RYAN CORNER WIND FARM

Shadow Flicker Assessment

Ryan Corner Development Pty Ltd

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Task and objective:
Independent assessment of expected shadow flicker durations at neighbouring land and at nearby houses due to the proposed Ryan Corner Wind Farm.

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Reference to part of this report which may lead to misinterpretation is not permissible.

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A	2015-11-06	Original release (electronic version only)	C Jonsson	M Purcell ; J Jobin	T Gilbert
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1 EXECUTIVE SUMMARY

Garrad Hassan Pacific Pty. Ltd. ("DNV GL") has been commissioned by Union Fenosa Wind Australia Pty Ltd on behalf of Ryan Corner Development Pty Ltd ("Union Fenosa" or "the Customer") to independently assess the expected annual shadow flicker duration in the vicinity of the proposed Ryan Corner Wind Farm ("the Project"). The assessment is to support a modification to the planning permit to allow the installation of turbines with larger dimensions. The results of the work are reported here. This document has been prepared pursuant to DNV GL proposal 170485-AUME-P-001-C, dated 05 September 2014, 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 maximum potential 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 Ryan Corner 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 [2]. 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.

Union Fenosa has commissioned DNV GL to assess the shadow flicker based upon a layout provided for the Ryan Corner Wind Farm consisting of 56 wind turbines [3]. Union Fenosa is considering turbines with a maximum rotor diameter of 130 m, maximum tip height of up to 180 m and a maximum hub height of up to 117 m. In order to model a worst case scenario, hypothetical turbine models with a hub height of either 115 m or 95 m and a rotor diameter of 130 m have been considered for the current analysis, as requested by Union Fenosa [3,4]. Union Fenosa has also provided the locations of 111 dwellings in the area surrounding the wind farm [5] and elevation contours for the site area [6]. These have been used to determine the theoretical duration of shadow flicker caused by the Ryan Corner Wind Farm at each dwelling.

The Victorian Planning Guidelines [7] recommend a shadow flicker limit of 30 hours per year in the area immediately surrounding a dwelling. In addition, the EPHC Draft National Wind Farm Development Guidelines [8] recommend a limit on the theoretical shadow flicker duration of 30 hours per year, and a limit on the actual shadow flicker duration of 10 hours per year.

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 duration occurring within 50 m of the dwelling.

The results indicate that, of the dwellings identified by Union Fenosa for study, there are locations within 50 m of nine dwellings that are predicted to experience some shadow flicker. Four of these locations are predicted to experience theoretical shadow flicker duration in excess of the recommended limit of 30 hours per annum; however, these are all stakeholder 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, one dwelling is expected to experience shadow flicker durations in excess of the recommended limit of 10 hours per year within 50 m of the house location.

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 (if not already in place) 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.

A comparison has also been performed between the shadow flicker durations associated with the previously modified configuration of the Project (as reported in [1]) and those for the current configuration. It is noted that six dwellings are predicted to experience increased shadow flicker durations as a result of the current configuration, while two dwellings are predicted to experience decreased shadow flicker durations.

It should be noted that the results presented here have been generated based on a hypothetical turbine configuration with a 115 m or 95 m hub height and 130 m blade diameter, as discussed in Section 2.2. If the turbine selected for the site has dimensions that mean the turbine rotor is 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

Union Fenosa is seeking an amendment to the planning approval for the Ryan Corner Wind Farm ("the Project"), which is located approximately 12 km northwest of Port Fairy and approximately 30 km west-northwest of Warrnambool. The amendment entails a configuration comprising larger turbine dimensions than those proposed in the original planning application, but fewer turbines.

The topography of the site is largely flat and has an elevation ranging between approximately 10 m and 40 m above sea level, with the highest areas located to the north. Ground cover on site comprises primarily grasses, interspersed with some areas of bushes and small patches of trees. A larger area of forestry is located immediately to the west.

Detailed elevation data for the site area was provided by Union Fenosa [6] and has been used in the analysis here.

2.2 Proposed Wind Farm Layout

The proposed turbine layout for the Ryan Corner Wind Farm is comprised of 56 wind turbine generators and has been supplied by Union Fenosa [3].

Union Fenosa is considering turbines with a maximum rotor diameter of 130 m, maximum tip height of up to 180 m and a maximum hub height of up to 117 m. In order to model a worst case scenario, DNV GL has modelled the shadow flicker using a hypothetical turbine with a 115 m or 95 m hub height and 130 m rotor diameter configuration, as requested by Union Fenosa [3,4]. 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 less than 180 m (for the turbines modelled at 115 m hub height) or 160 m (for the turbines modelled at 95 m hub height);
- A lower blade tip height of more than 50 m (for the turbines modelled at 115 m hub height) or 30 m (for the turbines modelled at 95 m hub height);

A list of coordinates of the proposed turbine locations along with the hub height modelled for each turbine is provided in Table 1.

2.3 House Locations

A list of houses neighbouring the wind farm was supplied to DNV GL by Union Fenosa [45]. The coordinates of those dwellings within 1.5 km of the wind farm are presented in Table 2. 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 Victorian Planning Guidelines [7] currently state:

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

In addition, the EPHC Draft National Wind Farm Development Guidelines released in July 2010 [8] include recommendations for shadow flicker limits relevant to wind farms in Australia.

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

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

These limits are assumed to apply to a single dwelling, and it is noted that there is no requirement under either the Victorian Planning Guidelines or 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 around 10 rotor diameters from a turbine [9], which is approximately 800 to 1300 m for modern wind turbines (that 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*

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

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 SHADOW FLICKER 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 provided 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 Victorian Planning Guidelines [7] do not provide any guidance on this parameter. The UK wind industry considers that 10 rotor diameters is appropriate [9], while the Draft National Guidelines suggest a distance equivalent to 265 maximum blade chords as an appropriate limit. Union Fenosa has nominated a turbine rotor diameter of 130 m for this study. DNV GL has assumed a maximum shadow length equivalent to the more conservative of the two approaches described above, and in this case, a length of 10 rotor diameters or 1300 m has been used. 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 are presented in Table 3.

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, which in turn increases the area around the turbine that is affected by shadow flicker.

4.3 Factors Affecting Shadow Flicker Duration

Shadow flicker duration calculated in the manner described in Section 4.2 tends to overestimate the annual number of hours of shadow flicker experienced at a specified location for several reasons, as outlined in the following:

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 a number of Bureau of Meteorology (BoM) stations located in the wider area surrounding the site, with twice daily approximations of the percentage of cloud cover visible across the sky. At the Portland (Cashmore Airport) station [10] approximately 55 km to the west of the site, the average annual cloud cover value obtained from readings at 9 am and 3 pm is approximately 5.2 oktas. This means that, on an average day, 5.2/8 or approximately 65% of the sky in the vicinity of the wind farm is covered with clouds. It is noted that the cloud cover statistics from this station were broadly similar to those from the other stations considered.

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 62% to 68% 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. Wind direction frequency distributions derived from wind measurements at the site have been provided by Union Fenosa [11] and used to estimate the reduction in shadow flicker duration due to rotor orientation. The measured wind rose is shown overlaid on the indicative shadow flicker map in Figure 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 37% to 45% 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 on average over the long-term. However it should be noted that the reduction in shadow flicker durations from the theoretical maximum due to turbine orientation and cloud cover may vary from year to year.

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 determines whether or not blade glint has the potential to be significant. As discussed in Section 3, 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 Ryan Corner Wind Farm, and the theoretical predicted shadow flicker durations at these dwellings are presented in Table 4 along with the maximum predicted durations within 50 m. The results are presented in the form of shadow flicker maps at 2 m and 6 m above ground in Figure 3 and Figure 4 respectively. Additionally, the results are presented in the form of shadow flicker duration contours in Figure 5 and Figure 6.

The results indicate that nine of the nearby dwellings are predicted to experience some shadow flicker based on the methodology recommended in the Draft National Guidelines. At four of these dwellings, all of which are project stakeholders, theoretical shadow flicker durations are predicted to be greater than the Victorian Planning Guidelines [7] 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 4. Consideration of turbine orientation and cloud cover reduces the predicted shadow flicker duration by 77% to 82% at the dwellings affected by shadow flicker.

After reductions due to turbine orientation and cloud cover are taken into account, one stakeholder dwelling is 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.

Table 5 also presents results comparing the predicted shadow flicker durations for the previously modified configuration of the Project (as reported in [1]) to the shadow flicker durations for the current configuration. At the time of the previous analysis [1] there was no requirement to assess shadow flicker durations in the vicinity of dwellings or at second storey heights, therefore a comparison has been carried out between shadow flicker durations at dwelling locations at a height of 2 m only. A results range is presented for the previously modified configuration as there were a number of turbine types considered in [11]. It is noted that six dwellings are predicted to experience increased shadow flicker durations as a result of the current configuration, while two dwellings are predicted to experience decreased shadow flicker durations.

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 (if not already in place) 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 115 m or 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 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 proposed Ryan Corner Wind Farm, based on the methodology proposed in the Draft National Guidelines [8]. The results of the assessment are presented in the form of shadow flicker maps, in Figure 3 to Figure 6. The shadow flicker results for each house location predicted to be affected by shadow flicker are also listed in Table 4.

The assessment of theoretical shadow flicker duration shows that nine of the dwellings identified by Union Fenosa are predicted to experience some level of theoretical shadow flicker within 50 m of the house location. Out of these, four stakeholder dwellings are predicted to be affected by theoretical shadow flicker durations of greater than the Victorian Planning Guidelines [7] recommended limit of 30 hours per year within 50 m of the house locations.

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 4, show that one stakeholder dwelling is 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.

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.

A comparison has been performed between the shadow flicker durations associated with the previously modified configuration of the Project (as reported in [1]) and those for the current configuration. It is noted that six dwellings are predicted to experience increased shadow flicker durations as a result of the current configuration, while two dwellings are predicted to experience decreased shadow flicker durations.

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 (if not already in place) 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.

7 REFERENCES

1. "Shadow Flicker Assessment for the Ryan Corner Wind Farm, Victoria", Garrad Hassan, Report 45090/PR/001-C, 25 August 2009.
2. "Influences of the opaqueness of the atmosphere, the extension of the sun and the rotor blade profile on the shadow impact of wind turbines", Freund H-D, Kiel F.H., DEWI Magazine No. 20, Feb 2002, pp43-51.
3. Email from S Mohajerani, Union Fenosa, to T Gilbert, DNV GL, on 06 July 2015.
4. Email from S Mohajerani, Union Fenosa, to T Gilbert, DNV GL, on 05 May 2015.
5. Email from S Mohajerani, Union Fenosa, to M Clifton-Smith, DNV GL, on 03 October 2014.
6. "Ryans_Corner_AGD66_nov05.dwg", received 5th April 2006.
7. "Policy and planning guidelines for development of wind energy facilities in Victoria", Sustainable Energy Authority Victoria, July 2012.
8. "National Wind Farm Development Guidelines – Public Consultation Draft", Environmental Protection and Heritage Council (EPHC), Jul 2010.
9. "Planning for Renewable Energy – A Companion Guide to PPS22", Office of the Deputy Prime Minister, UK, 2004.
10. "Climate statistics for Australian locations – PORTLAND (CASHMORE AIRPORT)," Bureau of Meteorology (online), http://www.bom.gov.au/climate/averages/tables/cw_090171.shtml, accessed 06 July 2015.
11. Email from S Mohajerani, Union Fenosa, to T Gilbert, DNV GL, on 03 July 2015.

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Turbine ID	Easting[1] [m]	Northing[1] [m]	Base Elevation [m]	Hub height [m]	Turbine ID	Easting[1] [m]	Northing[1] [m]	Base Elevation [m]	Hub height [m]
B6	598757	5758884	32	115	B39	597911	5763523	37	115
B8	599580	5759399	30	115	B40	598734	5763844	42	115
B9	599046	5759421	30	115	B41	598302	5763921	36	115
B10	597757	5758672	25	115	B43	598516	5764577	41	115
B13	597858	5759298	31	115	B44	598133	5764316	36	115
B14	597305	5759354	31	115	B45	597353	5764138	39	115
B15	597523	5759851	28	115	B46	596825	5763915	39	115
B16	597291	5760468	30	115	B47	597384	5763720	34	115
B17	597818	5760511	28	115	B48	596493	5763534	34	115
B18	598232	5760192	35	115	B49	597048	5763375	31	115
B20	599229	5760008	40	115	B52	596999	5762670	28	115
B21	599568	5760455	40	115	B54	596538	5762502	23	115
B22	598922	5760458	37	115	B55	597162	5762223	31	115
B23	598493	5760673	34	115	B58	596563	5762043	22	115
B24	599196	5760931	41	115	B59	597195	5761778	26	115
B25	598687	5761099	32	115	B60	597771	5761728	34	115
B26	598099	5760974	34	115	B62	596360	5761472	21	115
B28	599422	5761378	40	115	B63	596923	5761397	20	115
B29	598768	5761513	37	115	B64	597556	5761138	33	115
B30	598310	5761771	36	115	B66	596605	5760859	28	115
B31	599170	5762065	40	115	B67	597053	5760926	28	115
B32	598757	5762109	39	115	B69	595952	5760279	31	115
B33	598794	5762791	38	115	B70	595849	5759805	25	115
B34	598143	5762373	35	115	B72	596522	5760128	32	115
B35	599017	5763152	37	95	B73	597094	5759789	28	115
B36	598332	5762921	35	115	B74	596421	5759720	26	115
B37	597836	5763071	36	115	B75	598345	5759377	26	115
B38	598479	5763372	35	115	B76	598296	5758739	30	115

[1] Coordinate system: AMG Zone 54 (AGD66 datum).

Table 1: Proposed turbine layout for the Ryan Corner Wind Farm site

House ID	Easting[1] [m]	Northing[1] [m]
6	597484	5757347
7	597445	5757618
8 (s)	596985	5758281
9	596409	5758436
10	596143	5758383
11	597717	5765306
26	600505	5762154
27	600206	5763008
28 (s)	599961	5762673
29	599864	5763944
30 (s)	599672	5764614
31	599747	5764685
32	599198	5765407
33	598442	5766120
38	599327	5765854
78 (s)	595399	5761105
79 (s)	595442	5762217

Notes: 1. Coordinate system is AMG Zone 54 (AGD66 datum).
2. Project stakeholders are highlighted in the above table.

Table 2: Dwelling locations within 1.5 km of turbines at the proposed Ryan Corner Wind Farm

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 3: Shadow flicker model settings for theoretical shadow flicker calculation

				Theoretical				Predicted Actual[3]	
House ID	Easting[1] [m]	Northing[1] [m]	Contributing Turbines	At Dwelling[2] [hours/annum]		Max Within 50 m of Dwelling[2] [hours/annum]		Max Within 50 m of Dwelling[2] [hours/annum]	
				SF at 2 m	SF at 6 m	SF at 2 m	SF at 6 m	SF at 2m	SF at 6 m
8 (s)	596985	5758281	B10	33.0	33.1	41.9	43.3	7.5	7.7
26	600505	5762154	B31	0.0	0.0	9.6	9.2	2.1	2.0
27	600206	5763008	B35	8.5	8.0	9.6	9.3	2.0	2.0
28 (s)	599961	5762673	B32, B33, B35	29.6	28.5	57.5	56.1	12.4	12.1
29	599864	5763944	B40	12.7	12.3	14.1	13.8	3.2	3.1
30 (s)	599672	5764614	B43	11.6	11.4	13.0	12.7	2.8	2.7
31	599747	5764685	B43	10.4	10.0	11.6	11.0	2.5	2.4
78 (s)	595399	5761105	B62, B66	32.0	31.3	36.1	35.3	7.7	7.6
79 (s)	595442	5762217	B54, B58	27.0	26.5	30.1	29.5	6.5	6.4
Limits			**n/a**	**30**		**30**		**10**	

[1] AMG Zone 54 (AGD66 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 4: Theoretical and predicted actual annual shadow flicker durations for dwellings affected by shadow flicker.

	Theoretical shadow flicker at dwelling location		
House ID	**Previously modified configuration [hours/annum] SF at 2 m**	**Current configuration [hours/annum] SF at 2 m**	**Change between current and previously modified configuration [hours/annum]**
8 (s)	13 to 16	33.0	+15.0 to +20.0
26	-	0.0	-
27	-	8.5	+8.5
28 (s)	9 to 11	29.6	+18.6 to 20.6
29	-	12.7	+12.7
30 (s)	14 to 20	11.6	-8.4 to -2.4
31	-	10.4	+10.4
78 (s)	13 to 17	32.0	+15.0 to +19.0
79 (s)	42 to 52	27.0	-25.0 to -15.0
Limits	**30**	**30**	**-**

Table 5: Comparison between theoretical shadow flicker durations at dwelling location at 2m for previously modified and current project configuration.

Figure 1: Location of the proposed Ryan Corner Wind Farm

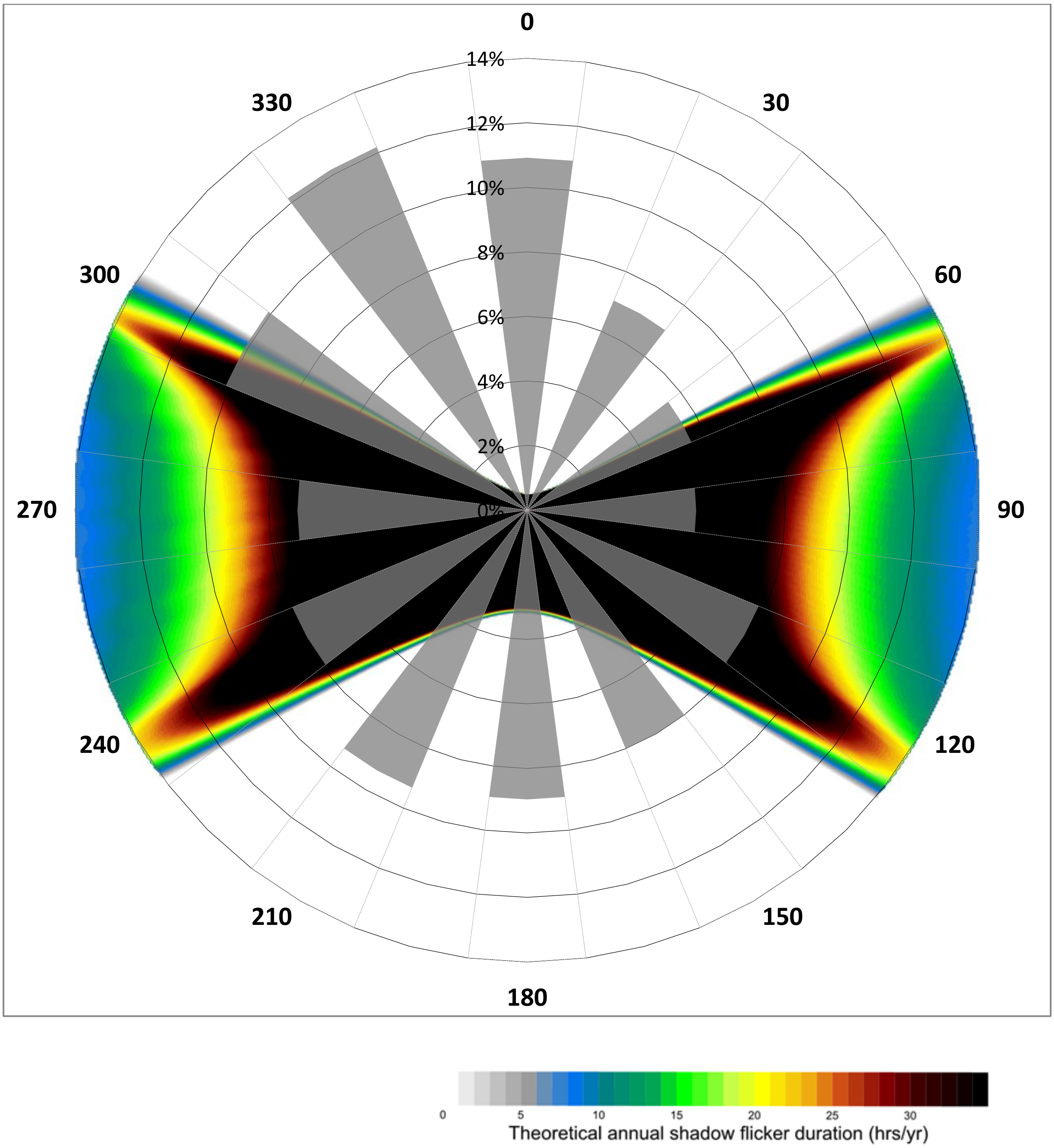

Figure 2: Indicative shadow flicker map and wind direction frequency distribution

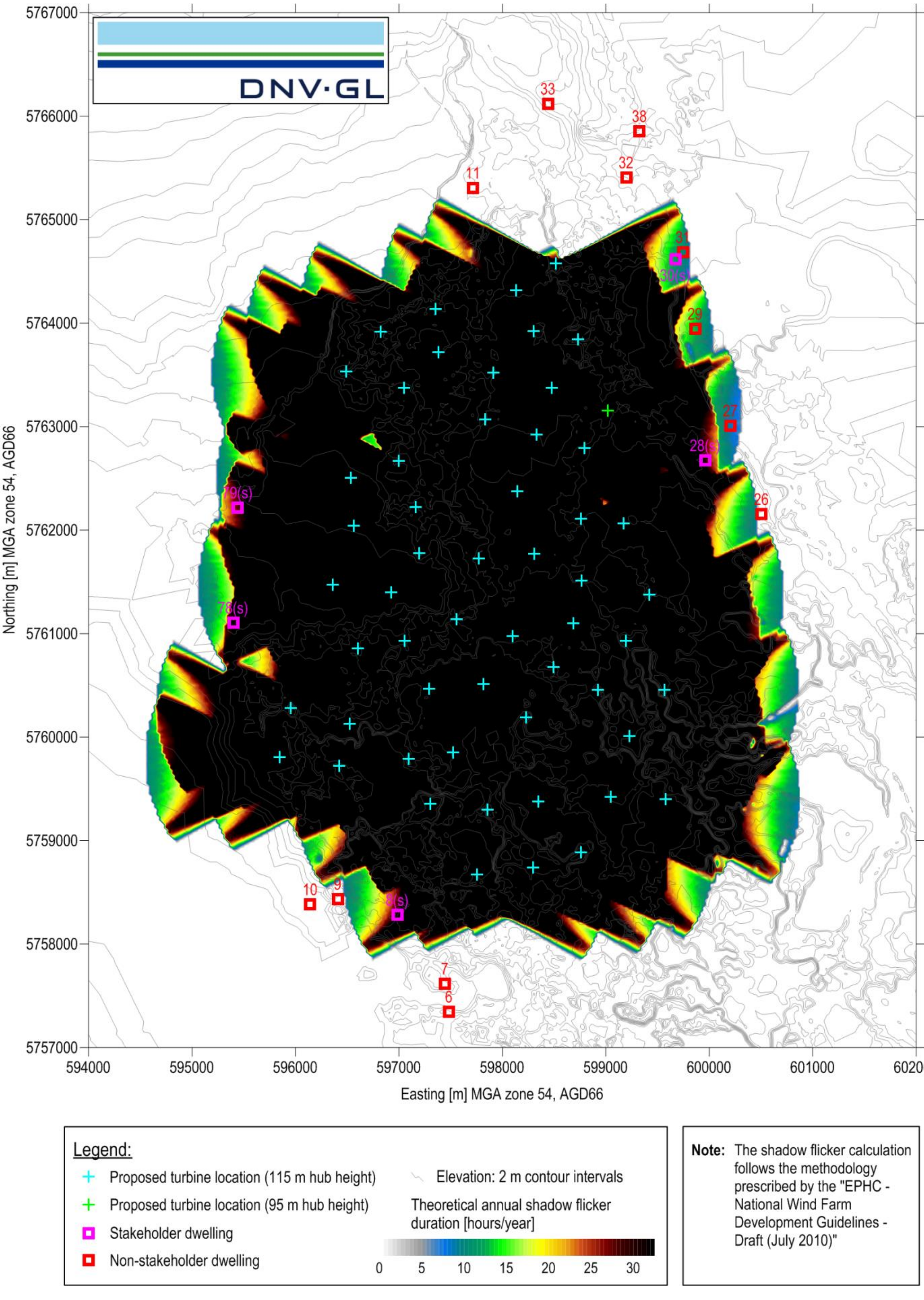

Figure 3: Map of the proposed Ryan Corner Wind Farm with turbines, dwelling locations and theoretical annual shadow flicker duration at 2 m above ground level

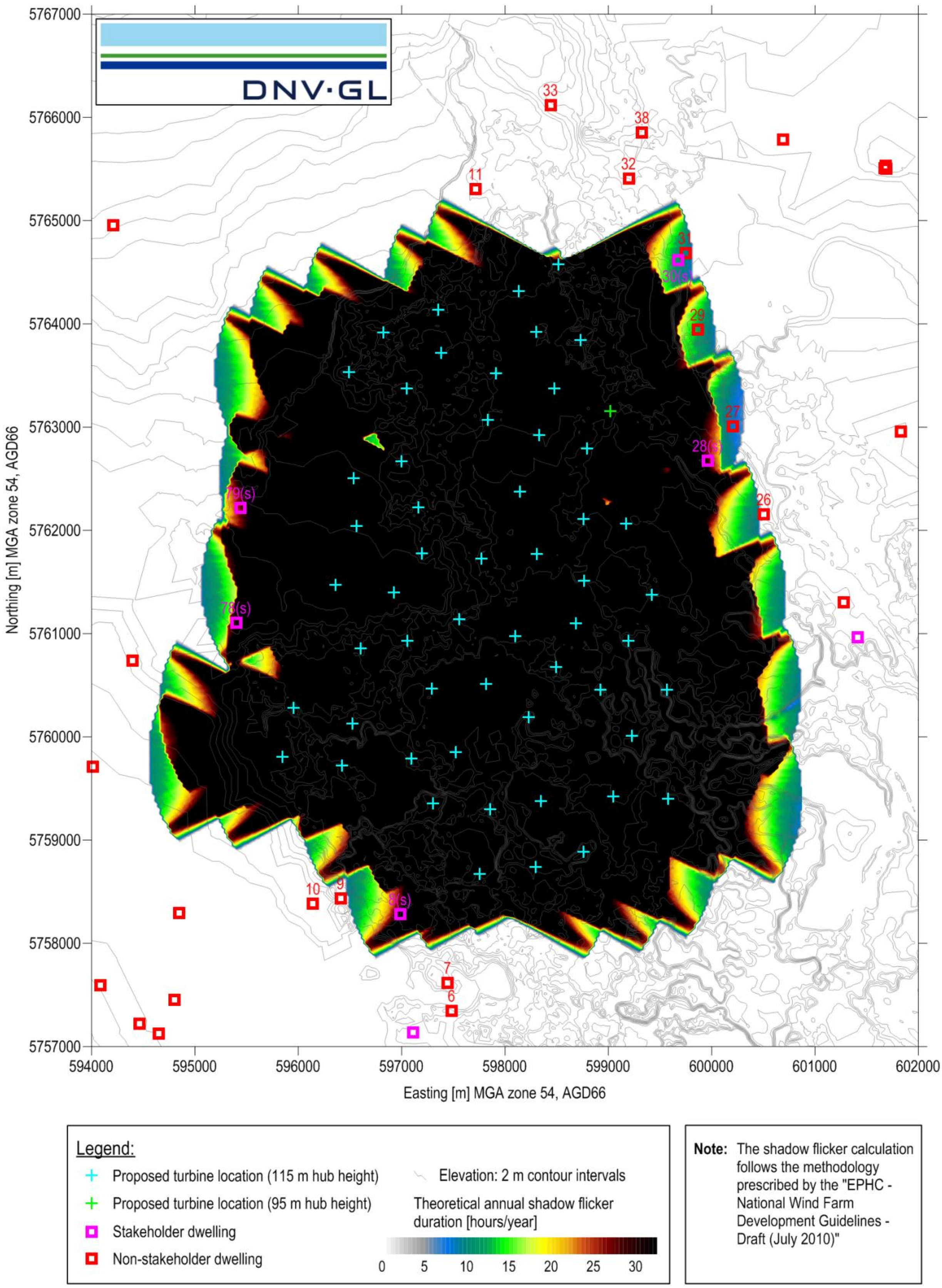

Figure 4: Map of the proposed Ryan Corner Wind Farm with turbines, dwelling locations and theoretical annual shadow flicker duration at 6 m above ground level

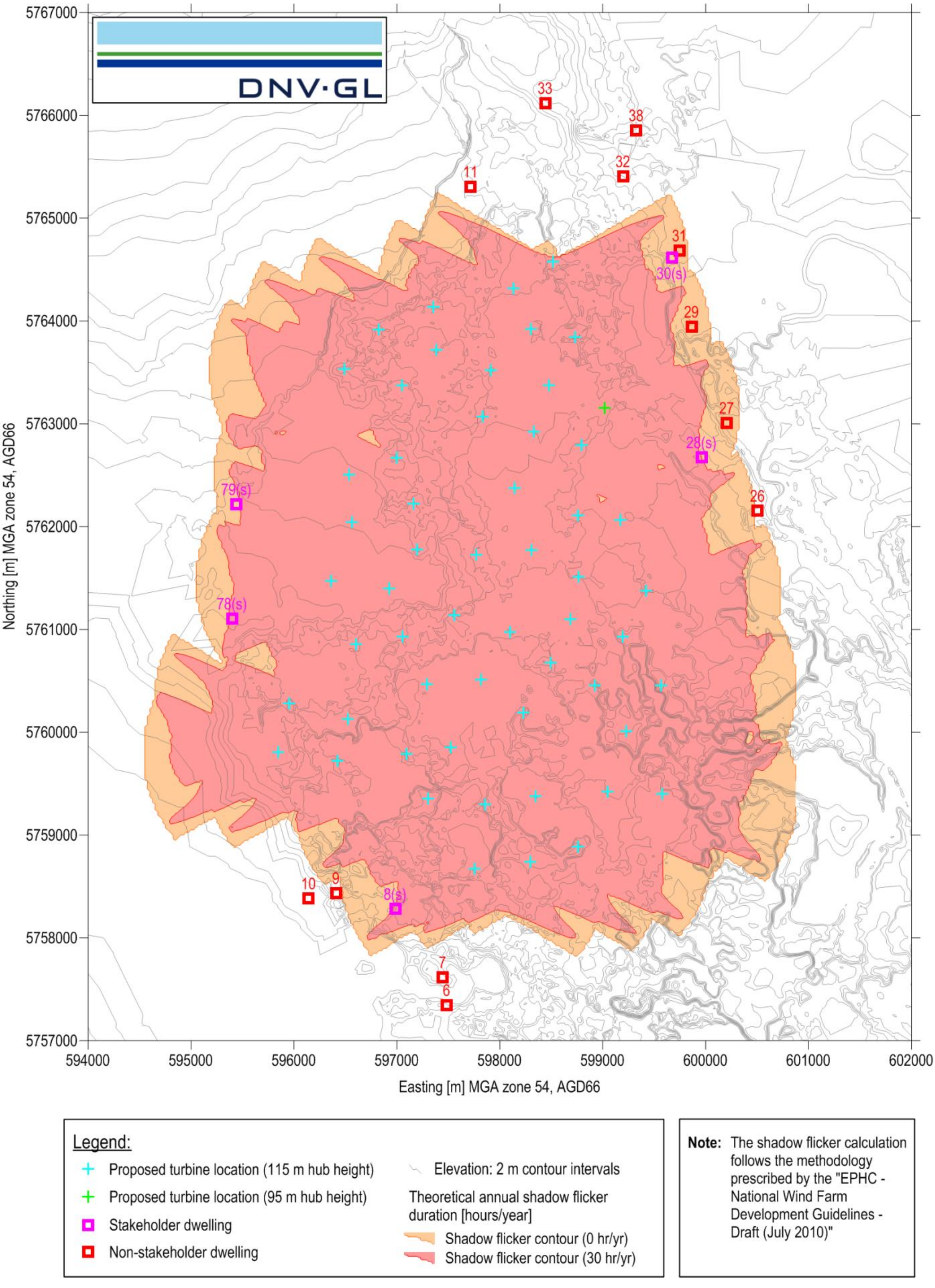

Figure 5: Map of the proposed Ryan Corner Wind Farm with turbines, dwelling locations and theoretical annual shadow flicker duration at 2 m above ground level

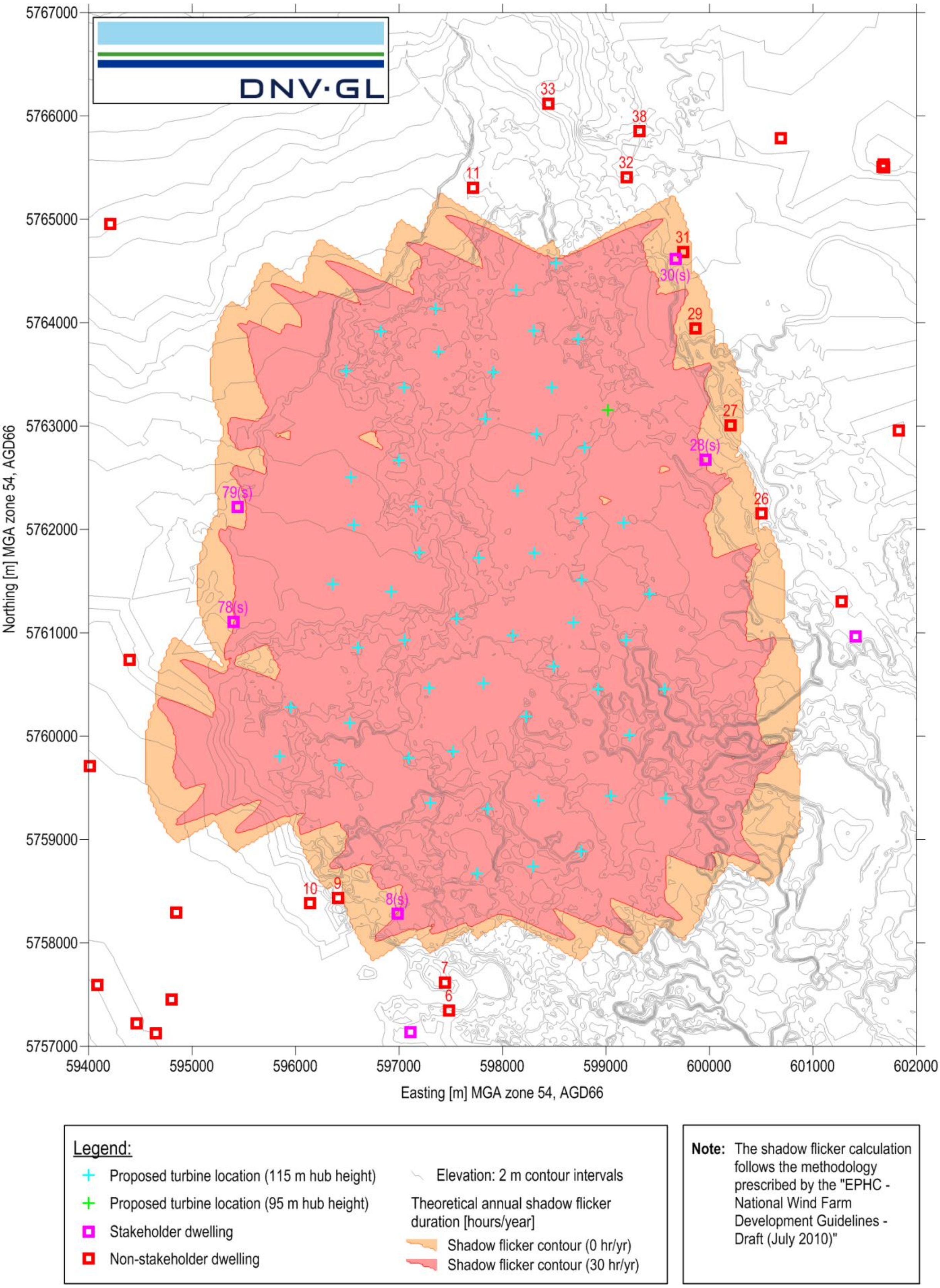

Figure 6: Map of the proposed Ryan Corner Wind Farm with turbines, dwelling locations and theoretical annual shadow flicker duration at 6 m above ground level

About DNV GL

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