DNV·GL

CROOKWELL 2 WIND FARM

Shadow Flicker and Blade Glint Assessment

Crookwell Development Pty Ltd

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1 EXECUTIVE SUMMARY

DNV GL has been commissioned by Union Fenosa Wind Australia Pty Ltd ("the Client" or "UFWA") on behalf of Crookwell Development Pty Ltd to independently assess the shadow flicker impact of proposed changes to the approved Crookwell 2 Wind Farm. UFWA intends to apply for a modification to the approved Crookwell 2 Wind Farm development consent granted in 2009, for an increase in overall turbine envelope size from 128 metres to 160 metres that includes a hub height of up to 95 metres, and a rotor diameter up to 130 metres, and a reduction in number of approved turbine locations from 46 to 33. The results of the work are reported here. This document has been prepared pursuant to DNV GL proposal 170691-AUME-P-001 Issue B, dated 16 July 2015, and is subject to the terms and conditions therein.

Shadow flicker involves the modulation of light levels resulting from the periodic passage of a rotating wind turbine blade between the sun and an observer. The duration of shadow flicker experienced at a specific location can be determined using a purely geometric analysis which takes into account the relative position of the sun throughout the year, the wind turbines at the site, local topography and the viewer. This method has been used to determine the shadow flicker duration at sensitive locations neighbouring the proposed Crookwell 2 Wind Farm.

However, this analysis method tends to be conservative and typically results in over-estimation of the number of hours of shadow flicker experienced at a dwelling [1]. Therefore, an attempt has been made to quantify the likely reduction in shadow flicker duration due to turbine orientation and cloud cover, and hence produce a prediction of the actual shadow flicker duration likely to be experienced at a dwelling.

The Crookwell 2 Wind Farm is located beside the Crookwell 1 and Crookwell 3 Wind Farms and UFWA has commissioned DNV GL to assess the cumulative shadow flicker impact of all the Crookwell turbines upon dwellings neighbouring the Crookwell 2 Wind Farm. DNV GL has been informed that the Crookwell 1 Wind Farm contains eight operational turbines with a rotor diameter of 44 m and hub height of 45 m [2]. The Crookwell 3 Wind Farm consists of 23 proposed turbines, which, for the purposes of this assessment, have been assumed to have a rotor diameter of 130 m and a hub height of 95 m [3]. UFWA have also requested that DNV GL assess the 33 turbine layout of Crookwell 2 considering a hypothetical turbine model with 130 m rotor diameter and 95 m hub height [4].

UFWA has also provided the locations of 116 dwellings in the vicinity of the wind farm [4, 5], 13 of which are identified as a project host landholder. UFWA have also supplied elevation contours for the site area [7]. These have been used to determine the theoretical duration of shadow flicker caused by the Crookwell 2 Wind Farm at each dwelling.

The Draft NSW Planning Guidelines [8] recommend a shadow flicker limit of 30 hours per year. However, the Draft NSW Guidelines do not contain or recommend a methodology for assessing shadow flicker durations. Planning guidelines in a number of other jurisdictions [9, 10] refer to the EPHC Draft National Wind Farm Development Guidelines [11] for guidance on the methodology for assessing shadow flicker durations. This assessment was based on the methodology recommended in the Draft National Wind Farm Development Guidelines. Calculations were carried out assuming houses had either one or two stories with window heights of either 2 m or 6 m, respectively. The relevant shadow flicker duration at a dwelling was taken as the maximum calculated duration occurring within 50 m of the dwelling.

The results indicate that, of the dwellings identified by UFWA for study, there are locations within 50 m of nine dwellings that are predicted to experience some shadow flicker from the Crookwell 2 wind turbines. Eight of these locations are predicted to experience a theoretical shadow flicker duration in excess of the recommended limit of 30 hours per year, however DNV GL has been informed that these are all host dwellings. When considering the predicted actual shadow flicker duration, which takes into account the reduction in shadow flicker due to turbine orientation and cloud cover, the same eight host dwellings are expected to experience shadow flicker durations in excess of the recommended limit of 10 hours per year within 50 m of the house location.

However, the shadow flicker durations predicted at some of the host dwellings are significantly higher than the recommended limits, and therefore DNV GL recommends that the Client approach the owners and occupiers of dwellings where the predicted shadow flicker duration exceeds the recommended limit to discuss the matter.

The prediction of the actual shadow flicker duration does not take into account any reduction due to low wind speed, vegetation or other shielding effects around each house in calculating the number of shadow flicker hours. Therefore, the values presented may still be regarded as conservative. The effects of shadow flicker can 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.

It should be noted that the results presented here have been generated based on a hypothetical turbine configuration with a 95 m hub height and 130 m blade diameter, as discussed in Section 2.2. If the turbine selected for the site has dimensions smaller than those considered here, but still within the turbine envelope, then shadow flicker durations in the vicinity of the site are likely to be lower than those predicted here.

Blade glint involves the reflection of light from a turbine blade, and can be seen by an observer as a periodic flash of light coming from the wind turbine. Blade glint is not generally a problem for modern turbines provided non-reflective coatings are used for the surface of the blades.

2 DESCRIPTION OF THE PROPOSED WIND FARM SITE

2.1 The Project

UFWA are developing the proposed Crookwell 2 Wind Farm, located approximately 13 km southeast of the town of Crookwell and 25 km northwest of Goulburn, NSW. The terrain at the proposed Crookwell 2 Wind Farm can be described as undulating, with elevations varying between approximately 800 m and 950 m above sea level. The site and surrounds can generally be described as open farmland interspersed with areas of tall trees and wind breaks. The Pejar dam is located to the south of the Crookwell 2 Wind Farm site.

Detailed elevation data for the site area and immediate surrounds was provided to DNV GL by UFWA [7]. The elevation contours for the Crookwell 2 Wind Farm are displayed in Figure 3.

2.2 Proposed Wind Farm Layout

The proposed amendment to the approved Crookwell 2 Wind Farm is for an increase in overall turbine envelope size from 128 metres to up to 160 metres that includes a hub height of up to 95 metres, and a rotor diameter up to 130 metres, and a reduction in number of approved wind turbine generator locations from 46 to 33 [23]. The turbines are proposed to be located upon the local hilltops across the site with base elevations ranging from approximately 860 m to 950 m above sea level.

DNV GL has modelled the shadow flicker using a hypothetical turbine with a 95 m hub height and 130 m blade diameter configuration, as requested by UFWA [4]. These turbine dimensions are intended to encapsulate the turbine configurations under consideration for the site. The results generated based on these dimensions will be conservative for turbine configurations with dimensions that remain inside the turbine envelope by satisfying all of the following criteria:

- A rotor diameter of 130 m or less;
- A maximum blade chord of 4.9 m;
- An upper blade tip height of 160 m or less;
- A lower tip height of 30 m or greater.

A list of coordinates of the proposed turbine locations are given in Table 2.

2.3 House Locations

A list of houses neighbouring the wind farm was supplied to DNV GL by UFWA [4, 5].

This list of houses also includes several house locations listed as 'uninhabitable' in discussions with UFWA [6]. These locations have been included in the analysis at this stage, however it is understood that UFWA aims to have agreements with the relevant host landowners to disregard these dwellings.

The coordinates of dwellings in the vicinity of the wind farm are presented in Table 1. DNV GL has assumed that all listed houses are potential inhabited residential locations. It should be noted that DNV GL has not carried out a detailed and comprehensive survey of house locations in the area and is relying on information provided by the Client.

3 PLANNING GUIDELINES

The Department of Planning and Environment has acknowledged UFWA's intention to modify the development consent for the Crookwell 2 Wind Farm [12] and has stated the following with regard to shadow flicker:

> *"…the [Environmental Assessment] should include at least the following: … a visual assessment of the project (as modified) on all residents within 5 km of the wind farm, including any changes to … shadow flicker [and] blade glint … ."*

In addition, the Draft NSW Planning Guidelines for Wind Farms (Draft NSW Guidelines) [8] currently state:

> *"The impact of 'shadow flicker' from wind turbines on neighbours' houses within 2 km of a proposed wind turbine should be assessed. The shadow flicker experienced at any dwelling should not exceed 30 hours per year as a result of the operation of the wind farm. Specialist modelling software should be used to model shadow flicker impacts prior to the finalisation of the turbine layout."*

Although the Draft NSW Guidelines specify a shadow flicker limit (30 hours per year), neither the SEARs or the Draft NSW Guidelines specify a methodology for assessing shadow flicker impacts. Guidelines for wind farm development in other jurisdictions (including Victoria [9] and Queensland [10]) refer to the EPHC Draft National Wind Farm Development Guidelines (Draft National Guidelines) [11] with regard to the methodology for assessing shadow flicker. DNV GL has utilised this methodology to conduct shadow flicker assessments across Australia and has utilised it to assess the shadow flicker impact for the Crookwell 2 Wind Farm.

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

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

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

The impact of shadow flicker is typically only significant up to a distance of approximately 10 rotor diameters from a turbine [13] or approximately 800 to 1300 m for modern wind turbines (which typically have rotor diameters of 80 to 130 m). 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 therefore suggest a distance equivalent to 265 maximum blade chords[1] as an appropriate limit, which corresponds to approximately 800 to 1325 m for modern wind turbines (which typically have maximum blade chord lengths of 3 to 5 m).

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

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

The Draft National Guidelines also provide commentary on the negligible risk of distraction of vehicle drivers, and state the following:

> *"There is a negligible risk associated with distraction of vehicle drivers who experience shadow flicker, for the following reasons:*
>
> - *Shadow flicker is little different for a vehicle in motion than the effect of shadows from trees on the side of the road or high passing vehicles, neither of which represent a significant risk in terms of road transport.*
> - *In spite of extensive searches, no references to motor vehicle accidents caused by this phenomenon have been found.*
>
> *It is noted, however, that until wind farms become widespread in Australia they will represent a novelty that could cause distraction for drivers (regardless of shadow flicker). Consideration should be given to development of viewing areas for wind farms close to high volume roads."*

[1] The maximum blade chord is the thickest part of the blade.

4 SHADOW FLICKER AND GLINT ASSESSMENT

4.1 Shadow Flicker 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:

- Direction of the property relative to the turbine;
- Distance from the turbine (the further the observer is from the turbine, the less pronounced the effect will be);
- 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);
- Turbine height and rotor diameter;
- Time of year and day (the position of the sun in the sky);
- Weather conditions (cloud cover reduces the occurrence of shadow flicker).

4.2 Theoretical Modelled Shadow Flicker Duration

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

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

In line with the methodology proposed in the Draft National Guidelines, DNV GL has assessed the shadow flicker at the surveyed house locations and has determined the highest shadow flicker duration within 50 m of the centre of each house location.

Shadow flicker has been calculated at dwellings at heights of 2 m, to represent ground floor windows, and 6 m, to represent second floor windows. The shadow receptors are simulated as fixed points, representing the worst case scenario, as real windows 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 to reduce computational requirements to acceptable levels.

As part of the shadow flicker assessment, it is necessary to make an assumption regarding the maximum length of a shadow cast by a wind turbine that is likely to cause annoyance due to shadow flicker. The UK wind industry considers that 10 rotor diameters is appropriate [13], while the Draft National Guidelines suggest a distance equivalent to 265 maximum blade chords as an appropriate limit. UFWA has nominated a hypothetical turbine rotor diameter of 130 m for this study. Without any details on the turbine blade chord available, DNV GL has implemented a maximum shadow a length of 10 rotor diameters or 1300 m. Under the Draft National Guidelines, this will be conservative for any turbine with a maximum blade chord of less than 4.9 m.

The model also makes the following assumptions and simplifications:

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

These simplifications mean that the results generated by the model are likely to be conservative.

The settings used to execute the model can be seen in Table 5.

To illustrate typical results, an indicative shadow flicker map for a turbine located in a relatively flat area is shown in Figure 2. 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 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.

4.3 Factors Affecting Shadow Flicker Duration

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

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

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

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

   Cloud cover measurements recorded at nearby meteorological stations may be used to estimate probable levels of cloud cover and to provide an indication of the resulting reduction in shadow flicker duration.

3. Aerosols (moisture, dust, smoke, etc.) in the atmosphere have the ability to influence shadows cast by a wind turbine.

   The length of the shadow cast by a wind turbine is dependent on the degree that direct sunlight is diffused, which is in turn dependent on the amount of dispersants (humidity, smoke and other aerosols) in the path between the light source (sun) and the receiver.

4. The modelling of the wind turbine rotor as a sphere rather than individual blades results in an overestimate of shadow flicker duration.

   Turbine blades are of non-uniform thickness with the thickest part of the blade (maximum chord) close to the hub and the thinnest part (minimum chord) at the tip. Diffusion of sunlight, as discussed above, results in a limit to the maximum distance that a shadow can be perceived. This maximum distance will also be dependent on the thickness of the turbine blade, and the human threshold for perception of light intensity variation. As such, a shadow cast by the blade tip will be shorter than the shadow cast by the thickest part of the blade.

5. The analysis does not consider that when the sun is positioned directly behind the wind turbine hub, there is no variation in light intensity at the receiver location and therefore no shadow flicker.
6. The presence of vegetation or other physical barriers around a shadow receptor location may shield the view of the wind turbine, and therefore reduce the incidence of shadow flicker.
7. Periods where the wind turbine is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce the annual shadow flicker duration.

4.4 Predicted Actual Shadow Flicker Duration

As discussed above in Section 4.3, there are a number of factors which may reduce the incidence of shadow flicker, such as cloud cover and variation in turbine orientation, that are not taken into account in the calculation of the theoretical shadow flicker duration. Exclusion of these factors means that the theoretical calculation is conservative. An attempt has been made to quantify the likely reduction in shadow flicker duration due to these effects and therefore produce a prediction of the actual shadow flicker duration likely to be experienced at a dwelling.

Cloud cover is typically measured in 'oktas' or eighths of the sky covered with cloud. DNV GL has obtained data from three Bureau of Meteorology (BoM) stations, located a distance of approximately 22 to 65 km from the site [14, 15, 16], with twice daily approximations of the percentage of cloud cover visible across the sky. Data from the Goulburn TAFE, Taralga Post Office and Linton Hostel in Yass were obtained, however only Goulburn was considered to be consistent and representative of the Crookwell site. The results show that the average annual cloud cover values obtained from readings at 9 am and 3 pm range between 4.1 and 4.9 oktas. This means that on an average day, 4.5/8 or approximately 56% of the sky in the vicinity of the wind farm is covered with clouds. Although it is not possible to definitively calculate the effect of cloud cover on shadow flicker duration, a reduction in the shadow flicker duration proportional to the amount of cloud cover is a reasonable assumption. An assessment of the likely reduction in shadow flicker duration due to cloud cover was conducted on a monthly basis, which indicated that a reduction of 54% to 58% is expected at the affected dwellings.

Similarly, turbine orientation can have an impact on the shadow flicker duration. The shadow flicker impact is greatest when the turbine rotor plane is approximately perpendicular to a line joining the sun and an observer, and a minimum when the rotor plane is approximately parallel to a line joining the sun and an observer. A wind direction frequency distribution previously derived by DNV GL from data collected by masts on site has been 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 2. An assessment of the likely reduction in shadow flicker duration due to variation in turbine orientation was conducted on an annual basis, which indicated that a reduction of 24% to 35% can be expected at the affected dwelling 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.

4.5 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. As discussed, 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 RESULTS OF THE ANALYSIS

A shadow flicker assessment was carried out at all dwelling locations, or "receptors", located within 1.5 km of the proposed Crookwell 2 Wind Farm, as outlined in Table 1. The theoretical predicted shadow flicker durations at all dwellings identified to be affected by shadow flicker are presented in Table 6. The maximum predicted theoretical shadow flicker durations within 50 m of these receptors are also presented in this table. The results are presented in the form of shadow flicker maps at 2 m and 6 m above ground in Figure 4 and Figure 5 respectively. Additionally, the results are presented in the form of shadow flicker duration contours in Figure 6 and Figure 7.

DNV GL has included the adjacent Crookwell 1 and Crookwell 3 Wind Farms to assess any cumulative shadow flicker impacting upon houses neighbouring Crookwell 2. DNV GL has only assessed those dwellings affected by shadow flicker cast from the Crookwell 2 turbines and this assessment is not intended to detail all dwellings that can expect shadow flicker from Crookwell 1 and Crookwell 3 wind turbines. Modelling procedures restrict DNV GL to assume all turbines within the model cast visible shadow to the same length. As discussed in Section 4.2, DNV GL has employed a shadow length of 10 rotor diameters (1300 m) for the planned Crookwell 2 hypothetical turbine type. This will result in any theoretical shadow flicker predicted from the smaller Crookwell 1 turbines to likely be conservative.

These results indicate that nine dwellings in the vicinity of the Crookwell 2 Wind Farm are predicted to experience some shadow flicker based on the methodology recommended in the Draft National Guidelines. Of these dwellings, eight project host landholder dwellings are predicted to be affected by theoretical shadow flicker durations of greater than the NSW Guidelines recommended limit of 30 hours per year within 50 m of the house locations.

An assessment of the level of conservatism associated with the theoretical results has been conducted by calculating the possible reduction in shadow flicker duration due to turbine orientation (based on the wind rose measured at the site) and cloud cover. These adjusted results are presented as predicted actual shadow flicker durations in Table 6. Consideration of turbine orientation and cloud cover reduces the predicted shadow flicker duration by 65% to 71% at the dwellings affected by shadow flicker.

After reductions due to turbine orientation and cloud cover are taken into account, the same eight host dwellings that exceed the 30 hour limit are predicted to be subject to an actual shadow flicker duration above the limit of 10 hours within 50 m of the house location, as recommended in the Draft National Guidelines.

It should be noted that the method prescribed by the Draft National Guidelines for assessing actual shadow flicker duration recommends that only reductions due to cloud cover, and not turbine orientation, be included. However, DNV GL considers that this additional reduction due to turbine orientation is appropriate as the projected area of the turbine, and therefore the expected shadow flicker duration, is reduced when the turbine rotor is not perpendicular to the line joining the sun and dwelling.

5.1 Mitigation Options

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, or the use of turbine control strategies which shut down turbines when shadow flicker is likely to occur.

It should be noted that the results presented here have been generated based on a hypothetical turbine model with a 95 m hub height and 130 m blade diameter configuration, as discussed in Section 2.2. If the turbine eventually selected for the site has dimensions smaller than those considered here, but still within the hypothetical turbine envelope, then shadow flicker durations in the vicinity of the site are likely to be lower than those predicted here.

6 CONCLUSION

An analysis has been conducted to determine the annual duration of shadow flicker experienced at dwellings in the vicinity of the approved Crookwell 2 Wind Farm for a modified turbine configuration, based on the methodology proposed in the Draft New South Wales Guidelines and the Draft National Guidelines. The results of the assessment are presented in the form of shadow flicker maps, in Figure 4 to Figure 7. The shadow flicker results for each house location predicted to be affected by shadow flicker are also listed in Table 6.

The assessment of theoretical shadow flicker duration shows that 9 of the dwellings identified by UFWA are predicted to experience some level of theoretical shadow flicker within 50 m of the house location. Eight of these dwellings are also predicted to be affected by theoretical shadow flicker durations of greater than the NSW Guidelines recommended limit of 30 hours per year within 50 m of the house locations, however these are all host dwellings.

The results of the cumulative impact assessment show that no shadow flicker from the Crookwell 1 and Crookwell 3 wind turbines is expected to affect the dwellings that receive shadow flicker from the Crookwell 2 turbines.

Approximation of the degree of conservatism associated with the worst-case results has been conducted by calculating the possible reduction in shadow flicker duration due to turbine orientation and cloud cover. The results of this analysis, also presented in Table 6, show that the same eight host dwellings are predicted to experience actual annual shadow flicker durations within 50 m of the house location that are in excess of the limit of 10 hours recommended in the Draft National Guidelines.

However, the shadow flicker durations predicted at some of the host dwellings are significantly higher than the recommended limits, and therefore DNV GL recommends that the Client approach the host dwellings where the predicted shadow flicker duration exceeds the recommended limit to discuss the matter.

The calculation of the predicted actual shadow flicker duration does not take into account any reduction due to low wind speed, vegetation or other shielding effects around each house in calculating the number of shadow flicker hours. Therefore, the values presented may still be regarded as a conservative assessment.

If shadow flicker presents a problem, mitigation strategies to reduce the duration of shadow flicker experienced at a dwelling can include: the installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies which shut down turbines when shadow flicker is likely to occur.

Blade glint is not likely to cause a problem for observers in the vicinity of the wind farm provided non-reflective coatings are used on the blades of the turbines.

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List of Tables

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House ID	Easting[1] (m)	Northing[1] (m)	Status	Distance to nearest turbine (m)
20	735970	6172727	Non-participant	1187
21	734279	6174723	Host landowner	732
22	733964	6173999	Host landowner	676
23	736342	6174616	Host landowner	644
24	736082	6174316	Host landowner	427
25	736368	6174580	Host landowner	667
26	736458	6174487	Host landowner	743
27	736496	6174408	Host landowner	720
28	736395	6174209	Host landowner	544
60	740389	6172231	Non-participant	1114
70	739339	6175736	Non-participant	1460
R117	735603	6172925	Non-participant	1044
R118	734952	6173081	Non-participant	1291
R120	733927	6176267	Non-participant	1058
R124	731448	6174361	Non-participant	1399
R130	734250	6177739	Non-participant	880

Notes: 1. Coordinate system is MGA Zone 55 GDA94

Table 1: Dwelling locations within 1.5 km of turbines at the proposed Crookwell 2 Wind Farm

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base Elevation [m]
F1	733099	6175609	948
F2	732921	6175270	910
F3	732784	6175029	900
F4	732790	6174758	888
F5	733554	6174834	880
F7	733468	6174459	870
F9	733130	6174119	870
F10	734850	6177095	910
F11	735322	6176679	890
F12	735383	6175929	890
F17	735938	6173914	860
F19	735702	6174542	890
F21	735787	6175152	870
F22	736007	6175416	880
F23	736060	6175745	860
F24	737463	6175724	899
F26	737273	6175188	880
F27	737640	6174955	875
F28	737568	6174695	870
F29	737195	6174580	860
F30	737485	6174324	870
F31	737509	6174035	860
F32	737847	6173582	867
F35	738050	6173982	872
F36	738339	6174672	893
F37	738359	6174384	898
F40	738544	6173920	890
F41	738227	6173622	871
F43	737901	6173227	870
F45	738887	6172965	870
F47	738381	6172683	860
F48	739373	6172687	889
F50	739227	6172360	881

[1] Coordinate system: MGA zone 55, GDA94 datum

Table 2: Proposed turbine layout for the Crookwell 2 Wind Farm site

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base Elevation [m]
B1	733051	6177408	920
B2	733681	6177885	950
B3	733676	6177669	940
B4	733633	6177379	930
B5	733514	6177230	930
B6	733408	6177025	925
B7	733109	6177860	940
B8	733113	6178135	940

[1] Coordinate system: MGA zone 55, GDA94 datum

Table 3: Turbine layout for the Crookwell 1 Wind Farm site

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base Elevation [m]
A2	741318	6175038	910
A3	741739	6174961	920
A4	742142	6174888	920
A5	742545	6174793	917
A8	741992	6174487	910
A9	742420	6174375	910
A10	742163	6174009	900
A12	742793	6173382	880
A13	743466	6173101	868
A15	744163	6173538	890
A16	743023	6172812	870
A17	743851	6172845	880
A20	743049	6172311	881
A21	743818	6172439	893
A22	743634	6172076	902
A24	742989	6171875	870
A25	743605	6171669	930
A28	733966	6170569	800
A29	734365	6170720	820
A30	734198	6170212	810
A31	734648	6170173	820
A32	735268	6170853	800
A33	735649	6170525	790

[1] Coordinate system: MGA zone 55, GDA94 datum

Table 4: Proposed turbine layout for the Crookwell 3 Wind Farm site

Model Setting	Value
Maximum shadow length	1300 m
Year of calculation	2027
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[1]	25 m grid centred on house location

[1] In addition to the 25 m resolution grid points, points were added every 45° on a 50 m radius circle centred on the house location.

Table 5: Shadow flicker model settings for theoretical shadow flicker calculation

House ID	Easting[1] [m]	Northing[1] [m]	Dwelling status	Contributing Turbines	Theoretical Annual: At Dwelling[2] [hr/yr] SF at 2 m	Theoretical Annual: At Dwelling[2] [hr/yr] SF at 6 m	Theoretical Annual: Max Within 50 m of Dwelling[2] [hr/yr] SF at 2 m	Theoretical Annual: Max Within 50 m of Dwelling[2] [hr/yr] SF at 6 m	Predicted Actual Annual[3]: At Dwelling[2] [hr/yr] SF at 2 m	Predicted Actual Annual[3]: At Dwelling[2] [hr/yr] SF at 6 m	Predicted Actual Annual[3]: Max Within 50 m of Dwelling[2] [hr/yr] SF at 2m	Predicted Actual Annual[3]: Max Within 50 m of Dwelling[2] [hr/yr] SF at 6 m
21	734279	6174723	Host dwelling	F5, F7, F9	34.9	79.9	87.8	87.2	11.7	26.3	30.4	30.2
22	733964	6173999	Host dwelling	F7, F9	54.2	51.5	83.7	81.4	16.1	15.1	25.9	25.1
23	736342	6174616	Host dwelling	F19, F21, F26, F27, F28, F29, F30, F31	144.0	140.0	200.8	198.2	43.4	42.4	61.7	60.7
24	736082	6174316	Host dwelling	F19, F29	115.0	117.4	160.6	163.8	36.3	36.9	48.3	49.4
25	736368	6174580	Host dwelling	F19, F21, F26, F27, F28, F29, F30, F31	142.3	137.9	182.6	179.0	45.8	45.1	56.7	55.6
26	736458	6174487	Host dwelling	F19, F21, F26, F27, F28, F29, F30, F31	129.3	129.0	140.5	139.9	44.7	44.4	46.0	46.4
27	736496	6174408	Host dwelling	F19, F27, F28, F29, F30, F31	125.0	125.0	140.9	142.0	41.6	41.5	47.1	47.2
28	736395	6174209	Host dwelling	F19, F28, F29, F30, F31	98.1	99.1	109.4	111.2	32.6	32.7	35.1	35.6
60	740389	6172231	-	F48, F50	15.4	16.6	15.9	17.2	5.2	5.6	5.3	5.8
Limits				**n/a**	**30**		**30**		**10**		**10**	

[1] MGA Zone 55 (GDA94 datum)
[2] Dwellings with zero hours shadow flicker have been omitted from this table, and values above the recommended limits are highlighted in red
[3] Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation

Table 6: Theoretical and predicted actual annual shadow flicker durations for dwellings affected by shadow flicker

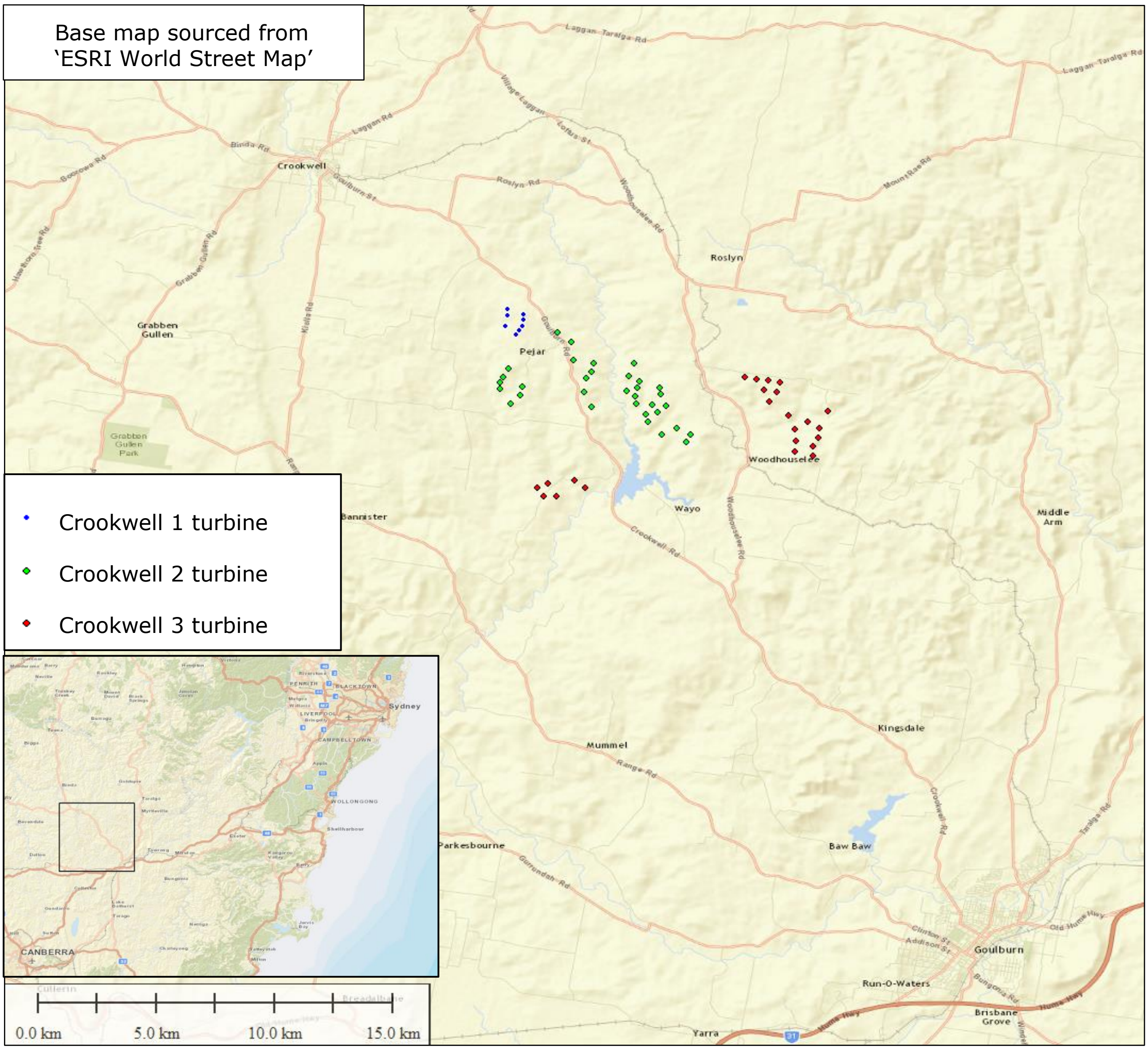

Figure 1: Location of the proposed Crookwell 2 Wind Farm

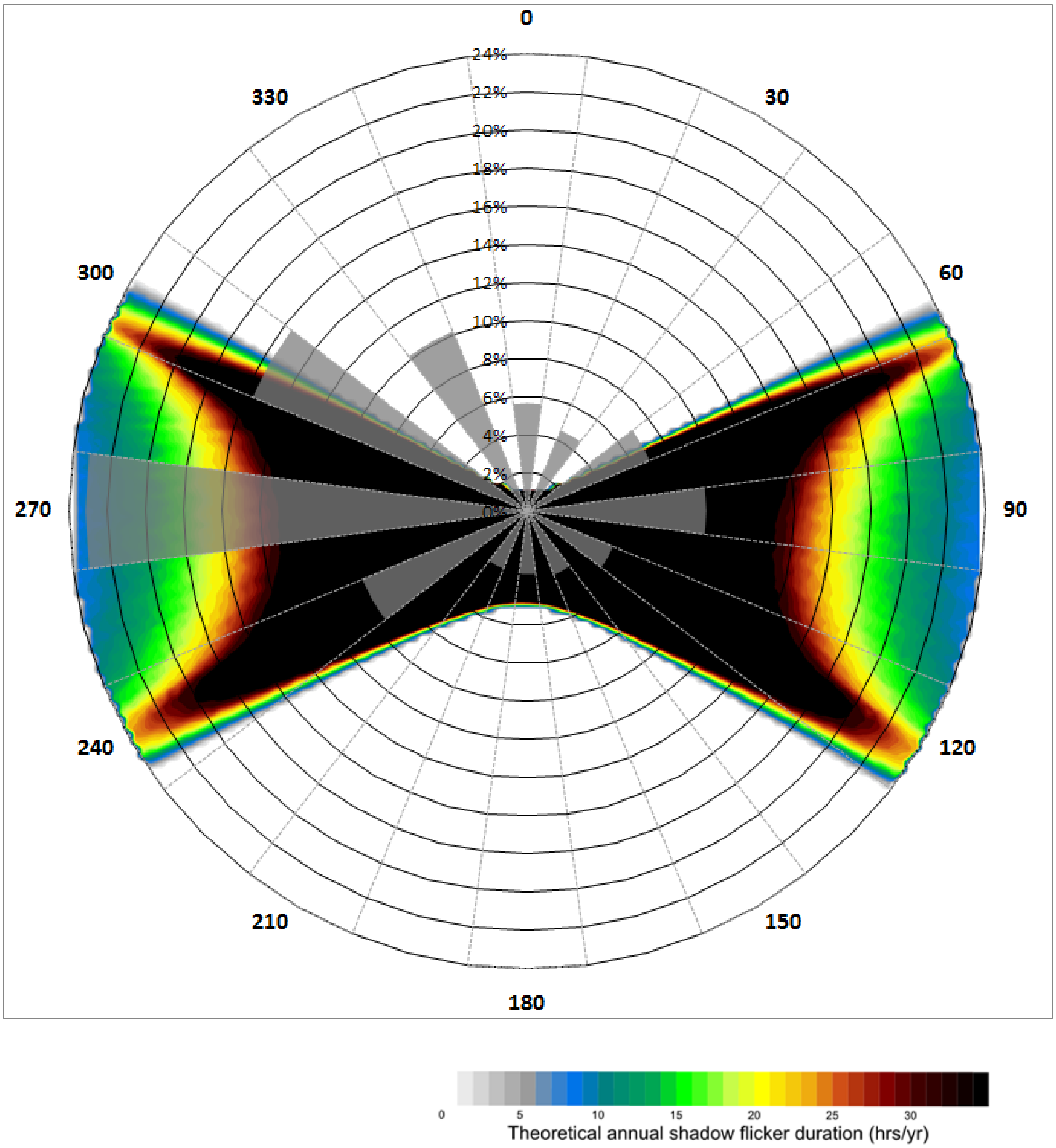

Figure 2: Indicative shadow flicker map and wind direction frequency distribution

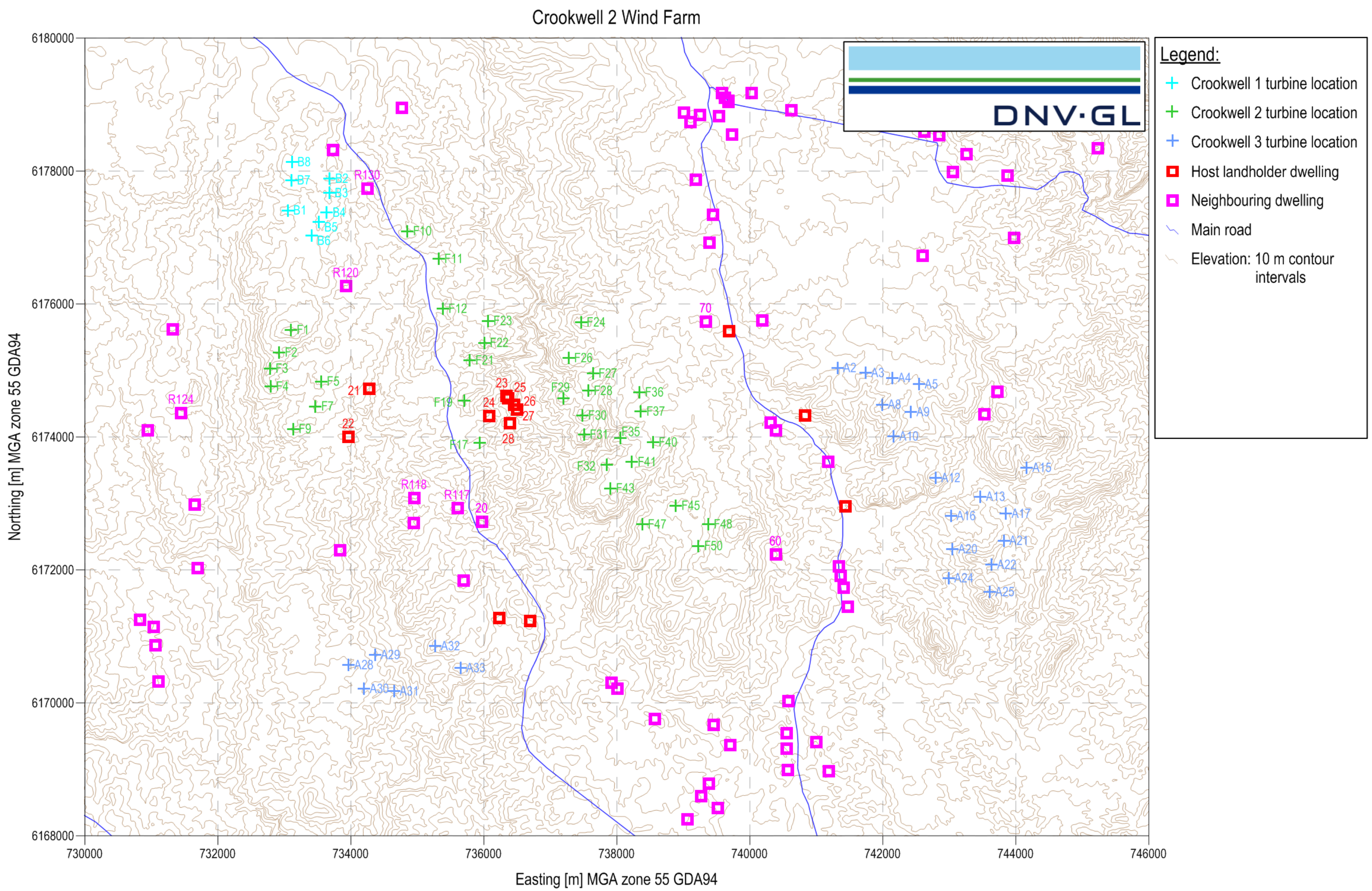

Figure 3: Map of the proposed Crookwell 2 Wind Farm with proposed turbines, neighbouring turbines, host dwelling and non-host dwelling locations.

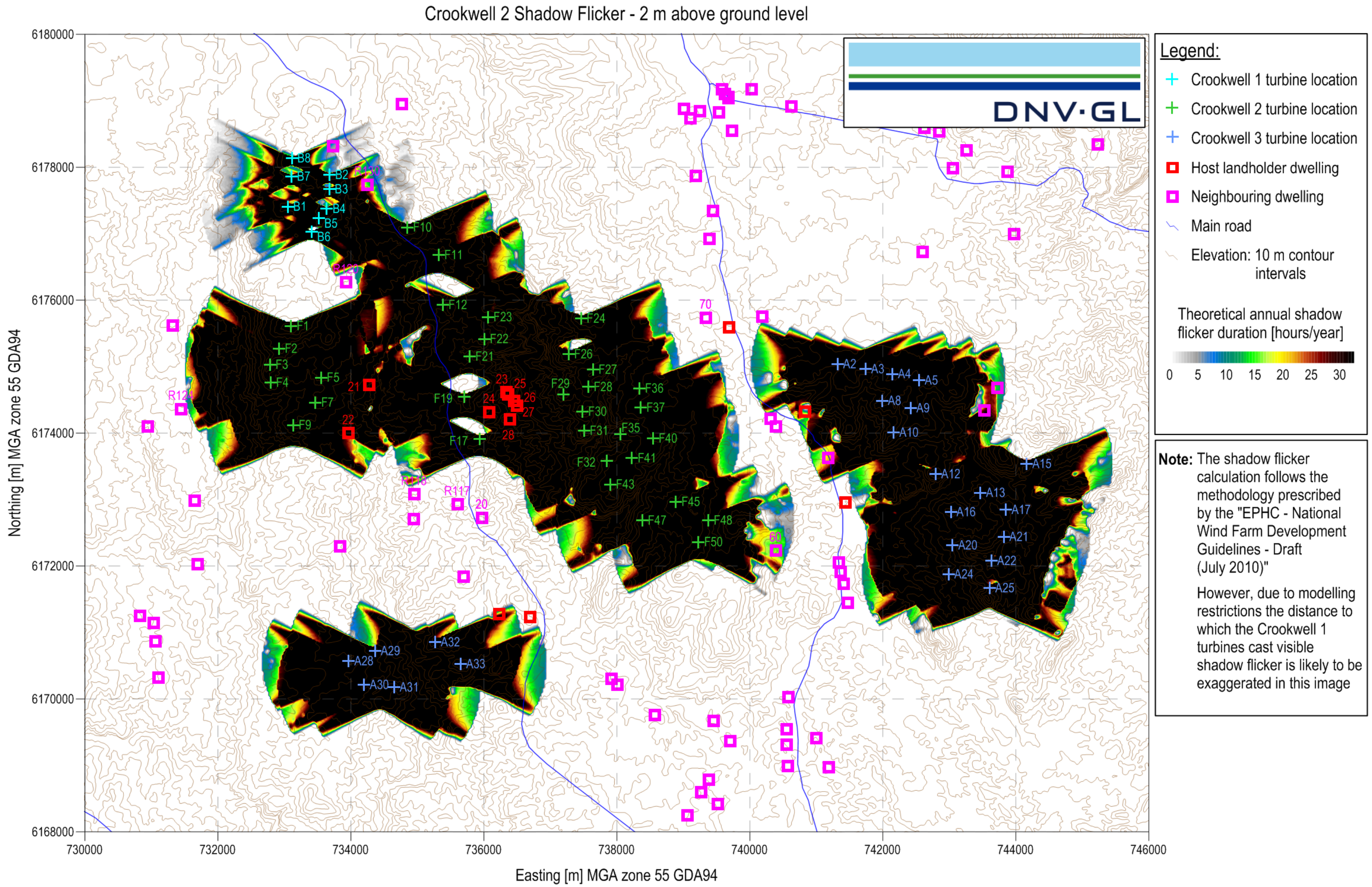

Figure 4: Map of the proposed Crookwell 2 Wind Farm with proposed turbines, neighbouring turbines, dwelling locations and theoretical annual shadow flicker duration at 2 m above ground level

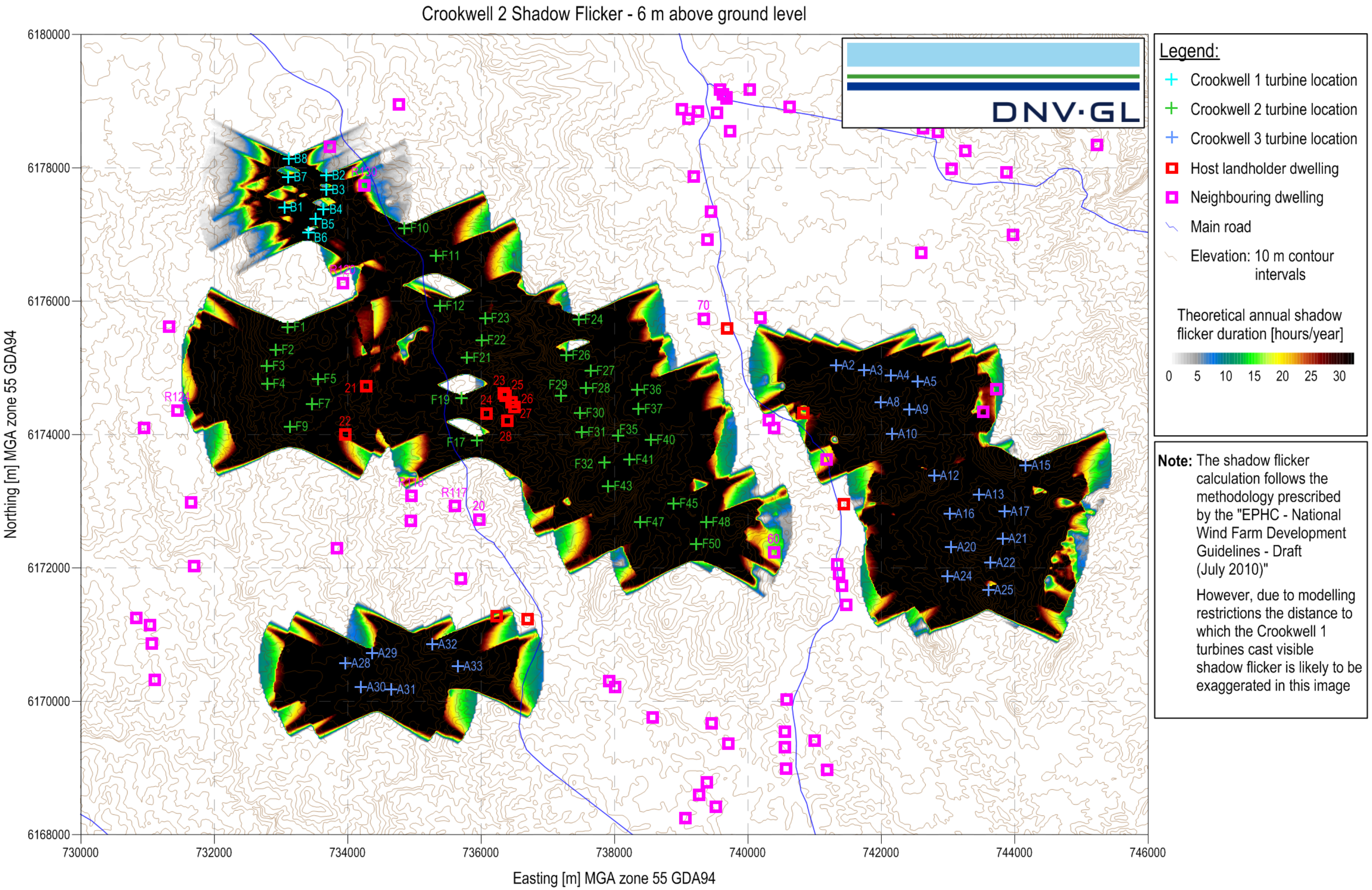

Figure 5: Map of the proposed Crookwell 2 Wind Farm with proposed turbines, neighbouring turbines, dwelling locations and theoretical annual shadow flicker duration at 6 m above ground level

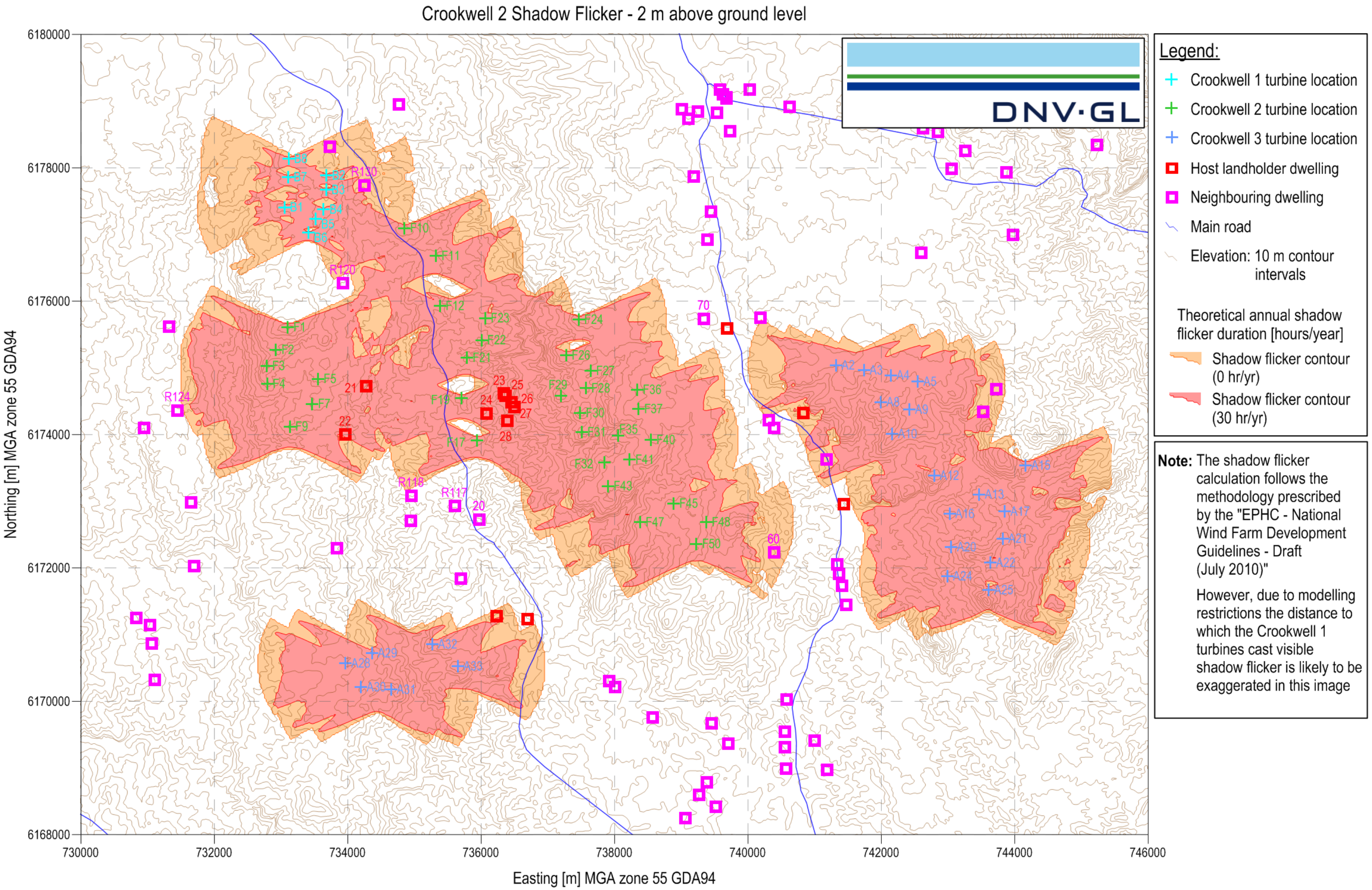

Figure 6: Map of the proposed Crookwell 2 Wind Farm with proposed turbines, neighbouring turbines, dwelling locations and theoretical annual shadow flicker duration at 2 m above ground level

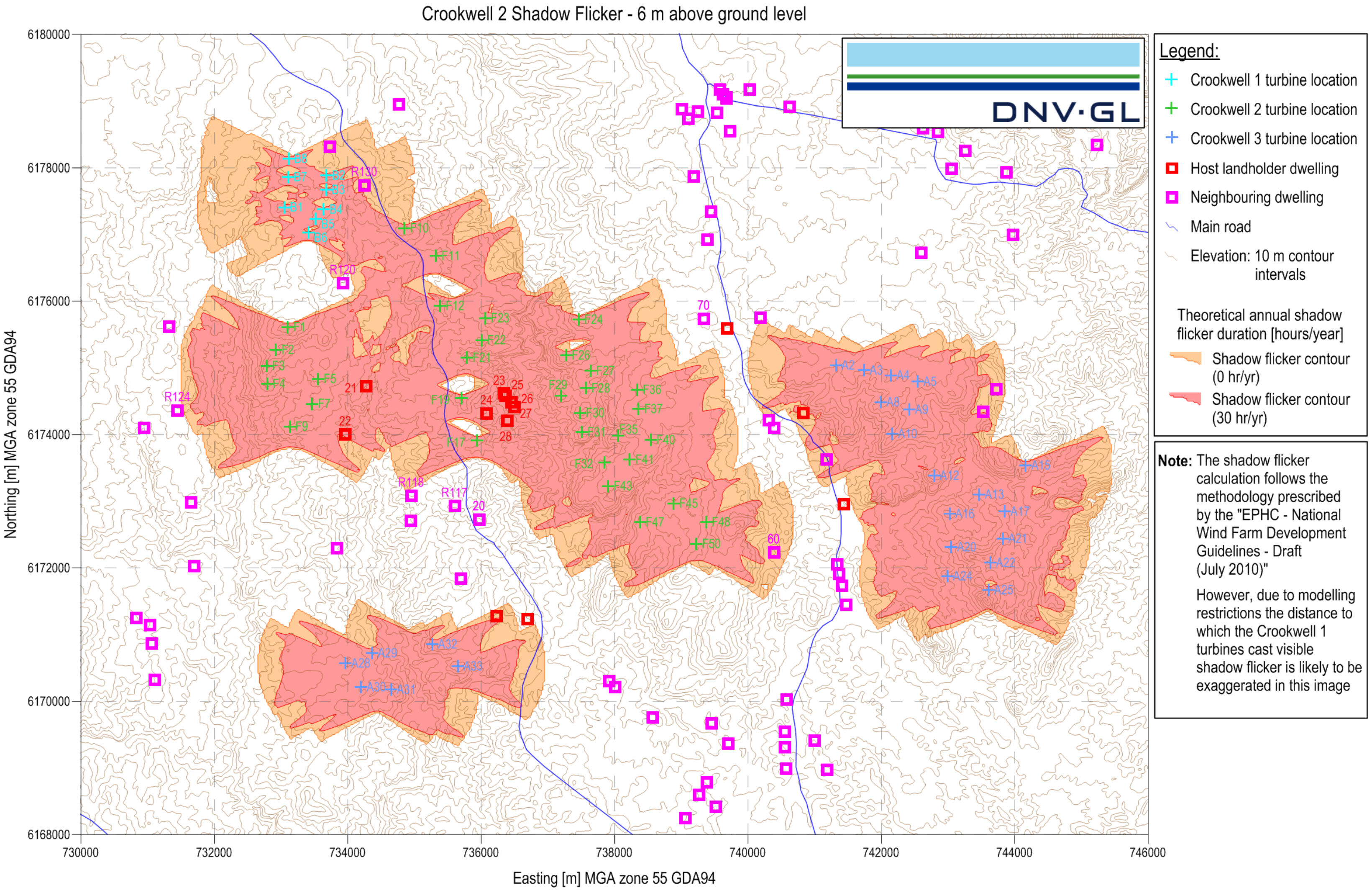

Figure 7: Map of the proposed Crookwell 2 Wind Farm with proposed turbines, neighbouring turbines, dwelling locations and theoretical annual shadow flicker duration at 6 m above ground level

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