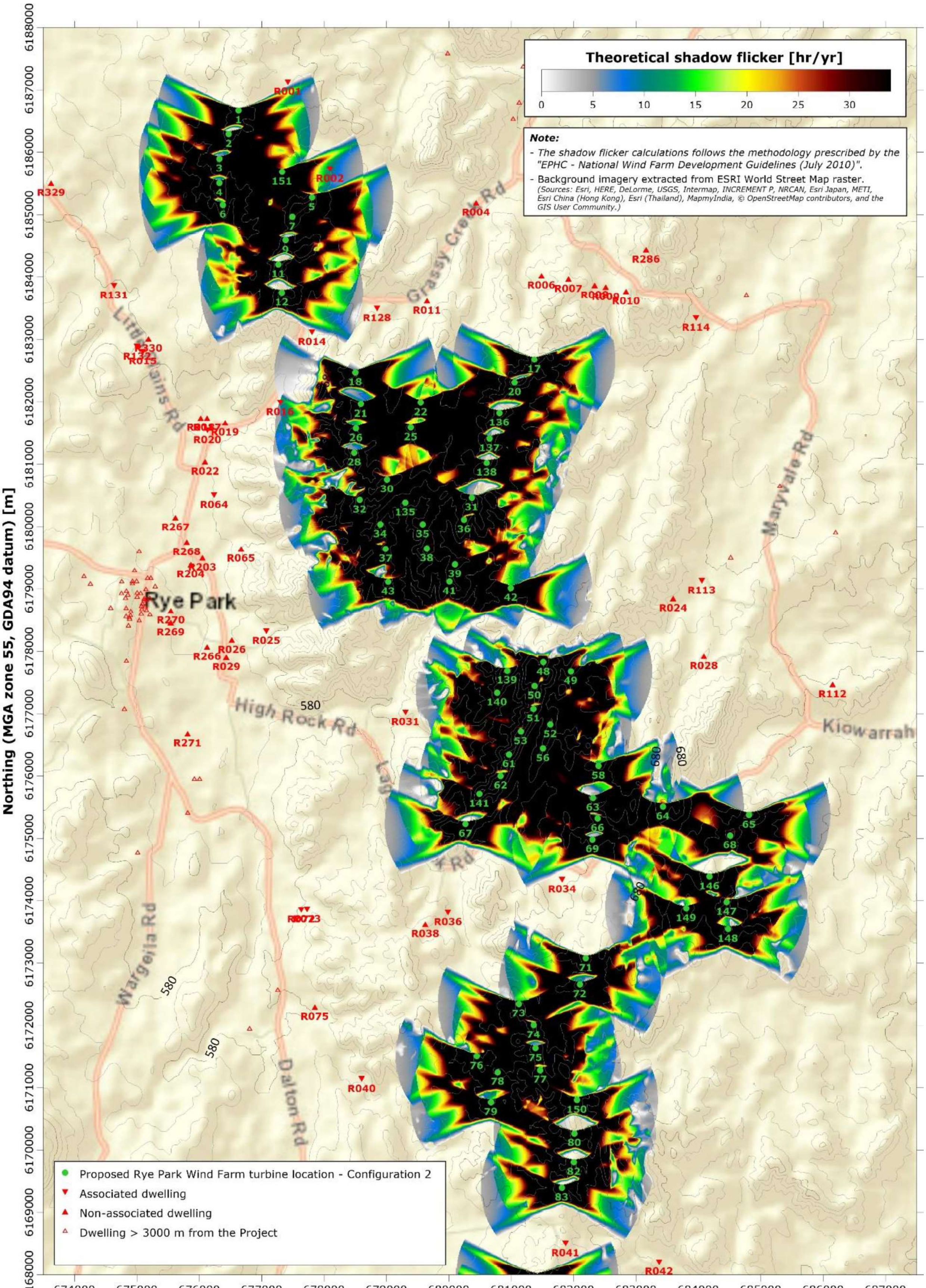

Figure 9 Theoretical annual shadow flicker duration map – Configuration 2 (north)

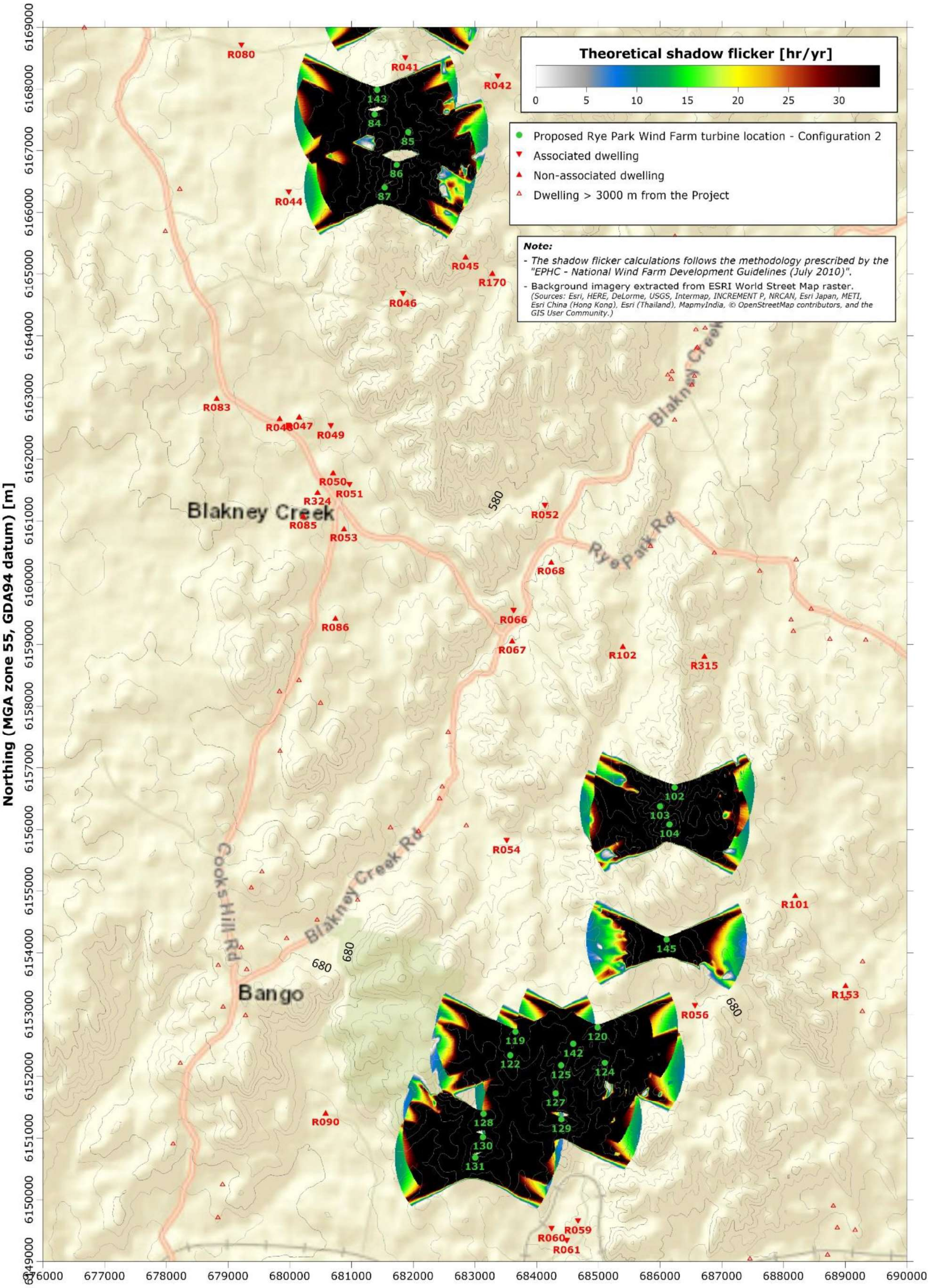

Figure 10 Theoretical annual shadow flicker duration map – Configuration 2 (south)

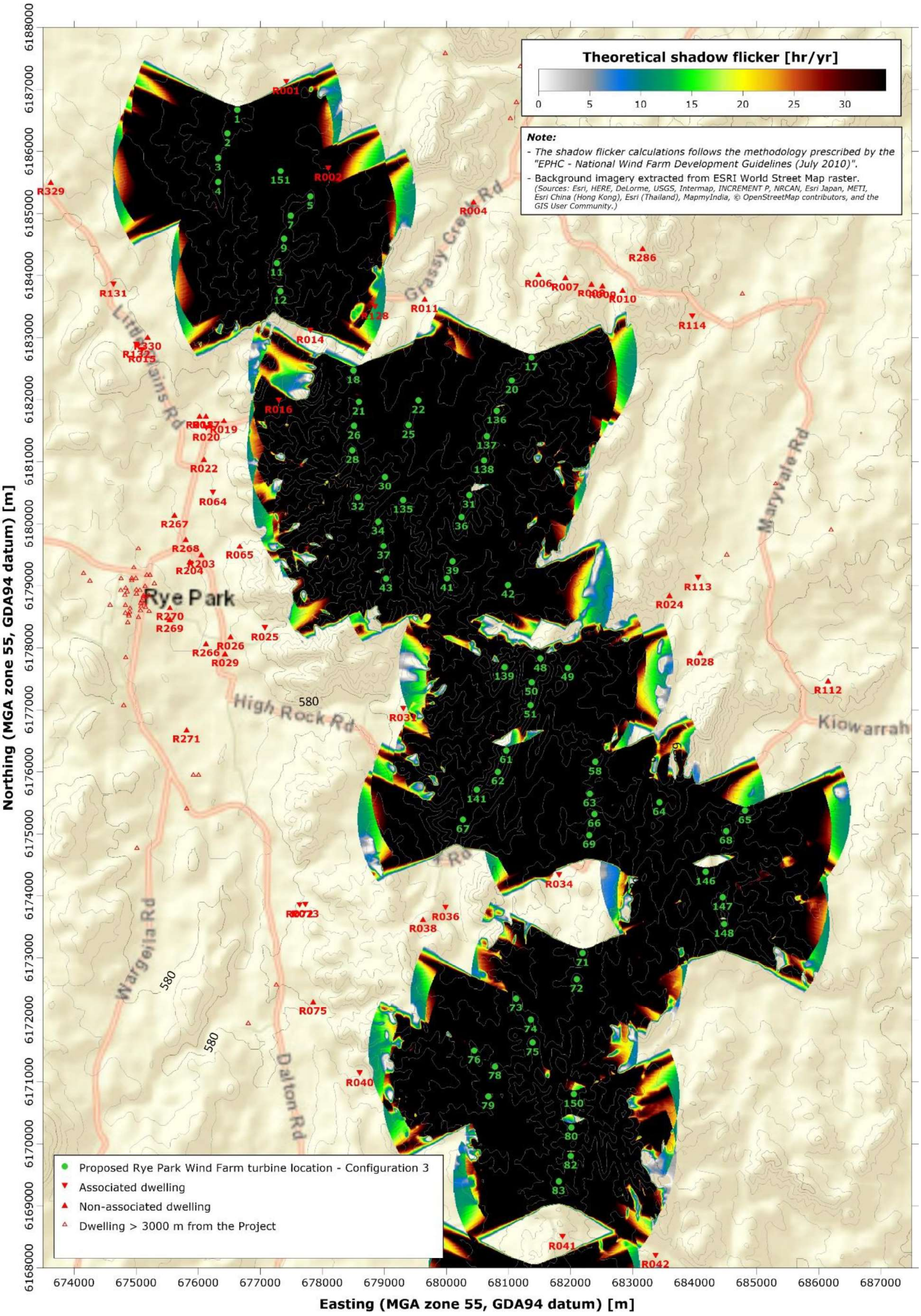

Figure 11 Theoretical annual shadow flicker duration map – Configuration 3 (north)

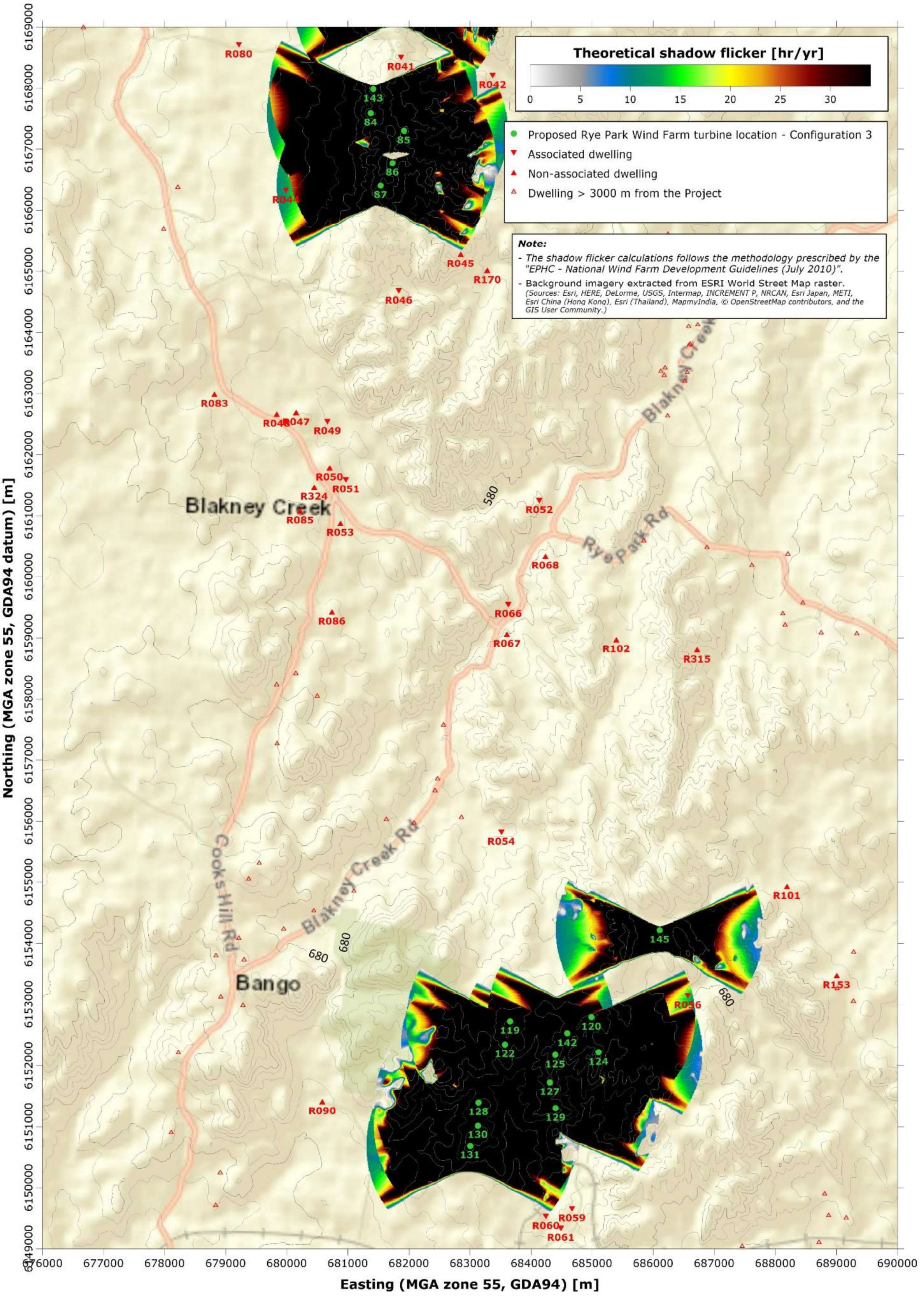

Figure 12 Theoretical annual shadow flicker duration map – Configuration 3 (south)

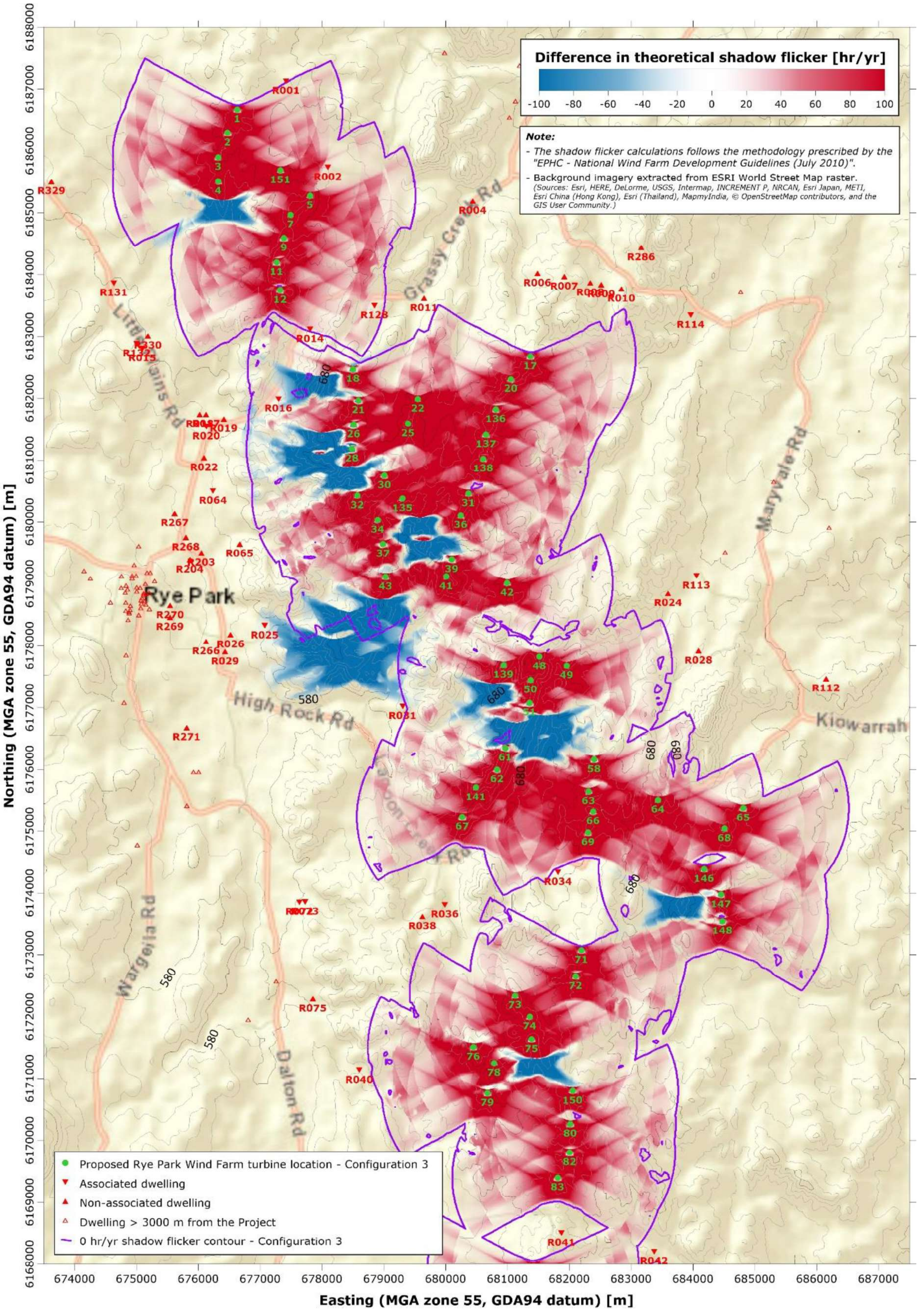

Figure 13 Additional theoretical shadow flicker exceedance areas – Configuration 3 compared to Configuration 1 (north)

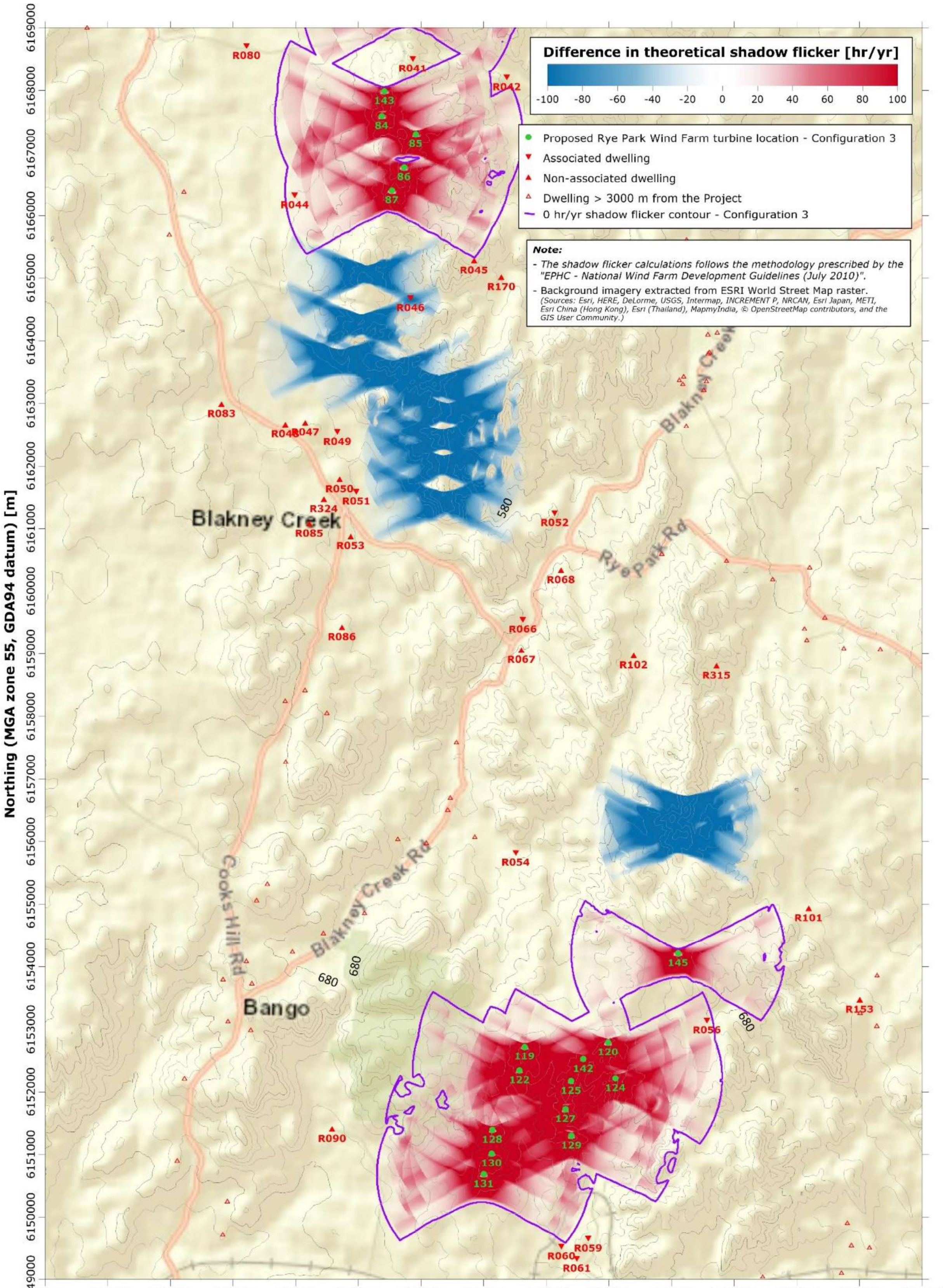

Figure 14 Additional theoretical shadow flicker exceedance areas – Configuration 3 compared to Configuration 1 (south)

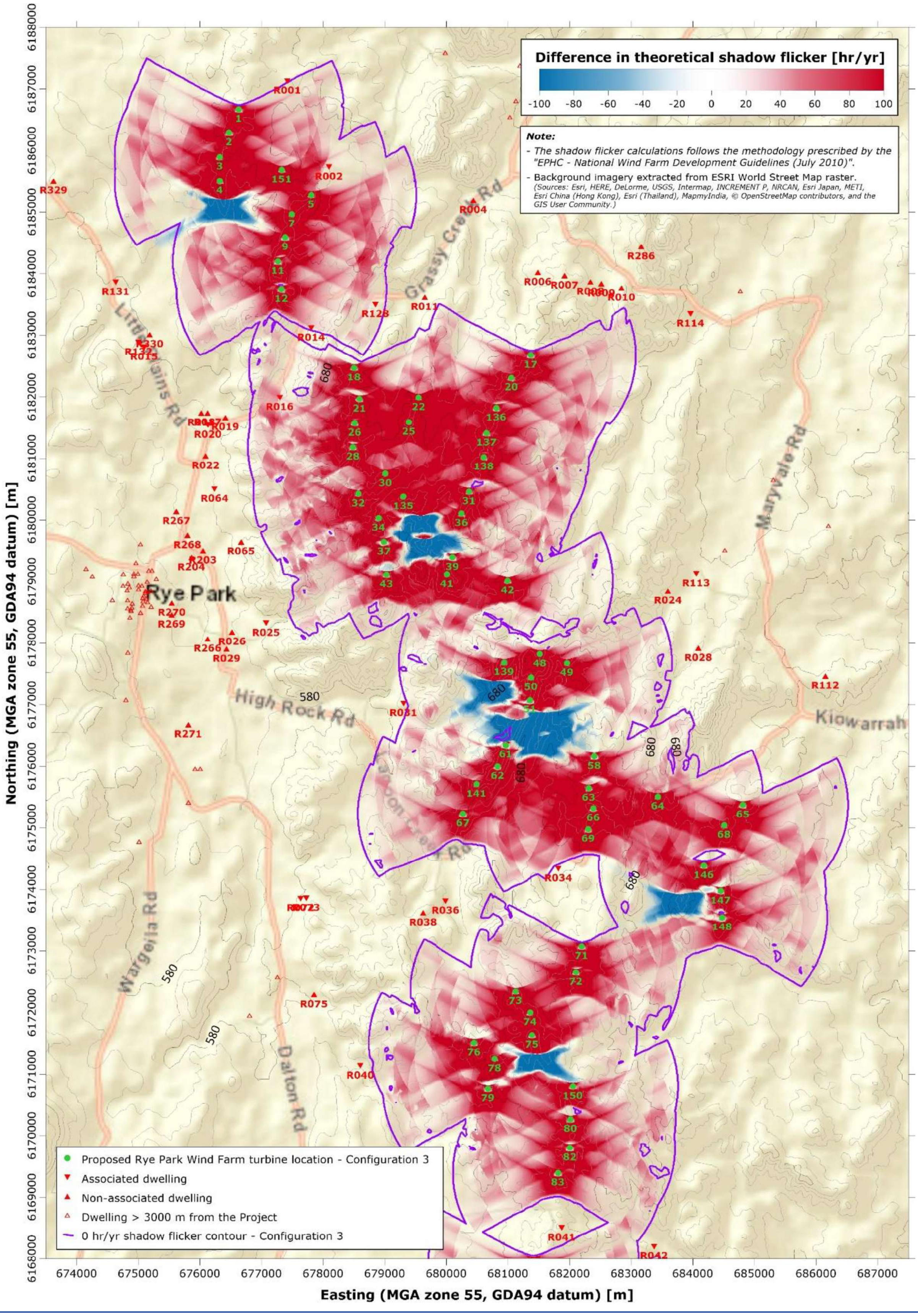

Figure 15 Additional theoretical shadow flicker exceedance areas – Configuration 3 compared to Configuration 2 (north)

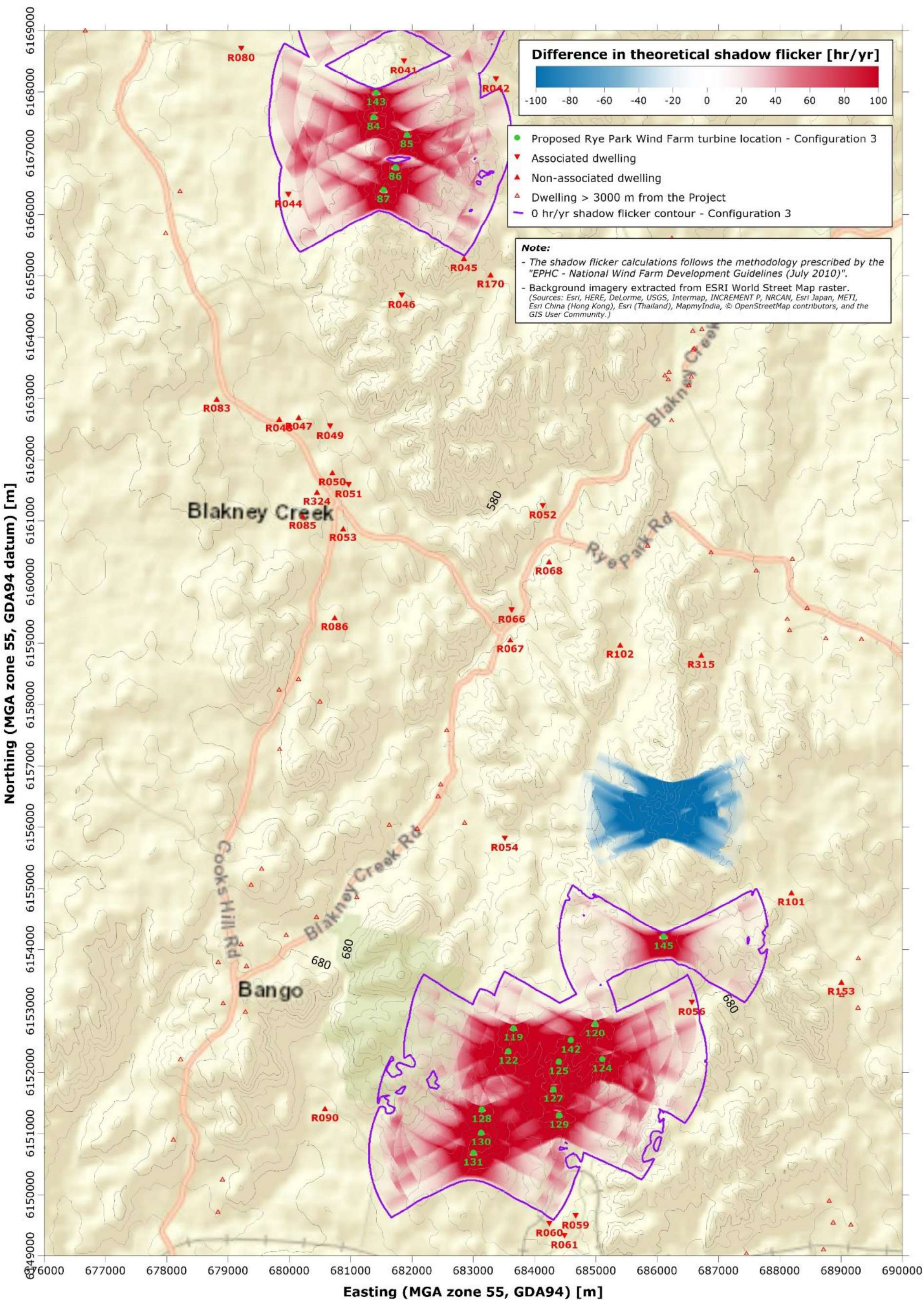

Figure 16 Additional theoretical shadow flicker exceedance areas – Configuration 3 compared to Configuration 2 (south)

APPENDIX A – ASSESSMENT OF PREDICTED ACTUAL SHADOW FLICKER DURATIONS

A.1 Background

As discussed in Section 4.1.5, there are a number of factors which may reduce the incidence of shadow flicker that are not considered in the calculation of the theoretical shadow flicker duration. Exclusion of these factors means that the theoretical calculation is likely to be conservative.

The two most significant, and easily estimated, effects are cloud cover and turbine orientation. When the sun is blocked due to cloud cover, the shadow intensity and hence the occurrence and duration of shadow flicker will be reduced. Similarly, turbine orientation can have an impact on the shadow flicker duration. When the turbine rotor is not perpendicular to a line joining the sun and an observer, the projected area of the turbine is reduced. Hence, the shadow flicker impact is greatest when the turbine rotor plane is approximately perpendicular to the line joining the sun and the observer, and a minimum when the rotor plane is approximately parallel to the line joining the sun and the observer.

The Draft National Guidelines recommend that the actual or measured shadow flicker duration should not exceed 10 hours per year at any dwelling. The Draft National Guidelines also provide a methodology for predicting the actual shadow flicker duration based on reductions due to cloud cover, and discuss the potential influence of other factors such as turbine orientation.

For the purpose of this assessment, the actual shadow flicker durations have been estimated to give stakeholders an indication of the difference between the theoretical shadow flicker impacts for the Project (as presented in Table 7 and discussed in Section 5.1.2) and the likely actual shadow flicker impacts, rather than to establish compliance.

A.1.1 Reducing shadow flicker due to cloud cover

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.

Cloud cover is typically measured in ‘oktas’ or effectively eighths of the sky covered with cloud. For Bureau of Meteorology (BoM) stations offering cloud cover data, the number of oktas of cloud cover visible across the sky is recorded twice daily, at 9 am and 3 pm, and the observations are provided as monthly averages. The average number of cloudy days in each month, where a cloudy day is defined as a day when the average of the morning and afternoon cloud cover observations is at least 6 oktas, is also recorded.

The Draft National Guidelines recommend accounting for reductions in the shadow flicker due to cloud cover based on observations from the nearest BoM station with at least three years of data as follows:

- determine the average proportion of cloudy days at 9 am and 3 pm for each month
- reduce the morning shadow flicker in each month by the proportion of cloudy days at 9 am, and reduce the afternoon shadow flicker in each month by the proportion of cloudy days at 3 pm
- determine total reduced shadow flicker duration for each month and then sum the monthly totals to obtain the resulting actual annual shadow flicker duration.

However, the methodology proposed in the Draft National Guidelines suffers from several limitations.

- Most significantly, the average monthly proportion of cloudy days is reported by the BoM as a single value rather than separate averages for the morning and afternoon based on the 9 am and 3 pm cloud cover observations. The Draft National Guidelines do not provide a method for determining the average proportion of cloudy days at 9 am and 3 pm using the available cloud cover data. Therefore, the proposed methodology cannot be implemented with the available data.

- Even if the required data were available, the proposed methodology does not account for potential reductions in shadow flicker due to cloud cover on days when the cloud cover is less than 6 oktas.
- The proposed methodology also does not account for situations where cloud cover observations at the nearest BoM station are not representative of the cloud cover at the site, due variation in cloud cover across the region or inconsistent or erroneous measurements.

Considering the available cloud cover data, a reasonable estimate of the likely impact of cloud cover on the shadow flicker duration can be obtained by reducing the morning and afternoon shadow flicker in each month by the average monthly cloud cover observations recorded at 9 am and 3 pm respectively. By considering the proportion of the sky covered with cloud rather than the number of cloudy days, this approach also includes the reductions in shadow flicker due to cloud cover on days when the cloud cover is less than 6 oktas. Potential inaccuracies in the cloud cover observations can be mitigated by averaging the data recorded at multiple BoM stations in the area around the wind farm, provided that the monthly observations for each station are consistent. Where the morning and afternoon cloud cover observations are similar, this approach may be simplified by applying a single reduction in shadow flicker for each month based on the average of the 9 am and 3 pm observations.

A.1.2 Reducing shadow flicker due to turbine orientation

The wind speed frequency distribution or wind rose at the site can be used to determine the probable turbine orientation and calculate the resulting reduction in shadow flicker duration.

The Draft National Guidelines suggest that the most accurate way to account for reductions in shadow flicker due to turbine orientation is to model the turbine rotor as a disc whose direction is determined probabilistically by the hourly and monthly wind distribution. Due to the perceived difficulty in obtaining suitable wind monitoring data and the additional analysis required to process that data, the Draft National Guidelines do not recommend including reductions due to turbine orientation when predicting the actual annual shadow flicker duration.

However, the Draft National Guidelines acknowledge that, in some cases, turbine orientation may have a substantial effect on the actual shadow flicker duration experienced at a given location. Therefore, if suitable data is available and the additional analysis effort is considered reasonable, DNV GL considers that there is no impediment to including reductions in shadow flicker due to turbine orientation when predicting the actual shadow flicker duration likely to be experienced at a given location.

A.2 Assessment methodology

A.2.1 Overview

To give stakeholders an indication of the difference between the theoretical shadow flicker impacts for the Project and the likely actual shadow flicker impacts at all relevant receptor locations, DNV GL has attempted to quantify the likely reduction in shadow flicker duration due to cloud cover and turbine orientation at those locations.

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. It is therefore likely that the adjusted shadow flicker durations presented here can still be regarded as a conservative assessment.

A.2.2 Reduction in shadow flicker due to cloud cover

DNV GL has reviewed the availability of cloud cover data at BoM stations in the area around the Project. Four BoM stations with suitable data were identified within approximately 100 km of the Project site:

- Goulburn TAFE (070263), located approximately 69 km east of the site [23]
- Taralga Post Office (070080), located approximately 78 km east of the site [24]
- Cootamundra Airport (073142), located approximately 87 km west of the site [25]
- Gundagai (Nangus Road) (073141), located approximately 100 km southwest of the site [26].

Some discrepancies were observed between the cloud cover observations recorded at the Goulburn and Taralga BoM stations, which are located closer to the coast, and those recorded at the Cootamundra and Gundagai BoM stations, which are further inland, particularly for the 9 am observations. Because the Project site is centrally located between the four BoM stations considered, representative values for the morning and afternoon cloud cover at the site were determined from distance-weighted averages of the cloud cover observations at all four stations for 9 am and 3 pm. Since the resulting monthly 9 am and 3 pm cloud cover values differed by less than 0.6 oktas, the analysis was simplified by considering the average daily cloud cover for each month rather than assessing the morning and afternoon cloud cover (and shadow flicker) separately.

The results of the analysis indicate that the average monthly cloud cover in the region extending to approximately 100 km from the Project site ranges between 48% and 61%, and the average annual cloud cover is approximately 53%. This means that on an average day, 53% of the sky in the vicinity of the Project 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. This reduction has been applied on a monthly basis as discussed in Section A.1.1. For example, if the cloud cover in a particular month is 50%, it is assumed that the actual shadow flicker experienced in that month will be 50% less than the theoretical modelled shadow flicker.

As discussed in Section A.1.1, the methodology used in this assessment deviates 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 and the limitations of the methodology proposed in the Draft National Guidelines, DNV GL believes that the approach adopted here provides a reasonable estimate of the likely impact of cloud cover on the shadow flicker duration.

A.2.3 Reduction in shadow flicker due to turbine orientation

A wind direction frequency distribution previously derived by DNV GL from data collected by the site monitoring masts was 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 6. The likely reduction in shadow flicker duration due to variation in turbine orientation was assessed on an annual basis.

As discussed in Section A.1.2, 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, the primary reason for this recommendation is the perceived difficulty in obtaining and analysing suitable wind monitoring data. Given that suitable wind data was available for the Project site and had already been processed and analysed, DNV GL considers that it is appropriate to apply an additional reduction in shadow flicker due to turbine orientation in this case.

A.3 Assessment results

A.3.1 Overview

The number of dwellings that are predicted to experience actual shadow flicker for each configuration, considering reductions in shadow flicker due to cloud cover and turbine configuration, and the expected changes in shadow flicker impact for Configuration 3 (80 turbine layout proposed by the modification application) compared to Configuration 1 (109 turbine layout – original development application) and Configuration 2 (92 turbine layout – existing development consent), are summarised in Table 12.

The predicted actual shadow flicker durations at all dwellings identified to be affected by shadow flicker are presented in Table 13, Table 14, and Table 15 for Configurations 1, 2, and 3 respectively. The maximum predicted shadow flicker durations within 50 m of these receptors are also presented in these tables. The results are also shown in the form of shadow flicker maps in Figure 17 to Figure 22. 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.

A.3.2 Discussion of shadow flicker results

For all three turbine configurations, the conclusions arising from the actual shadow flicker results when reductions due to cloud cover and turbine orientation are taken into account are similar to the theoretical shadow flicker results discussed in Section 5.1.2.

For Configuration 1, seven associated dwellings (R001, R002, R014, R016, R025, R031, and R046) are predicted to experience some shadow flicker when reductions in shadow flicker duration due to cloud cover and rotor orientation are taken into account. For Configuration 2, four associated dwellings (R001, R002, R014, and R016) are predicted to experience some actual shadow flicker. For Configuration 3, seven associated dwellings are also predicted to experience some actual shadow flicker (R001, R002, R014, R016, R044, R056, and R128), although the affected dwellings are different to those affected by Configuration 1.

For Configuration 1, four associated dwellings (R002, R016, R046, and R128) are predicted to experience actual shadow flicker durations that exceed the 10 hours per year limit recommended by the Draft National guidelines. For Configurations 2 and 3, two associated dwellings (R002 and R016) and three associated dwellings (R002, R014, and R016) respectively are predicted to experience actual shadow flicker durations that exceed 10 hours per year.

For all three configurations, no non-associated dwellings are predicted to experience shadow flicker durations above the 10 hours per year limit recommended by the Draft National Guidelines.

DNV GL notes that the actual shadow flicker durations at some associated dwellings are high for Configurations 1 and 3, with predicted actual shadow flicker durations reaching approximately 35 hours for Configuration 1 and approximately 22 hours for Configuration 3.

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. Therefore, the values presented may still be regarded as conservative.

The results presented have been generated based on hypothetical turbine models. If the turbine selected for the site has dimensions smaller than those considered, but within the indicative turbine envelope, then shadow flicker durations are likely to be lower than those predicted here.

A.3.3 Comparison to the previous shadow flicker assessment

The previous shadow flicker assessment [2] also attempted to predict the actual shadow flicker durations that would be experienced at dwellings in the vicinity of the Project for Configuration 1 by taking into account the reduction in shadow flicker due to cloud cover and rotor orientation. The results of the previous assessment are summarised and compared to the results obtained in the current assessment for Configuration 1 in Table 16.

While the current assessment considers the average monthly cloud cover at the site based on the proportion of the sky covered with cloud, the previous assessment applied a reduction in shadow flicker duration based on the average annual cloud cover based on the number of cloudy days. Since the extent and duration of shadow flicker experienced at any location depends, in part, on the time of year, assessing the reduction in shadow flicker due to cloud cover on a yearly rather than monthly basis may change the actual shadow flicker durations predicted at dwellings in the vicinity of the wind farm. Additionally, using the number of cloudy days rather than the amount of sky covered in cloud to estimate the reduction in shadow flicker due to cloud cover may influence the predicted actual shadow flicker durations, as indicated in Section A.1.1.

DNV GL also notes that the previous assessment compared the predicted actual shadow flicker durations against a limit of 30 hours per year, rather than the limit of 10 hours per year recommended by the Draft National Guidelines and considered in this assessment. The comparison presented in Table 16 lists the dwellings that are expected to receive actual shadow flicker durations above the limit of 10 hours per year recommended in the Draft National Guidelines for both the previous and current assessments.

Using a maximum shadow length of 1060 m and taking into account reductions in shadow flicker duration due to cloud cover and rotor orientation, the previous shadow flicker assessment predicted that three currently habitable dwellings would experience some shadow flicker. All three of those dwellings were predicted to experience actual shadow flicker durations that would exceed the 10 hours per year shadow flicker limit recommended by the Draft National Guidelines and considered in the current assessment. The same three dwellings are predicted to experience actual shadow flicker above the 10 hours per year limit for Configuration 1 in the current shadow flicker assessment. This is despite the smaller maximum shadow length applied in the previous assessment (1060 m) compared to the maximum shadow length applied in the current assessment (1300 m), due to differences in the methodologies used to assessment the reduction in shadow flicker due to cloud cover.

Using a maximum shadow length of 2000 m and taking into account reductions in shadow flicker duration due to cloud cover and rotor orientation, the previous shadow flicker assessment predicted that 27 currently habitable dwellings would experience some shadow flicker. Eight of those dwellings were predicted to experience actual shadow flicker durations that would exceed the 10 hours per year shadow flicker limit recommended by the Draft National Guidelines and considered in the current assessment. This is more than the three dwellings predicted to experience shadow flicker above the 10 hours per year limit for Configuration 1 in the current shadow flicker assessment. This is due to the larger maximum shadow length applied in the previous assessment (2000 m) compared to the maximum shadow length applied in the current assessment (1300 m) and differences in the methodologies used to assess the reduction in shadow flicker due to cloud cover.

Table 12 Summary of shadow flicker assessment results for the Project – predicted actual shadow flicker

Predicted actual shadow flicker within 50 m of dwelling	Number of dwellings affected						Anticipated change in impact for Configuration 3	
	Configuration 1 (development application)		Configuration 2 (consented)		Configuration 3 (proposed by Mod-1)			
	Total	Non-associated dwellings	Total	Non-associated dwellings	Total	Non-associated dwellings	Relative to Configuration 1	Relative to Configuration 2
Above 0 hours/year	7 (R001, R002, R014, R016, R025, R031, R046)	0	4 (R001, R002, R014, R016)	0	7 (R001, R002, R014, R016, R044, R056, R128)	0	3 additional dwellings affected (R044, R056, R128) 3 dwellings no longer affected (R025, R031, R046)	3 additional dwellings affected (R044, R056, R128)
Above Draft National Guidelines recommended limit of 10 hours/year	3 (R002, R016, R046)	0	2 (R002, R016)	0	4 (R002, R014, R016, R128)	0	2 additional dwellings affected (R014, R128) 1 dwelling no longer affected (R046)	2 additional dwellings affected (R014, R128)

Table 13 Predicted actual shadow flicker duration – Configuration 1

Dwelling ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Predicted actual shadow flicker[3] At dwelling [hr/yr] 2 m	Predicted actual shadow flicker[3] At dwelling [hr/yr] 6 m	Predicted actual shadow flicker[3] Max within 50 m of dwelling [hr/yr] 2 m	Predicted actual shadow flicker[3] Max within 50 m of dwelling [hr/yr] 6 m
R001	Associated	677418	6187127	1	0.0	0.0	1.4	1.9
R002	Associated	678095	6185733	151	**11.0**	**11.0**	**12.5**	**12.5**
R014	Associated	677807	6183115	12	0.0	0.0	1.5	0.9
R016	Associated	677297	6181991	16 21 26	**21.5**	**21.8**	**25.4**	**25.6**
R025	Associated	677075	6178323	47	6.4	6.4	7.7	7.7
R031	Associated	679304	6177019	144	1.8	1.4	4.2	3.8
R046	Associated	681835	6164679	90 93	**33.5**	**33.9**	**35.2**	**35.3**
Draft National Guidelines recommended limit					***10 hr/yr***			

1. Dwellings identified in Table 5 with no predicted shadow flicker occurrence for a distance limit of 10 times the rotor diameter, have been omitted from this table.
2. Coordinate system: UTM Zone 55, WGS84 datum.
3. Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.

Table 14 Predicted actual shadow flicker duration – Configuration 2

Dwelling ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Predicted actual shadow flicker[3] At dwelling [hr/yr] 2 m	Predicted actual shadow flicker[3] At dwelling [hr/yr] 6 m	Predicted actual shadow flicker[3] Max within 50 m of dwelling [hr/yr] 2 m	Predicted actual shadow flicker[3] Max within 50 m of dwelling [hr/yr] 6 m
R001	Associated	677418	6187127	1	0.0	0.0	1.4	1.9
R002	Associated	678095	6185733	151	**11.0**	**11.0**	**12.5**	**12.5**
R014	Associated	677807	6183115	12	0	0	1.5	0.9
R016	Associated	677297	6181991	21 26	9.5	9.8	**12.5**	**12.6**
Draft National Guidelines recommended limit					***10 hr/yr***			

1. Dwellings identified in Table 5 with no predicted shadow flicker occurrence for a distance limit of 10 times the rotor diameter, have been omitted from this table.
2. Coordinate system: UTM Zone 55, WGS84 datum.
3. Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.

Table 15 Predicted actual shadow flicker duration – Configuration 3

Dwelling ID[1]	Status	Easting[2] [m]	Northing[2] [m]	Contributing turbines	Predicted actual shadow flicker[3] At dwelling [hr/yr] 2 m	Predicted actual shadow flicker[3] At dwelling [hr/yr] 6 m	Predicted actual shadow flicker[3] Max within 50 m of dwelling [hr/yr] 2 m	Predicted actual shadow flicker[3] Max within 50 m of dwelling [hr/yr] 6 m
R001	Associated	677418	6187127	1	0.0	0.0	2.9	3.4
R002	Associated	678095	6185733	1 2 151	**18.5**	**18.4**	**35.2**	**34.9**
R014	Associated	677807	6183115	12	2.9	2.3	**10.5**	9.8
R016	Associated	677297	6181991	18 21 26	**20.9**	**21.1**	**22.1**	**22.6**
R044	Associated	679986	6166322	87	4.7	4.8	5.0	5.0
R056	Associated	686567	6153140	120	5.3	5.2	5.8	5.8
R128	Associated	678848	6183498	11 12	4.7	4.9	**10.0**	**10.3**
Draft National Guidelines recommended limit					***10 hr/yr***			

1. Dwellings identified in Table 5 with no predicted shadow flicker occurrence fora distance limit of 10 times the rotor diameter, have been omitted from this table.
2. Coordinate system: UTM Zone 55, WGS84 datum.
3. Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.

Table 16 Comparison of shadow flicker assessment results for Configuration 1 with the results of the previous shadow flicker assessment for the Project – predicted actual shadow flicker

Predicted actual shadow flicker within 50 m of dwelling	Number of dwellings affected		
	Previous shadow flicker assessment		Current shadow flicker assessment
	Maximum shadow length of 1060 m	Maximum shadow length of 2000 m	Maximum shadow length of 1300 m
Above 0 hours/year	4 (3 currently habitable) (R002, R016, R030[1], R046)	28 (27 currently habitable) (R002, R016, R018, R019, R020, R022, R025, R026, R029, R030[1], R031, R034, R042, R044, R045, R046, R047, R048, R049, R050, R051, R052, R053, R056, R059, R064, R128, R324)	7 (R001, R002, R014, R016, R025, R031, R046)
Above Draft National Guidelines recommended limit of 10 hours/year	4 (3 currently habitable) (R002, R016, R030[1], R046)	9 (8 currently habitable) (R002, R016, R019, R025, R030[1], R031, R046, R049, R051)	3 (R002, R016, R046)

1. Dwelling has been identified as uninhabitable [22] and excluded from the current shadow flicker assessment.

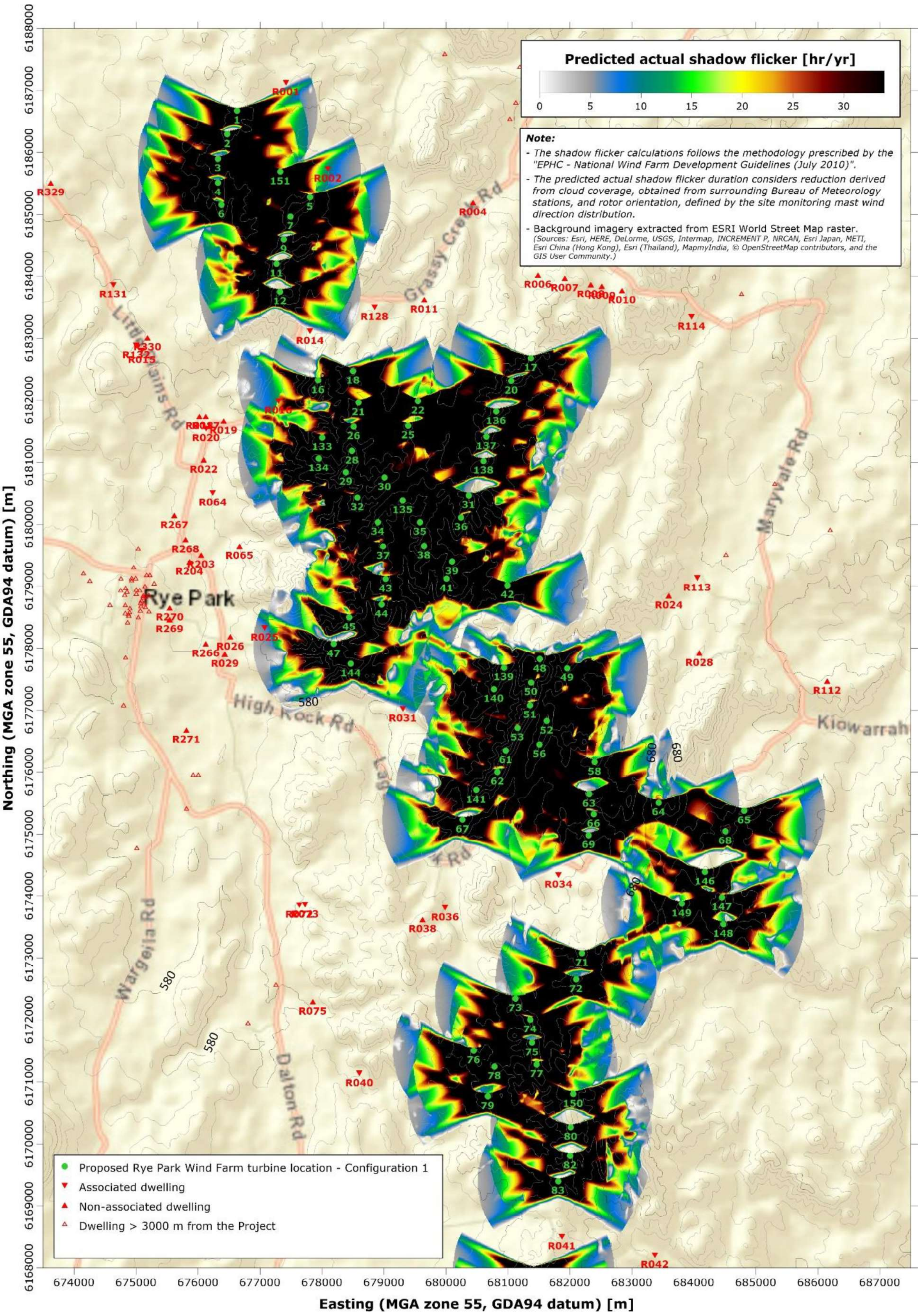

Figure 17 Predicted actual annual shadow flicker duration map – Configuration 1 (north)

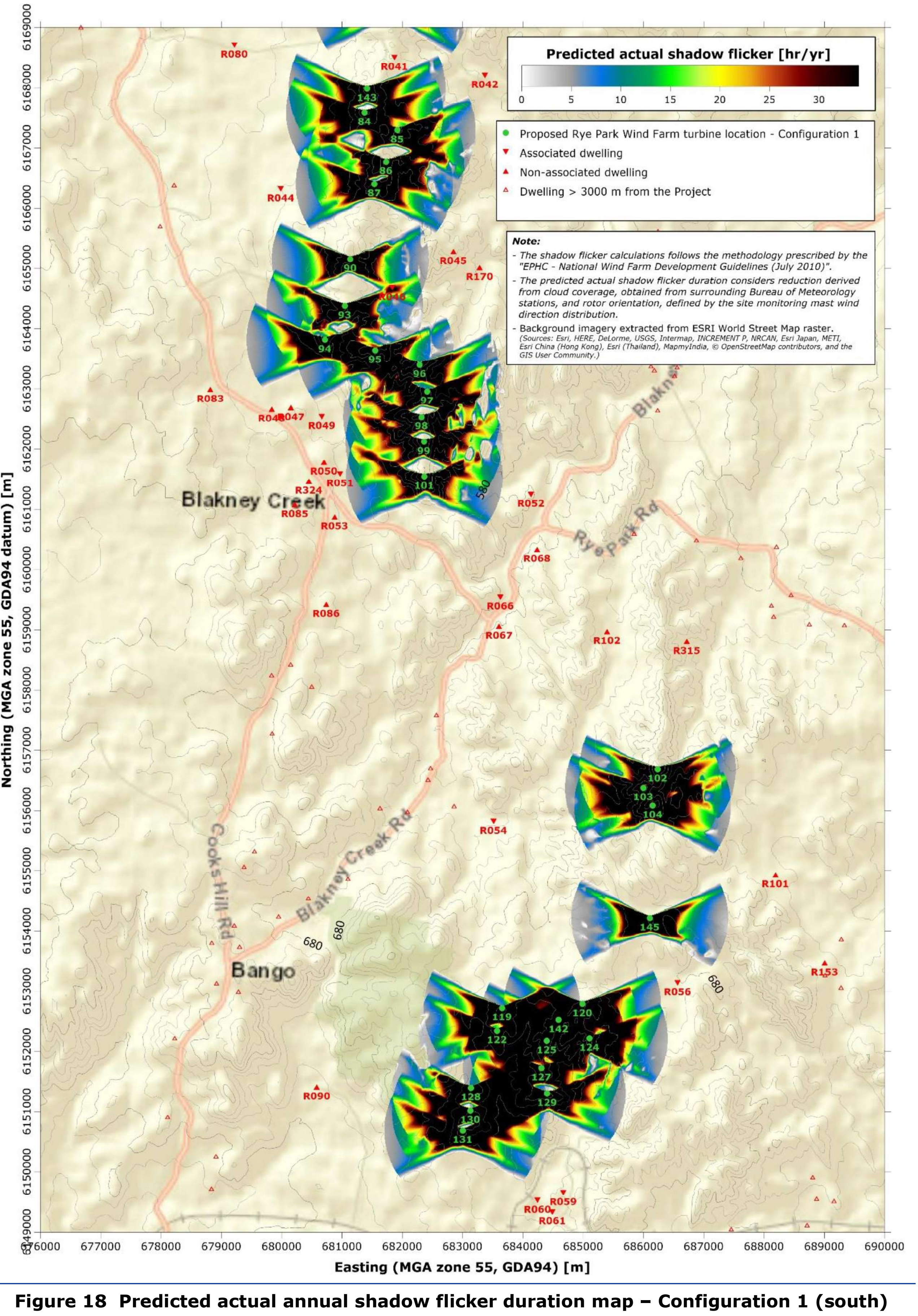

Figure 18 Predicted actual annual shadow flicker duration map – Configuration 1 (south)

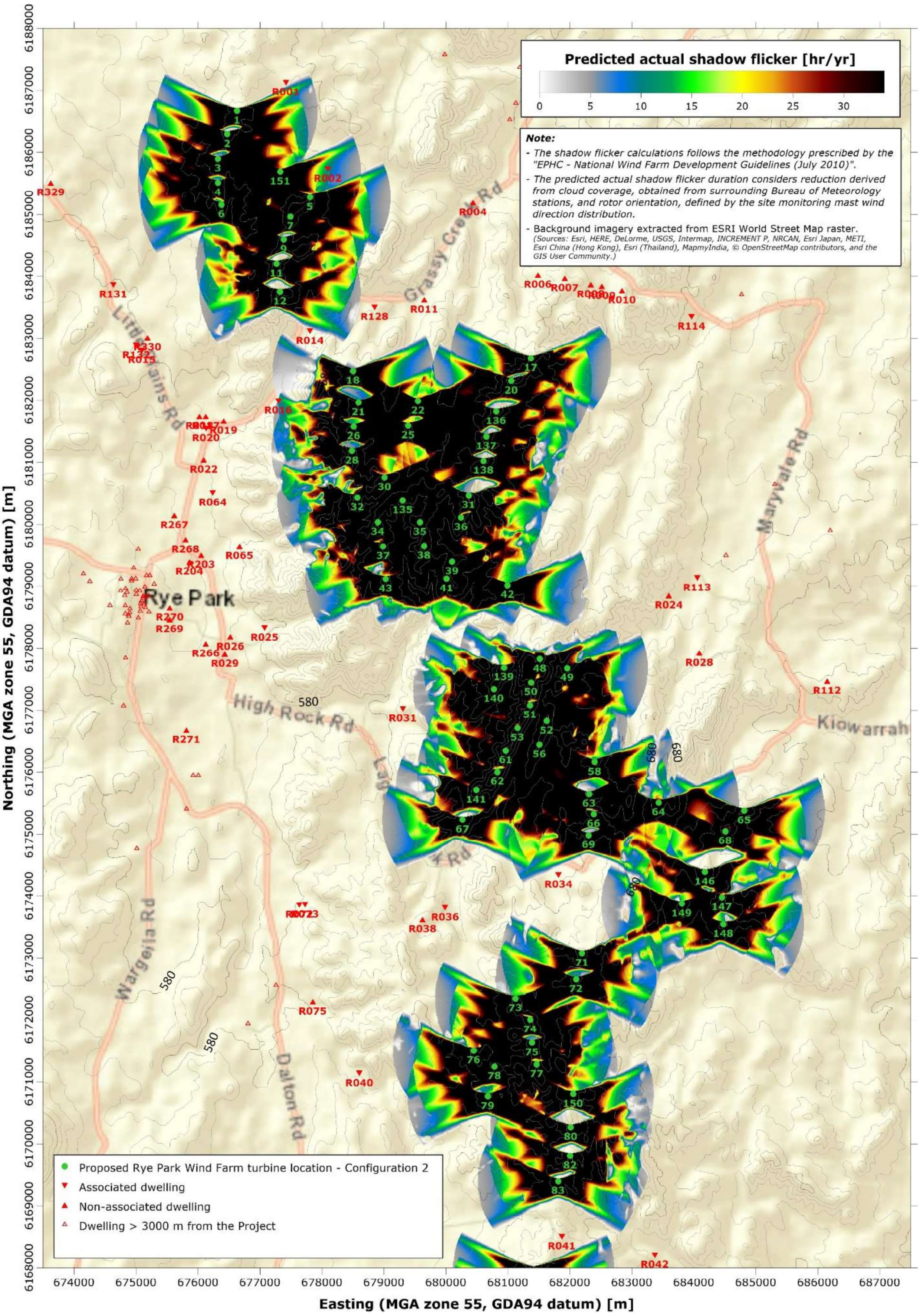

Figure 19 Predicted actual annual shadow flicker duration map – Configuration 2 (north)

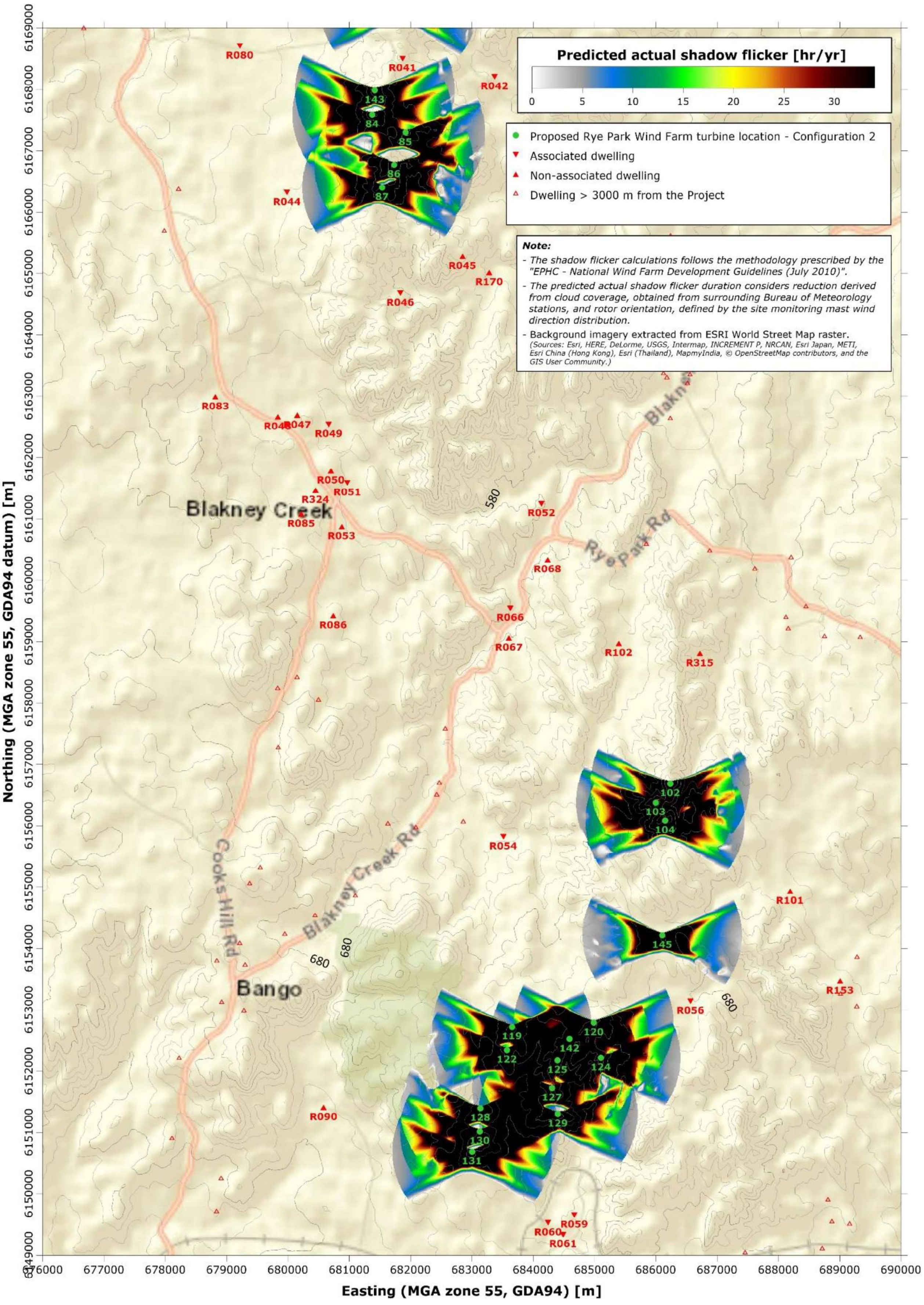

Figure 20 Predicted actual annual shadow flicker duration map – Configuration 2 (south)

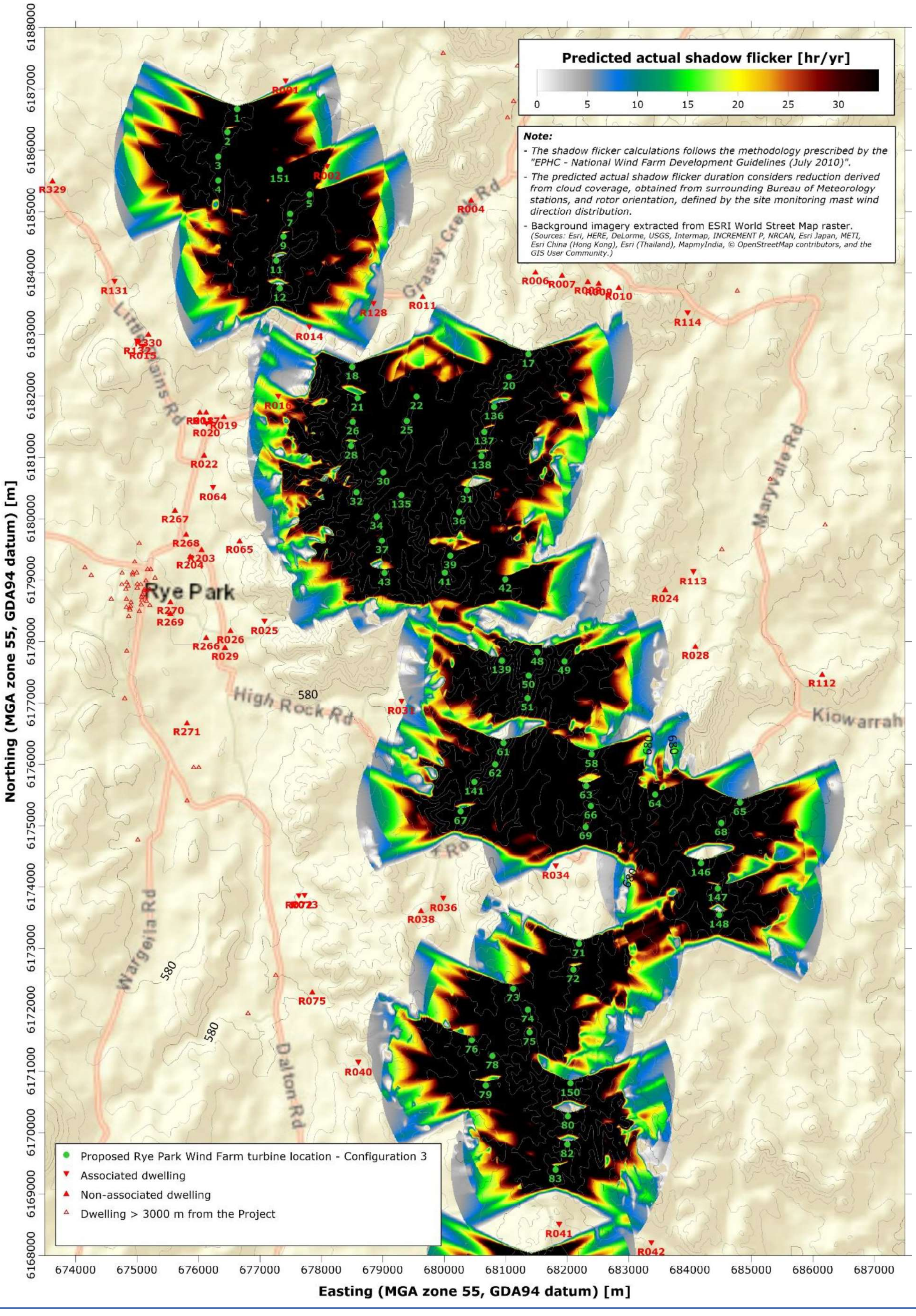

Figure 21 Predicted actual annual shadow flicker duration map – Configuration 3 (north)

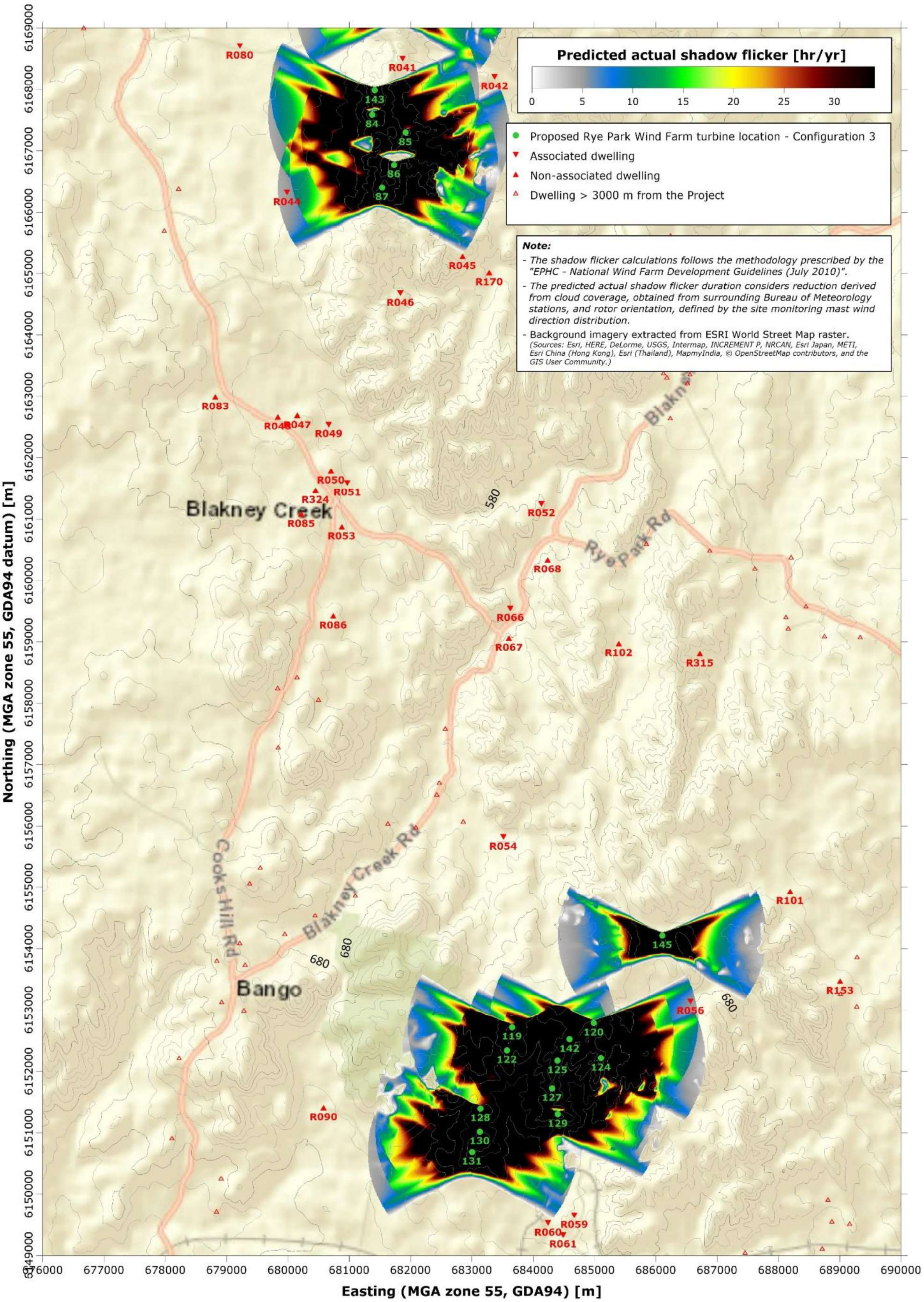

Figure 22 Predicted actual annual shadow flicker duration map – Configuration 3 (south)

APPENDIX B – ASSESSMENT OF SHADOW FLICKER BELOW A MODERATE LEVEL OF INTENSITY

B.1 Background

As discussed in Sections 3.1.2 and 4.1.3, the impact of shadow flicker is only significant up to a limited distance from the wind turbine. At a distance greater than approximately 10 times the rotor diameter, or 265 times the maximum blade chord length, it is typically 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 annoyed by shadow flicker intensities below a "moderate level of intensity".

Although the methodology proposed in the Draft National Guidelines only considers shadow flicker above a moderate level of intensity, DNV GL believes there is value in also considering the potential for shadow flicker at lower intensities to cause annoyance.

For the purpose of this assessment, the theoretical shadow flicker durations for shadow flicker below a moderate level of intensity have been estimated to give stakeholders an indication of the potential impacts compared to the results for shadow flicker above a moderate level of intensity (as presented in Table 7 and discussed in Section 5.1.2), rather than to establish compliance.

B.2 Assessment methodology

To consider the potential impacts of shadow flicker below a moderate level of intensity, DNV GL has assessed the shadow flicker durations for the Project for a distance limit of 15 times the rotor diameter. This is equal to 1.5 times the original distance limit of 10 times the rotor diameter assumed in Section 4.1.3, and corresponds to a maximum shadow length of 1950 m for Configurations 1 and 2 and 2475 m for Configuration 3. A shadow length of 15 times the rotor diameter was chosen to include shadow flicker below a "moderate level of intensity" but above the threshold of perception, which may cause annoyance to some people, and is based on DNV GL's observations of actual shadow flicker intensities at operational wind farms in Australia.

The theoretical number of hours of shadow flicker experienced annually at each dwelling location for the increased distance limit of 15 times the rotor diameter was calculated as described in Section 4.1.2.

B.3 Assessment results

The number of dwellings that are predicted to experience theoretical shadow flicker for each configuration, considering shadow flicker below a moderate level of intensity, and the expected changes in shadow flicker impact for Configuration 3 (80 turbine layout proposed by the modification application) compared to Configuration 1 (109 turbine layout – original development application) and Configuration 2 (92 turbine layout – existing development consent), are summarised in Table 17.

Depending on the turbine configuration considered, up to seven additional dwellings are predicted to experience a theoretical shadow flicker duration that exceeds the relevant limits when shadow flicker below a moderate level of intensity is considered, compared to the number of dwellings affected when only shadow flicker above a moderate level of intensity is considered. This includes up to two non-associated dwellings. Although there is no requirement under the Draft National Guidelines to consider shadow flicker below a moderate level of intensity, the shadow flicker experienced at these dwellings may cause annoyance in some circumstances. DNV GL recommends that the Customer considers the results of this assessment and uses them to inform discussions with landowners.

Table 17 Summary of shadow flicker assessment results for the Project – theoretical shadow flicker below a moderate level of intensity

Predicted actual shadow flicker within 50 m of dwelling	Number of dwellings affected						Anticipated change in impact for Configuration 3	
	Configuration 1 (development application)		Configuration 2 (consented)		Configuration 3 (proposed by Mod-1)			
	Total	Non-associated dwellings	Total	Non-associated dwellings	Total	Non-associated dwellings	Relative to Configuration 1	Relative to Configuration 2
Above 0 hours/year	32 (R001, R002, R011, R014, R016, R017, R018, R019, R020, R022, R025, R026, R029, R031, R034, R040, R042, R044, R045, R046, R047, R048, R049, R050, R051, R052, R053, R054, R056, R059, R064, R128)	12 (R011, R017, R018, R019, R022, R026, R029, R045, R047, R048, R050, R053)	13 (R001, R002, R011, R014, R016, R031, R034, R040, R042, R044, R056, R059, R128)	1 (R011)	32 (R001, R002, R011, R014, R015, R016, R017, R018, R019, R020, R022, R025, R028, R031, R034, R036, R040, R042, R044, R056, R059, R064, R065, R080, R090, R101, R111, R128, R132, R170, R328, R330)	13 (R011, R017, R018, R019, R022, R028, R065, R090, R101, R111, R170, R328, R330)	12 additional dwellings affected (R015, R028, R036, R065, R080, R090, R101, R111, R132, R170, R328, R330) 12 dwellings no longer affected (R026, R029, R045, R046, R047, R048[1], R049, R050, R051, R052, R053, R054)	19 additional dwellings affected (R015, R017, R018, R019, R020, R022, R025, R028, R036, R064, R065, R080, R090, R101, R111, R132, R170, R328, R330)
Above Development Consent limit of 30 hours/year	8 (R002, R016, R019, R025, R031, R046, R049, R051)	1 (R019)	3 (R002, R016, R031)	0	11 (R002, R014, R016, R019, R031, R034, R042, R044, R056, R065, R128)	2 (R019, R065)	7 additional dwellings affected (R014, R034, R042, R044, R056, R065, R128) 4 dwellings no longer affected (R025, R046, R049, R051)	3 additional dwellings affected (R019, R056, R065)

About DNV GL

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