GL Garrad Hassan

SHADOW FLICKER MANAGEMENT PLAN FOR THE PROPOSED BERRYBANK WIND FARM

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CONTENTS

1 EXECUTIVE SUMMARY AND INTRODUCTION

Garrad Hassan Pacific Pty Ltd (GL GH) has been commissioned by Berrybank Development Pty Ltd (BDPL) to independently assess the shadow flicker in the vicinity of the proposed Berrybank Wind Farm and develop a management plan based on the results obtained. The results of the work are reported here. This document has been prepared pursuant to the GL GH proposal P1082/PP/01 Issue A, dated 29 September 2010, and is subject to the terms and conditions contained therein.

Shadow flicker involves the modulation of light levels resulting from the periodic passage of a rotating wind turbine blade between the sun and a viewer. 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, and the viewer. This method has been used to determine the shadow flicker duration at sensitive locations neighbouring the proposed Berrybank 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].

BDPL has supplied layouts for the wind farm, a list of potential turbine models, surveyed locations of 65 buildings in the vicinity of the wind farm, and elevation contours for the site area [2]. These have been assessed here to determine the theoretical annual duration of shadow flicker at each dwelling.

Two layouts have been considered; the first, labelled Case A, is composed of 95 turbines with a hub height of 80 m and a rotor diameter of 90 m, while the second, labelled Case B, is composed of 89 turbines with a hub height of 80 m and a rotor diameter of 101 m.

The shadow flicker modelling analysis has been based on the Victorian Planning Guidelines [3] which 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 [4] have also been considered. The Draft National Guidelines 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. The Draft National Guidelines also recommend a modelling methodology.

An estimate of shadow flicker duration has been undertaken by assessing theoretical shadow flicker. This procedure constitutes the worst case scenario and assumes that:

- The turbine rotors are always perpendicular to the line of sight between the shadow receptors and the sun;
- The sky is clear of any clouds;
- The turbine rotors are always turning, and;
- Apart from the terrain, there is no obstruction between the turbines and the shadow receptors.

Modelling was undertaken at 2 m and 6 m above ground, to account for the possibility that dwellings may have two storeys.

The planning permits [9, 10] issued for the Berrybank wind farm state that turbines can be micro-sited under specific constraints. The constraints relating to shadow flicker, extracted from the permits, are listed below.

Extracts from planning permits	**Report reference**
"No turbines are located closer than 1000 metres from any non stakeholder dwelling existing prior to the issue date of this permit."	Table 1
"Micro-siting of wind turbines...is where the siting of a wind turbine is altered by no more than 100 metres but is not relocated closer to a nearby boundary of a non-stakeholder property than shown on the endorsed plans." *"The relocation of the turbine(s)...will not give rise to an adverse change to...shadow flicker..."*	Section 5.4 Figure 7 Figure 8
"Shadow flicker from the wind energy facility must not exceed 30 hours per annum at the surroundings of any dwellings existing prior to the issue date of this permit. *This condition does not apply to any dwelling on land on which part of the wind energy facility is erected."*	Table 6

To fulfil these requirements, the shadow flicker results described above, calculated from the turbine layout proposed in the planning application, have been used as the basis to establish allowable micrositing zones that will not increase the shadow flicker durations experienced by surrounding non-stakeholder dwellings.

Based on the allowable micrositing zones, BDPL developed two revised layouts for the site, and the shadow flicker durations were reassessed using the revised turbine locations presented in Table 3 and Table 4.

The shadow flicker modelling for the revised layouts shows that, based on the methodology recommended in the Draft National Wind Farm Development Guidelines, there are 11 existing dwellings that are predicted to experience some shadow flicker within 50 m of the dwelling. Out of these 11 dwellings, one (House 65) is expected to experience theoretical shadow flicker duration in excess of 30 hours per year.

However, GL GH has now been informed that House 65 should be excluded from the shadow flicker assessment due to an agreement between the owners and BDPL stating that, for the operational life of the wind farm, no person shall be residing in the house.

Therefore, when excluding House 65, compliance with, both, the Victorian Planning Guidelines and the Draft National Wind Farm Development Guidelines is predicted to be achieved for all the provided dwelling locations.

It should be noted that, for both layouts considered, Turbine 10 has been microsited such that, when compared with the layout included in the development application, there is in an increase in the theoretical shadow flicker duration predicted within 50 m of House 58, as shown in Table 6 and Table 7. BDPL has indicated that the owner of House 58 is generally supportive of the project and is also related to a participating land owner. In addition, GL GH has conducted a high level review of the tree cover surrounding House 58, and based on publicly available aerial and ground-based images, it is expected that the existing vegetation will provide significant sheltering from shadow flicker originating from Turbine 10.

Additionally, a detailed assessment of the shadow flicker impact on a specific land parcel was conducted. The owners of the considered parcel, Lot 2 TP134239C, were contacted and informed of the theoretical shadow flicker occurrence on their property.

Based on the theoretical shadow flicker modelling, and considering a zone of influence of 50 m around any location within the land parcel, less than 1% of the parcel's area could theoretically experience shadow flicker likely to cause annoyance, based on the methodology recommended in the Draft National Guidelines and Victorian limits.

2 GENERAL SITE DESCRIPTION

2.1 Site description

The Berrybank site is located approximately 45 km southwest of Ballarat, in Victoria. The general location of the area of interest is shown in Figure 1. A more detailed contour map of the region surrounding the proposed wind farm, which also includes proposed turbine, house locations and cadastral boundaries [5], can be seen in Figure 3 to Figure 6.

The town of Ballarat is situated some 100 km west-northwest of Melbourne. The proposed wind farm is located on relatively flat land and turbine elevation varies between approximately 150 m and 200 m.

The site appears to be predominantly covered by farmland.

2.2 House locations

A list of the co-ordinates of dwellings in the vicinity of the wind farm has been provided by BDPL [6]. Only houses within 1100 m of the proposed wind farm have been considered in the current analysis, and are shown in Table 1.

All co-ordinates presented in this report are in MGA Zone 54 (AGD94 datum).

2.3 Lot 2 TP134239C

At the time of conducting this assessment, no house was located on the land parcel identified as Lot 2 TP134239C. However, the owner of this parcel has proposed a plan to construct a dwelling within the parcel area.

The intended building location has not been clarified for BDPL, but an analysis has been conducted to indentify parts of the parcels that could be affected by shadow flicker. The parcel is located immediately southwest of the site area, in proximity to turbine 62.

2.4 Proposed Wind Farm layout

BDPL has supplied two layouts for the wind farm, which are composed of 95 and 89 turbines. The proposed turbine dimensions are presented in Table 2.

A list of co-ordinates of proposed turbine locations has been provided by BDPL [7], with the grid coordinates given in MGA Zone 54 (AGD94 datum). These co-ordinates, together with the identifiers which have been supplied by BDPL are shown in Table 3 and Table 4. Also listed in the table, is the distance of which each turbine was moved, from the location presented in the planning application.

Figure 3 to Figure 6 show maps of the site with the proposed turbine layouts and surrounding house locations.

3 PURPOSE

The purpose of this assessment is to:

- Conduct a shadow flicker assessment for the Berrybank Wind Farm, considering two layout cases.
- Establish allowable turbine micrositing areas that will not increase the shadow flicker impact at surrounding non-stakeholder dwellings.
- Establish areas on Lot 2 TP134239C that are expected to experience shadow flicker to assist with the determination of a suitable location for a proposed dwelling.

4 RELEVANT GOVERNMENT LEGISLATION, GUIDELINES, OR STANDARDS

In Victoria, the Victorian Planning Guidelines contain information on the assessment of shadow flicker due to wind farm installation. The document currently states;

> *"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 [4] 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 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.

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 [8] or approximately 1000 to 1100 m for commonly installed 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 therefore suggest a distance equivalent to 265 maximum blade chords[1] as an appropriate limit, which corresponds to approximately 800 to 1050 m for modern wind turbines (which typically have maximum blade chord lengths of 3 to 4 m). The UK wind industry and UK government consider that 10 rotor diameters is appropriate, which corresponds to approximately 800 to 1100 m for commonly installed wind turbines (which typically have rotor diameters of 80 to 110 m).

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

5 METHODOLOGY

5.1 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 may appear through a window opening. The likelihood and duration of the effect depends upon a number of factors, including:

- Orientation 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 plane of rotation of 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)

5.2 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 generic wind turbines considered 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 conservatively 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, GL GH 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 6m, 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 simulations have been carried out with a temporal resolution of 1 minute; if shadow flicker occurs in any 1 minute period, the model records this as 1 minute of shadow flicker.

An assumption has been made 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 [8], while the Draft National Guidelines suggest a distance equivalent to 265 maximum blade chords as an appropriate limit.

Due to the fact that multiple options are available for the turbine dimension used in the layout, the shadow flicker modelling was aimed at obtaining the worst case scenario. The model used a hub height of 80 m and a rotor diameter of 101 m, corresponding to the largest rotor diameter option. The maximum blade chord considered for the analysis has been set at 3.9 m, based on the maximum dimension found from a list of turbine representative of such a rotor diameter. The maximum shadow flicker limit, from either the rotor diameter or maximum chord criteria, is equal to 1033.5 m. It should be noted that the shadow flicker limit used in the modelling has been rounded to 1040 m.

Also, the model 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 specified location 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. Shadow flicker model settings for theoretical shadow flicker calculations

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To illustrate typical results, an indicative shadow flicker map for a turbine located in a 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 areas around the turbine affected by shadow flicker.

5.3 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 disk 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 shadow flicker duration.

No attempt has been made to account for the factors above when determining the shadow flicker durations presented in this assessment. It is therefore likely that the shadow flicker durations presented here can still be regarded as a conservative assessment.

5.4 Turbine micrositing

The planning permits for the Berrybank Wind Farm [9, 10], allow micrositing of turbine locations, which is defined as:

> *"... where the siting of a wind turbine is altered by not more than 100 metres but is not relocated closer to a nearby boundary of a non-stakeholder property than shown on the endorsed plans."*

However, the planning permits also impose the following constraints stating that micrositing:

> *"... is only allowed where the Minister for Planning is satisfied that the relocation of the turbine(s) and associated access track(s) and reticulation lines(s) will not give rise to an adverse change to assessed landscape, vegetation, cultural heritage, visual amenity, shadow flicker, noise, fire risk or aviation impacts when compared to the site shown on the endorsed plans."*

Based on the extract above, it is understood that the micrositing of a turbine should not cause an increase of the shadow flicker duration observed at any of the surrounding dwellings. It has been assumed that this restriction does not apply to dwellings owned by project stakeholders.

The current assessment aims to define allowable micrositing regions, considering the requirement that there should not be an adverse change to shadow flicker at surrounding non-stakeholder residences. Other requirements in the planning permit, such as those stating that a turbine should not be moved closer to the boundary of a non-stakeholder property, or cause adverse changes to other potential impacts, have not been considered.

In order to ensure that the turbine micrositing does not cause an increase in shadow flicker duration at any non-stakeholder dwelling, the maximum theoretical shadow flicker duration within 50 m of each dwelling was calculated based on the layout proposed in the wind farm planning application and turbine under consideration. This value was then used to represent the shadow flicker duration limit which could not be exceeded at each non-stakeholder dwelling.

Micrositing exclusion zones were then established using the following steps:

1. Shadow flicker contours were generated representing the duration limits for each dwelling (as calculated above), using a representative turbine on the site. Turbine 71 was selected in this case as it is close to the centre of the site and in relatively flat terrain. The grid on which the contours were based had a resolution of 5 m, and was calculated for a height above ground of 2 m, which was found to be the most conservative of the two heights considered. Where more than one turbine was found to contribute to the shadow flicker at a dwelling, shadow flicker contours were generated for each turbine, based on the shadow flicker contribution from that turbine;

2. The shadow flicker contours for each dwelling and turbine, were located on the relevant turbine, and their boundaries extended by the minimum of 50 m and the distance between the nearest point on the contour and the relevant dwelling. This was to account for the distance between the point at which the maximum shadow flicker occurred and the dwelling, or any inaccuracies in the contour arising from the resolution of the grid used to generate the contour.

3. The contours of calculated shadow flicker were then translated to the house location, to establish exclusion zones, within which turbines may not be located without exceeding the allowable limits.

4. A 100 m micrositing buffer was established around each turbine.

5. The shadow flicker exclusion zone contours were removed from the micrositing buffers, leaving the allowable micrositing areas.

The allowable micrositing areas, which can be seen in Figure 7 to Figure 10, illustrate the southern and northern portions of the site, for both cases.

6 RESULTS OF THE ANALYSIS

The results presented in this section are based on modelling results obtained from the revised turbines locations, presented in Table 3 and Table 4.

6.1 Shadow Flicker Assessment

The theoretical maximum predicted shadow flicker durations at receptors within the vicinity of the proposed Berrybank Wind Farm are presented in Table 6 and Table 7. The maximum predicted theoretical shadow flicker durations within 50 m of receptors are also presented in these tables. The results are presented in the form of a shadow flicker maps at 2 m and 6 m above ground, to account for the possibility of single and double storey buildings, in Figure 3 to Figure 6. The results of the shadow flicker modelling conducted at 2 m above ground were also used to generate 0 hours and 30 hours per annum contours. These contours are presented in Figure 7 to Figure 10.

The results of the shadow flicker assessment indicate that 11 dwellings are predicted to experience some shadow flicker. Of these 11 dwellings, one (House 65) is expected to experience theoretical shadow flicker durations of more than 30 hours per year.

However, GL GH has now been informed that this dwelling should be excluded for the shadow flicker assessment due to an agreement between the owners and BDPL stating that, for the operational life of the wind farm, no person shall be residing in the house.

It should be noted that, for both layouts considered, Turbine 10 has been microsited such that, when compared with the layout included in the development application, there is in an increase in the theoretical shadow flicker duration predicted within 50 m of House 58, as shown in Table 6 and Table 7. BDPL has indicated that the owner of House 58 is generally supportive of the project and is also related to a participating land owner. In addition, GL GH has conducted a high level review of the tree cover surrounding House 58, and based on publicly available aerial and ground-based images, it is expected that the existing vegetation will provide significant sheltering from shadow flicker originating from Turbine 10.

6.2 Turbine Micrositing Areas

The allowable micrositing areas, originating from the shadow flicker modelling obtained using the planning application layout, can be seen in Figure 7 to Figure 10, illustrating the southern and northern portions of the site, respectively.

6.3 Detailed Shadow Flicker Study of Lot 2 TP134239C

A detailed assessment of the theoretical impact of shadow flicker on Lot 2 TP134239C was conducted, and is presented in Figure 11 to Figure 14. Based on the results of the shadow flicker modelling conducted for this study, less than 1% of the land area occupied by this parcel, located along its northern edge, could be experiencing low durations of shadow flicker.

7 CONSULTATION WITH LOCAL COMMUNITY

The owners of Lot 2 TP134239C have been contacted regarding the potential for shadow flicker on their property, and to discuss suitable locations for a proposed dwelling that will not experience undue shadow flicker impact. GL GH has been advised by the owners of the property that a dwelling location has been established, however it has not been possible for GL GH to obtain the location of the proposed dwelling.

8 MITIGATION AND MANAGEMENT OPTIONS

If shadow flicker presents a problem, its effects can be reduced through a number of 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.

9 CONCLUSIONS AND RECOMMENDATIONS

An analysis has been conducted to determine the duration of shadow flicker experienced at shadow receptors in the vicinity of the proposed Berrybank Wind Farm, based on the methodology proposed in the Draft National Guidelines. The results of the assessment are presented in the form of a shadow flicker map in Figure 3 to Figure 6. The shadow flicker results for each receptor identified to GL GH are also listed in Table 6 and Table 7.

An analysis, based on the turbine layout presented in the development application, was performed to determine allowable micrositing areas such that shadow flicker impact is not increased at non-stakeholder dwellings. The resulting micrositing zones are shown in Figure 7 to Figure 10. It is recommended that turbines are only sited within the allowable micrositing areas, and only if the new location is in accordance with the planning permit conditions.

After BDPL obtained knowledge of the allowable micrositing areas, the layout presented in the planning application was revised, and the shadow flicker durations reassessed using the altered turbine locations presented in Table 3 and Table 4.

It should be noted that, for both layouts considered, Turbine 10 has been microsited such that, when compared with the layout included in the development application, there is in an increase in the theoretical shadow flicker duration predicted within 50 m of House 58, as shown in Table 6 and Table 7. BDPL has indicated that the owner of House 58 is generally supportive of the project and is also related to a participating land owner. In addition, GL GH has conducted a high level review of the tree cover surrounding House 58, and based on publicly available aerial and ground-based images, it is expected that the existing vegetation will provide significant sheltering from shadow flicker originating from Turbine 10.

The revised assessment of theoretical shadow flicker hours shows that all the dwellings identified by BDPL comply with the recommended limit of 30 shadow flicker hours per year.

A detailed assessment of the predicted shadow flicker impact on Lot 2 TP134239C was completed. The results of this analysis, illustrated in Figure 11 to Figure 14, show that there is potential for low durations of shadow flicker on less than 1% of the parcel area. This value could be lower due to the presence of trees between the turbine 62 and the affected parcel area.

No information could be obtained regarding the house location proposed by the land owner of Lot 2 TP134239C. However, if shadow flicker proves to be an issue at the house location, the use of turbine control strategies or the planting of trees could reduce the area affected by shadow flicker.

10 REFERENCES

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7. Turbines coordinate data set, MS Excel Spreadsheet format, provided by BDPL, 14th June 2012

8. "Planning for Renewable Energy – A Companion Guide to PPS22", Office of the Deputy Prime Minister, UK, 2004

9. Planning Permit #20092820, PDF file format, Provided by BDPL, 19th November 2010

10. Planning Permit #20092821, PDF file format, Provided by BDPL, 19th November 2010

LIST OF TABLES

LIST OF FIGURES

House ID[2,3]	Easting [m][1]	Northing [m][1]	Case A		Case B	
			Distance from nearest turbine [m]	Nearest turbine	Distance from nearest turbine [m]	Nearest turbine
House 9	*724123*	*5799807*	*1092*	*30*	*1147*	*39*
House 10	718587	5797888	1041	25	1041	25
House 18	719391	5803724	1067	3	1067	3
House 27	716501	5793929	1092	48	1092	48
House 54	*720176*	*5800321*	*699*	*5*	*699*	*5*
House 55	*719613*	*5799970*	*943*	*11*	*943*	*11*
House 56	719602	5799532	1039	18	1039	18
House 58	717818	5801367	1063	10	1063	10
House 61	*719390*	*5796269*	*788*	*73*	*788*	*73*
House 62	*721670*	*5796577*	*828*	*15*	*857*	*68*
House 65	*723797*	*5798337*	*293*	*64*	*293*	*64*
House 66	*722414*	*5798736*	*768*	*52*	*768*	*52*
House 67	*718431*	*5793106*	*1070*	*33*	*1070*	*33*
House 68	*718429*	*5793061*	*1046*	*33*	*1046*	*33*
House 69	718535	5793693	1097	75	1097	75
House 78	*720663*	*5793064*	*769*	*95*	*769*	*95*
House 79	719983	5793140	1087	95	1087	95
House 80	719684	5793375	1085	81	1085	81
House 81	*719130*	*5793548*	*942*	*81*	*942*	*81*
House 83	721502	5791385	1099	42	1099	42
House 103	723431	5793860	1085	41	1085	41
House 112	*720055*	*5800295*	*710*	*11*	*710*	*11*

[1] The house coordinates are in MGA Zone 54 (GDA94 datum).
[2] The houses presented in *italic fonts* have an agreement with BDPL.
[3] The houses presented in grey fonts have been identified as uninhabitable.

Table 1. House locations in the vicinity of the proposed Berrybank Wind Farm turbines.

Dimensions	Case A	Case B
Tower Hub Heights [m]	80	80
Blade Maximum Chord [m][1]	3.9	3.9
Rotor Diameter [m]	90	101
Total Height To Tip [m]	125	131

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

Table 2. Turbine dimensions options

Turbine ID	Easting [m][1]	Northing [m][1]	Distance Moved [m][2]	Turbine ID	Easting [m][1]	Northing [m][1]	Distance Moved [m][2]
001	718723	5802176	71	052	722857	5798109	68
002	719252	5802580	49	053	720508	5792033	88
003	719751	5802721	59	054	722575	5797699	65
004	720024	5797726	88	055	720424	5790132	0
005	720710	5799869	74	056	721609	5798587	75
006	719878	5802241	41	057	720523	5797897	0
007	719461	5801353	75	058	720518	5795662	80
008	720879	5800436	75	059	720996	5795836	81
009	719747	5801765	77	060	721916	5797989	81
010	718763	5800876	93	061	721359	5797985	34
011	719698	5800908	82	062	717035	5792325	36
012	718972	5801428	80	063	720366	5790697	83
013	720348	5801559	0	064	723517	5798249	89
014	720545	5801081	73	065	719881	5797190	0
015	721790	5797395	93	066	720611	5796396	92
016	720318	5796959	0	067	719389	5797117	0
017	721257	5799665	0	068	720853	5796843	0
018	720639	5799429	0	069	720991	5797527	0
019	721859	5800552	0	071	720253	5796063	85
020	722364	5800847	62	072	719083	5795244	69
021	721322	5800299	74	073	719681	5795538	84
022	722296	5800211	0	074	717068	5792757	0
023	722795	5799662	91	075	719007	5794682	88
024	722780	5800575	81	076	719471	5794946	0
025	719616	5798063	0	077	720499	5794664	61
026	721074	5799204	0	078	720210	5795076	70
027	721740	5799891	0	079	720783	5795235	91
028	722175	5799582	86	080	722250	5794038	72
030	723139	5800286	75	081	719449	5794433	92
031	720387	5791193	37	082	719910	5794638	86
032	720956	5794268	67	083	721485	5794779	63
033	717508	5792561	0	084	721336	5793795	49
034	719239	5802012	66	085	721919	5794981	59
036	720052	5798486	89	086	722299	5793079	48
037	720560	5798451	85	087	721763	5795464	62
038	721050	5798620	87	088	720459	5794148	94
039	723772	5798717	90	089	720989	5794775	51
040	722821	5792881	0	090	721490	5794283	0
041	723294	5792785	0	092	722380	5793540	95
042	721339	5792470	84	093	722499	5794676	62
043	722465	5792519	0	094	722012	5794479	95
044	725612	5797947	0	095	720840	5793811	49
045	724851	5798766	0	096	721820	5793754	75
046	724684	5797804	95	097	721932	5792792	45
047	724303	5798164	79	098	721749	5793249	0
048	717298	5793181	0	099	722975	5792402	0
049	723949	5797815	90	100	721274	5795359	85
051	725119	5798064	0				

[1] The turbine coordinates are in MGA Zone 54 (GDA94 datum).
[2] Distance moved from the turbine location listed in the planning application.

Table 3. Proposed turbine layout for the Berrybank Wind Farm site (Case A).

Turbine ID	Easting [m][1]	Northing [m][1]	Distance Moved [m][2]	Turbine ID	Easting [m][1]	Northing [m][1]	Distance Moved [m][2]
001	718723	5802176	71	051	725119	5798064	0
002	719252	5802580	49	052	722857	5798109	68
003	719751	5802721	59	053	720508	5792033	88
004	720024	5797726	88	055	720424	5790132	0
005	720710	5799869	74	056	721609	5798587	75
006	719878	5802241	41	057	720523	5797897	0
007	719461	5801353	75	058	720518	5795662	80
008	720879	5800436	75	059	720996	5795836	81
009	719747	5801765	77	060	721916	5797989	81
010	718763	5800876	93	061	721359	5797985	34
011	719698	5800908	82	062	717035	5792325	36
012	718972	5801428	80	063	720366	5790697	83
013	720348	5801559	0	064	723517	5798249	89
014	720545	5801081	73	065	719881	5797190	0
016	720318	5796959	0	066	720611	5796396	92
017	721257	5799665	0	067	719389	5797117	0
018	720639	5799429	0	068	720853	5796843	0
019	721859	5800552	0	069	720991	5797527	0
020	722364	5800847	62	071	720253	5796063	85
021	721322	5800299	74	072	719083	5795244	69
022	722296	5800211	0	073	719681	5795538	84
023	722795	5799662	91	074	717068	5792757	0
024	722780	5800575	81	075	719007	5794682	88
025	719616	5798063	0	076	719471	5794946	0
026	721074	5799204	0	077	720499	5794664	61
027	721740	5799891	0	078	720210	5795076	70
028	722175	5799582	86	079	720783	5795235	91
031	720387	5791193	37	080	722250	5794038	72
032	720956	5794268	67	081	719449	5794433	92
033	717508	5792561	0	082	719910	5794638	86
034	719239	5802012	66	083	721485	5794779	63
036	720052	5798486	89	084	721336	5793795	49
037	720560	5798451	85	086	722299	5793079	48
038	721050	5798620	87	088	720459	5794148	94
039	723772	5798717	90	089	720989	5794775	51
040	722821	5792881	0	090	721490	5794283	0
041	723294	5792785	0	092	722380	5793540	95
042	721339	5792470	84	094	722012	5794479	95
043	722465	5792519	0	095	720840	5793811	49
044	725612	5797947	0	096	721820	5793754	75
045	724851	5798766	0	097	721932	5792792	45
046	724684	5797804	95	098	721749	5793249	0
047	724303	5798164	79	099	722975	5792402	0
048	717298	5793181	0	100	721274	5795359	85
049	723949	5797815	90				

[1] The turbine coordinates are in MGA Zone 54 (GDA94 datum).
[2] Distance moved from the turbine location listed in the planning application.

Table 4. Proposed turbine layout for the Berrybank Wind Farm site (Case B).

Model Setting	At dwellings location	Shadow flicker map	Shadow flicker contours (micro-siting)
Maximum shadow length	1040 m	1040 m	1040 m
Year of calculation	2025	2025	2025
Minimum elevation of the sun	3°	3°	3°
Time step	1 min	10 min	5 min
Rotor modelled as	Sphere	Sphere	Sphere
Sun modelled as	Disc	Disc	Disc
Rotor-tower offset	None	None	None
Receptor height	2 and 6 m	2 and 6 m	2 m
Grid size	n/a	25 m	5 m

Table 5. Shadow flicker model settings for theoretical shadow flicker calculations

House ID	Easting[1] [m]	Northing[1] [m]	At Dwelling[2] [hr/yr]		Max Within 50m of Dwelling[2] [hr/yr]	
			At 2 m	At 6 m	At 2 m	At 6 m
10	718587	5797888	0.0	0.0	7.7	7.1
54	720176	5800321	15.6	15.2	18.1	17.5
56	719602	5799532	0.0	0.0	8.0	7.4
58	717818	5801367	0.0	0.0	12.9	12.6
61	719390	5796269	11.9	11.3	13.2	12.6
62	721670	5796577	11.7	11.3	21.0	18.8
66	722414	5798736	13.7	13.1	15.4	14.9
67	718431	5793106	0.0	0.0	4.1	3.9
68	718429	5793061	0.0	0.0	12.6	12.1
112	720055	5800295	11.1	10.6	13.2	13.4
Limits			**30**	**30**	**30**	**30**

[1] The house coordinates are in MGA Zone 54 (GDA94 datum).
[2] The shaded rows represent houses under agreement with BDPL

Table 6. Theoretical shadow flicker durations (Case A).

House ID	Easting[1] [m]	Northing[1] [m]	At Dwelling[2] [hr/yr]		Max Within 50m of Dwelling[2] [hr/yr]	
			At 2 m	At 6 m	At 2 m	At 6 m
10	718587	5797888	0.0	0.0	9.0	8.6
54	720176	5800321	18.9	18.2	21.9	20.9
56	719602	5799532	0.0	0.0	9.5	8.9
58	717818	5801367	0.0	0.0	14.5	14.2
61	719390	5796269	14.3	13.5	16.0	15.1
62	721670	5796577	13.9	13.3	24.8	23.9
66	722414	5798736	16.5	15.7	18.2	18.2
67	718431	5793106	0.0	0.0	5.3	5.1
68	718429	5793061	0.0	0.0	14.0	13.4
112	720055	5800295	13.2	12.5	17.0	17.0
Limits			**30**	**30**	**30**	**30**

[1] The house coordinates are in MGA Zone 54 (GDA94 datum).
[2] The shaded rows represent houses under agreement with BDPL

Table 7. Theoretical shadow flicker durations (Case B).

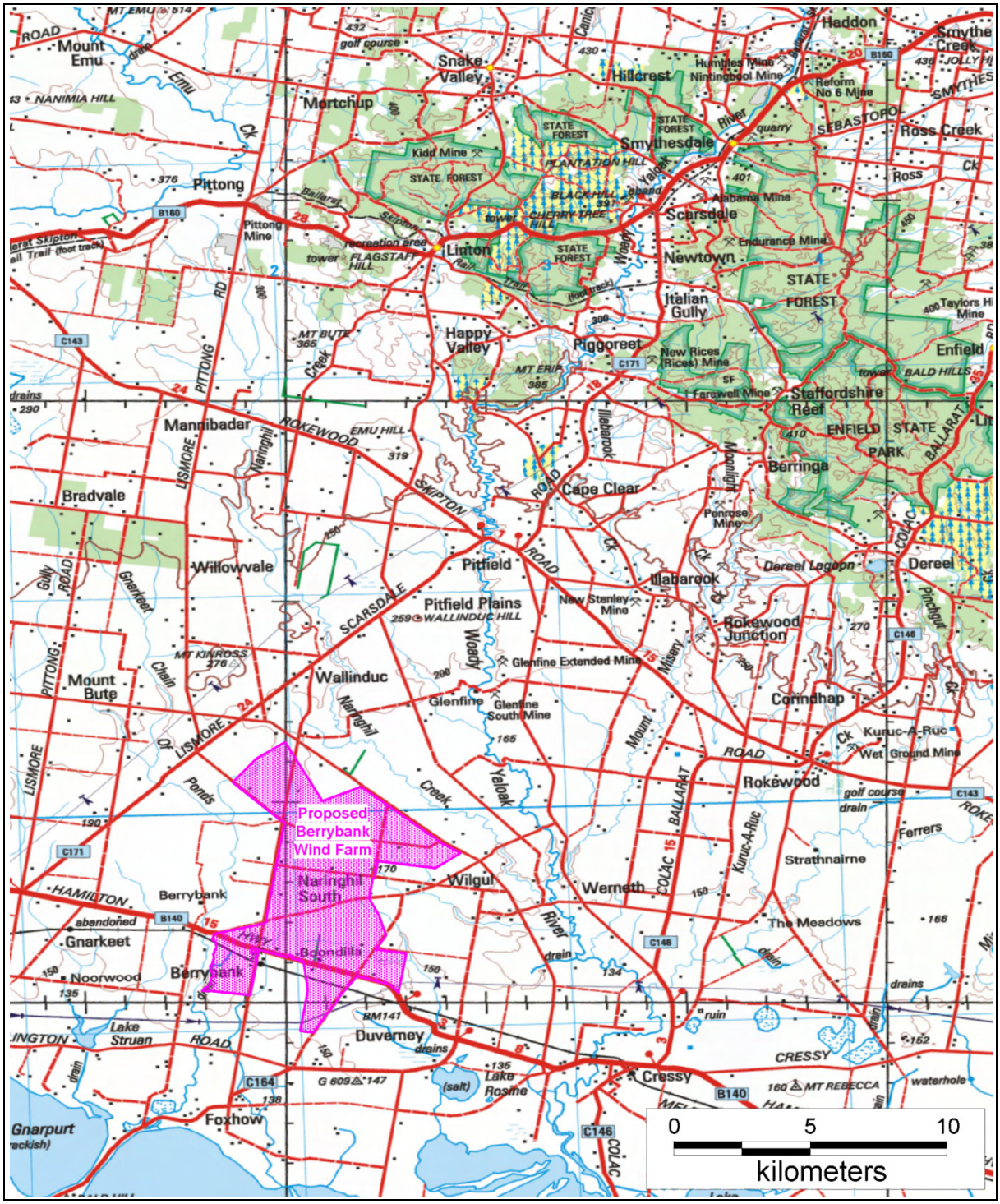

Figure 1. Location of the proposed Berrybank Wind Farm.

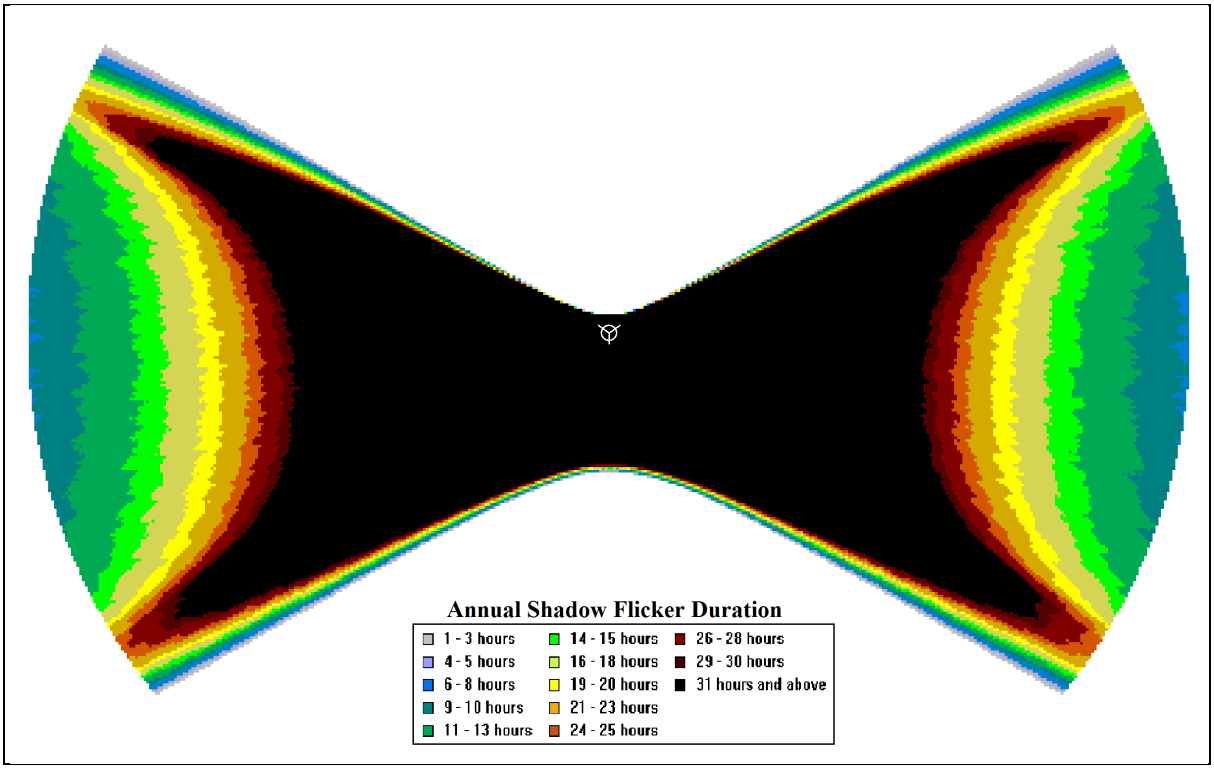

Figure 2. Indicative shadow flicker map (turbine 71).

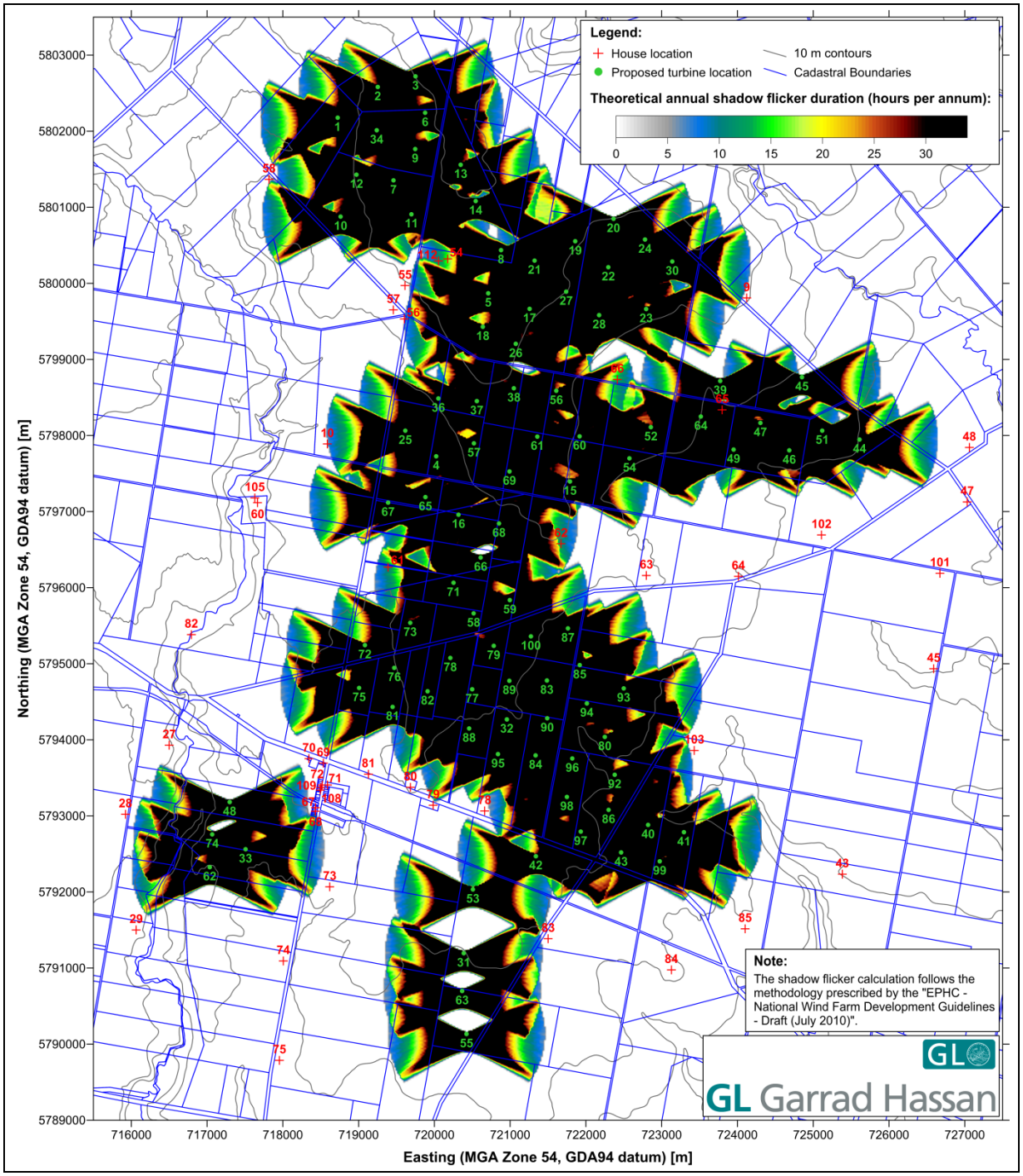

Figure 3. Map of proposed Berrybank Wind Farm showing turbines, house locations and theoretical shadow flicker duration at 2 m (Case A).

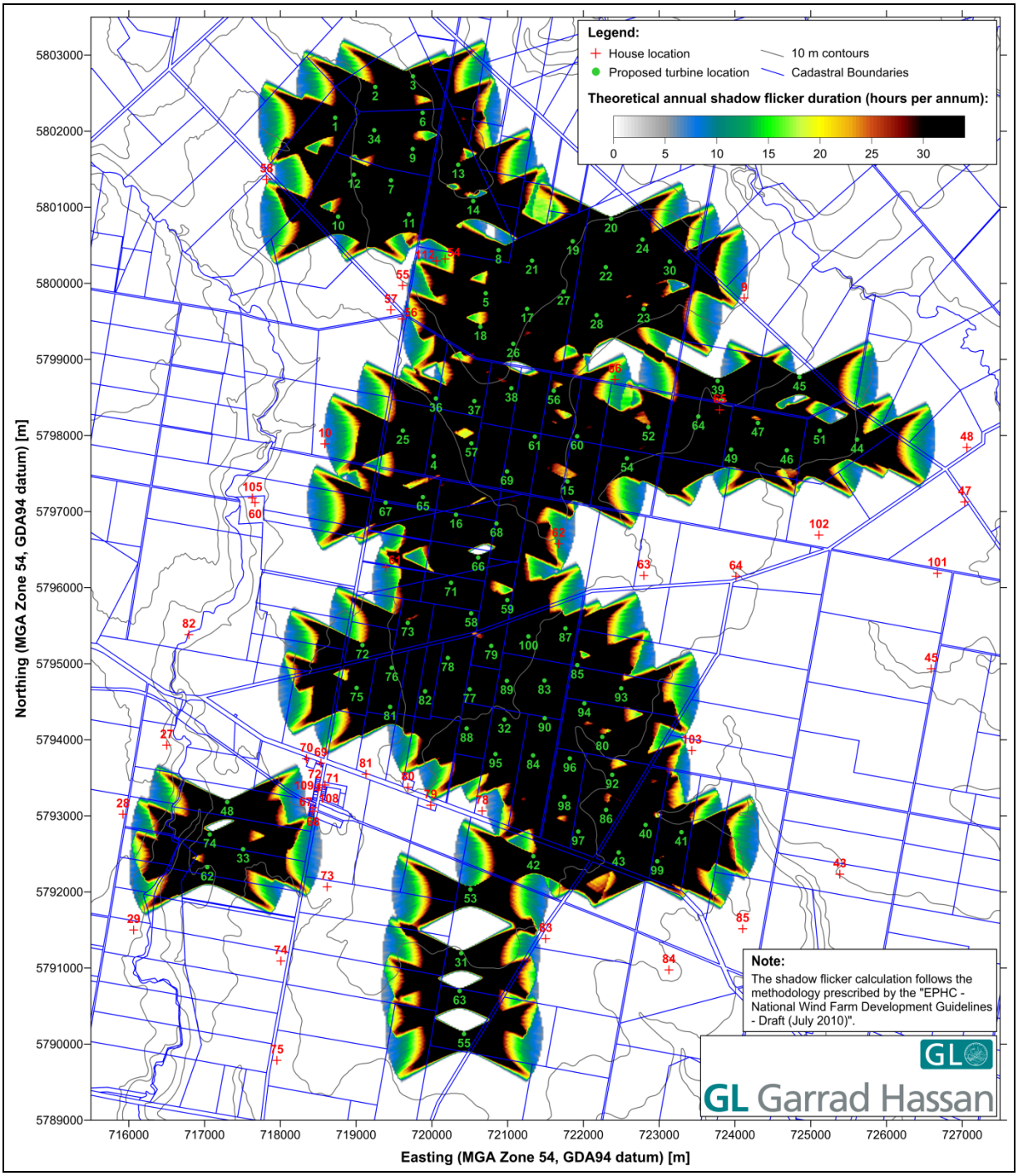

Figure 4. Map of proposed Berrybank Wind Farm showing turbines, house locations and theoretical shadow flicker duration at 6 m (Case A).

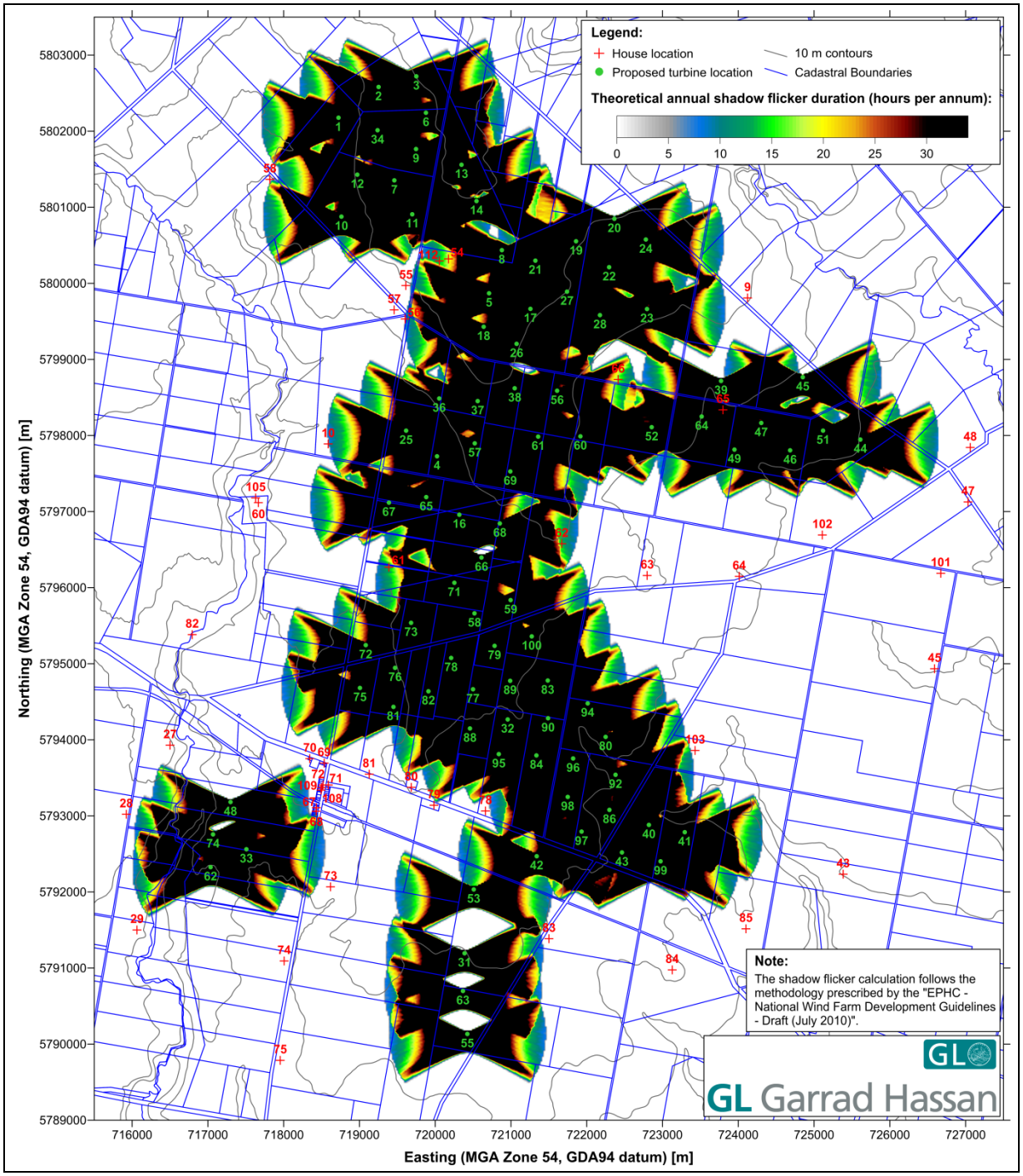

Figure 5. Map of proposed Berrybank Wind Farm showing turbines, house locations and theoretical shadow flicker duration at 2 m (Case B).

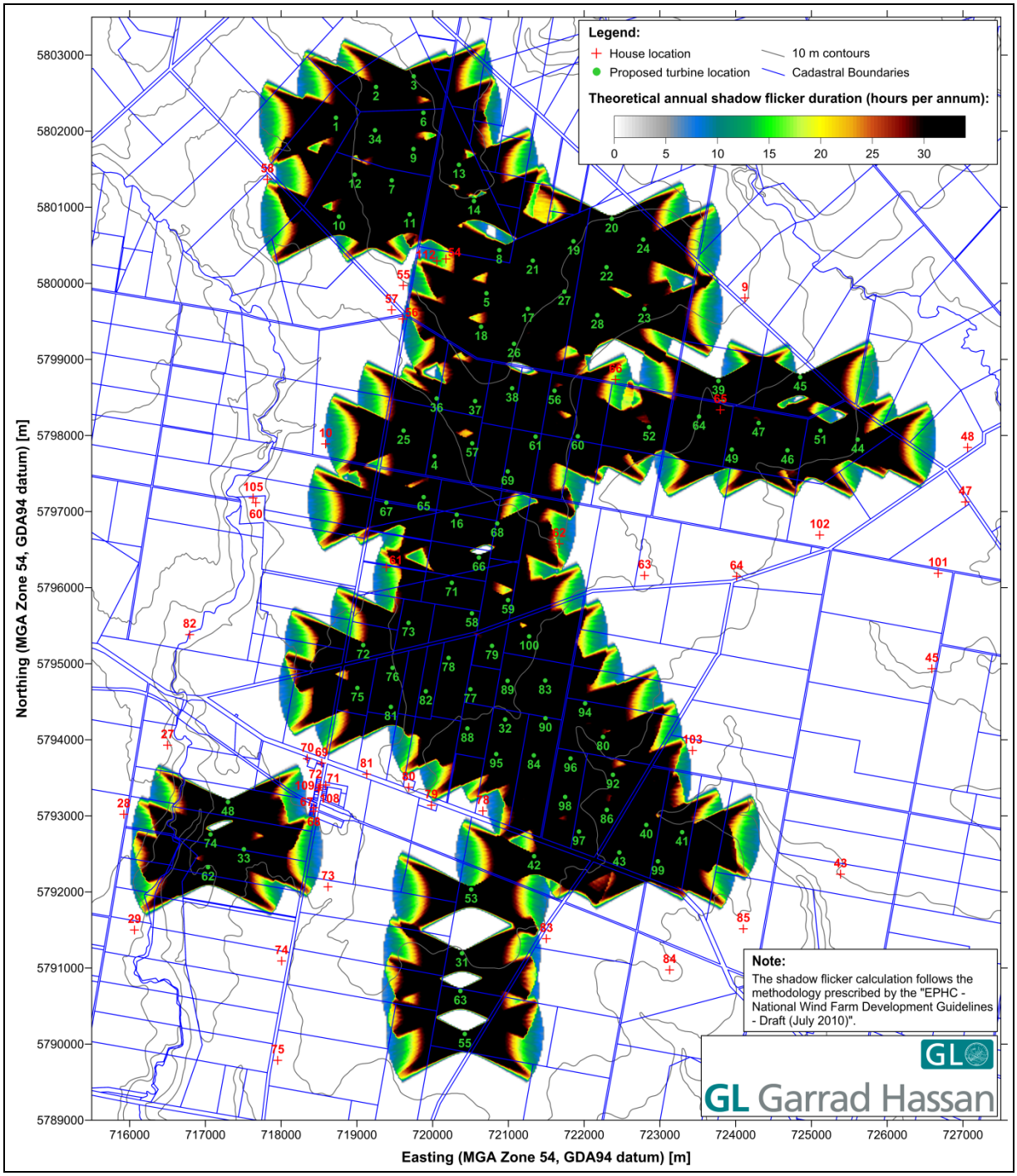

Figure 6. Map of proposed Berrybank Wind Farm showing turbines, house locations and theoretical shadow flicker duration at 6 m (Case B).

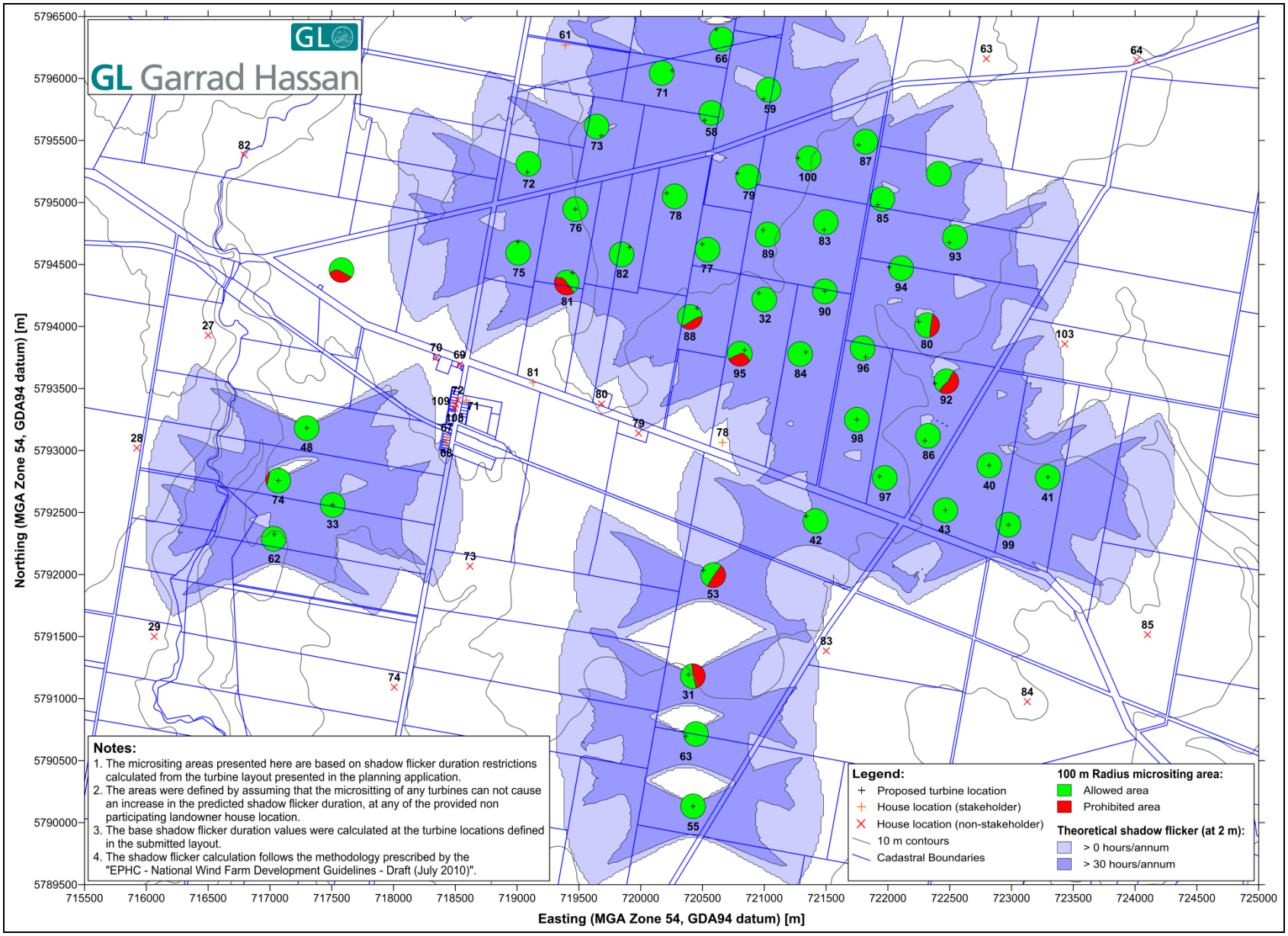

Figure 7. Micrositing area allowance due to shadow flicker (southern section – Case A)

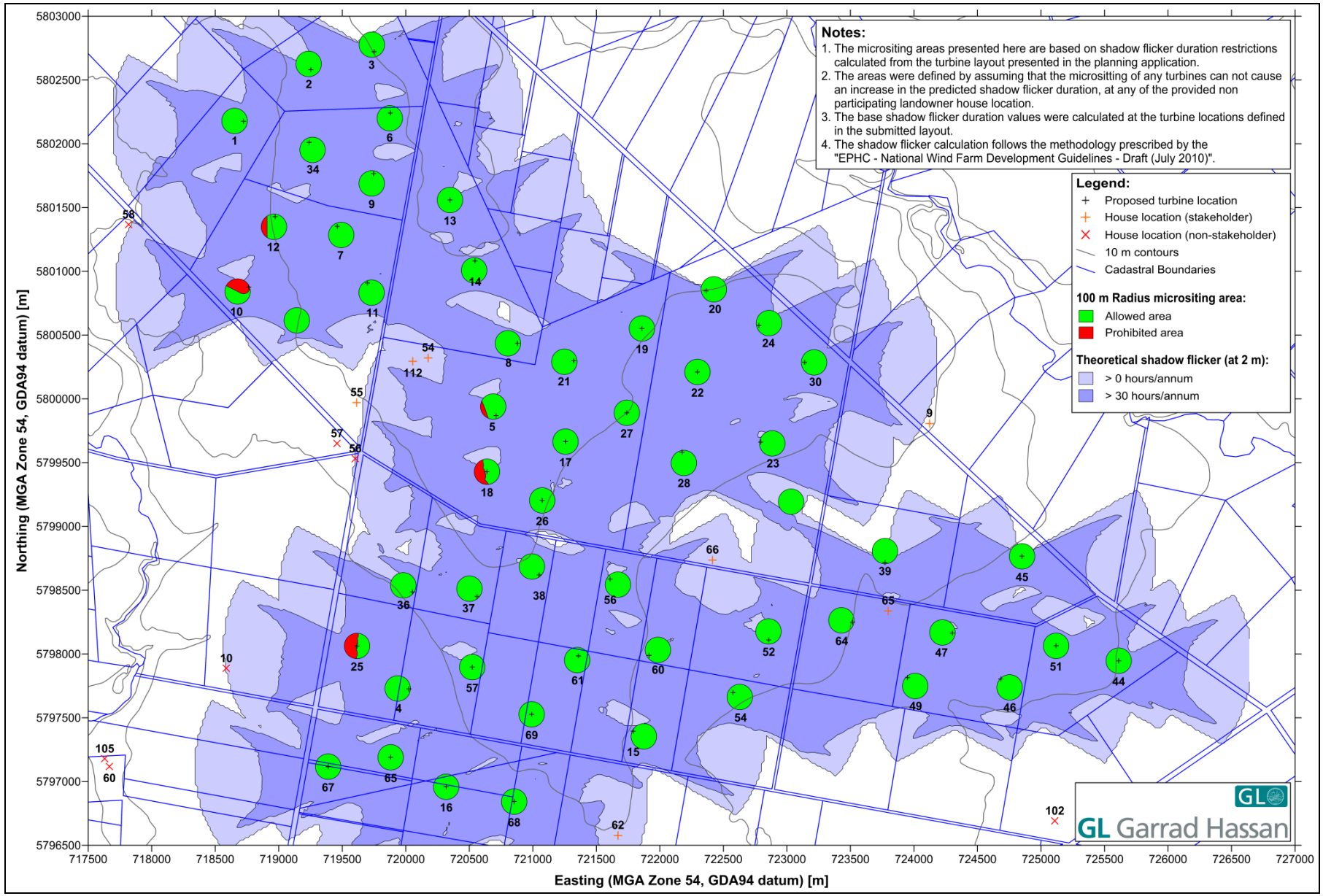

Figure 8. Micrositing area allowance due to shadow flicker (northern section – Case A)

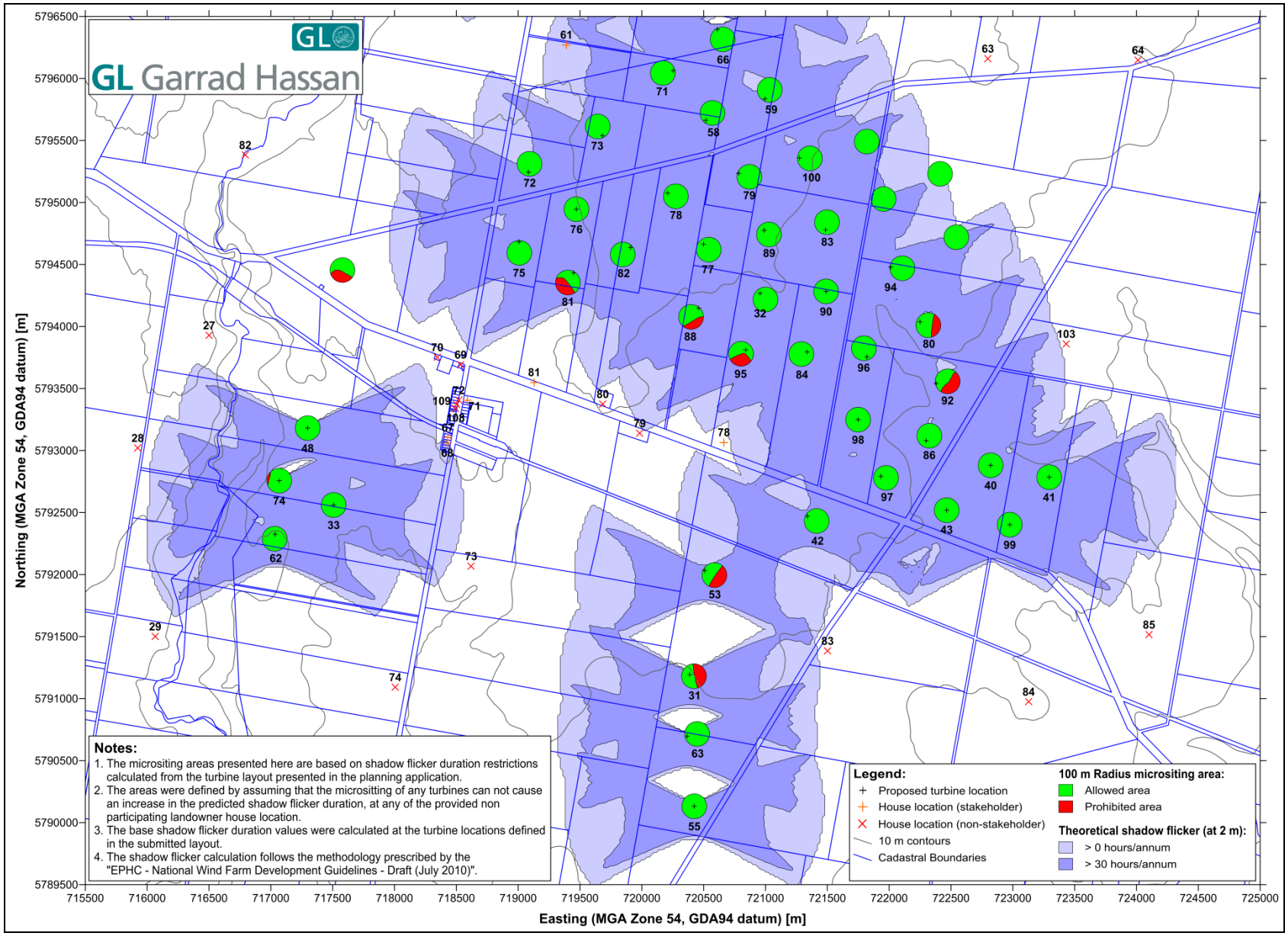

Figure 9. Micrositing area allowance due to shadow flicker (southern section – Case B)

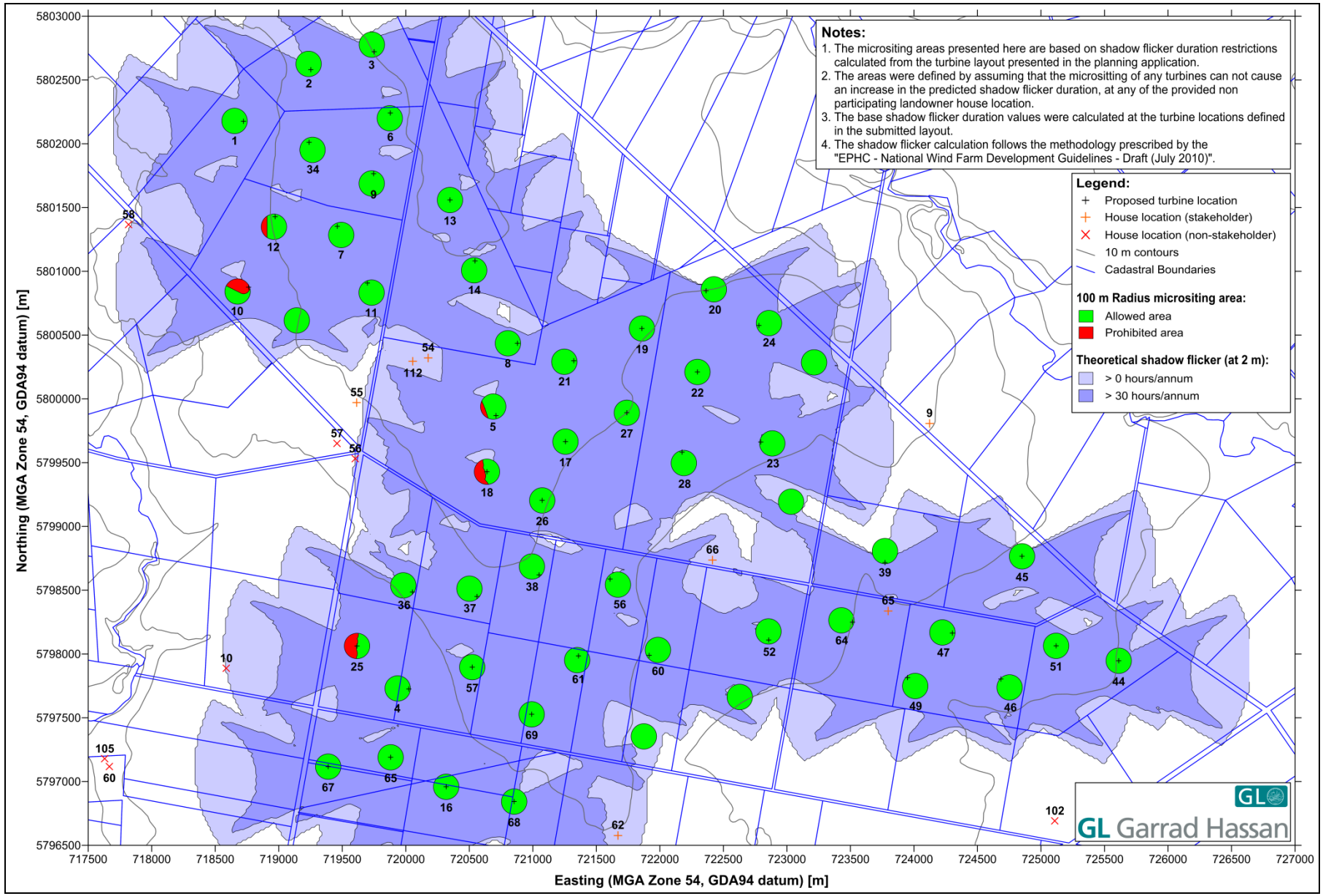

Figure 10. Micrositing area allowance due to shadow flicker (northern section – Case B)

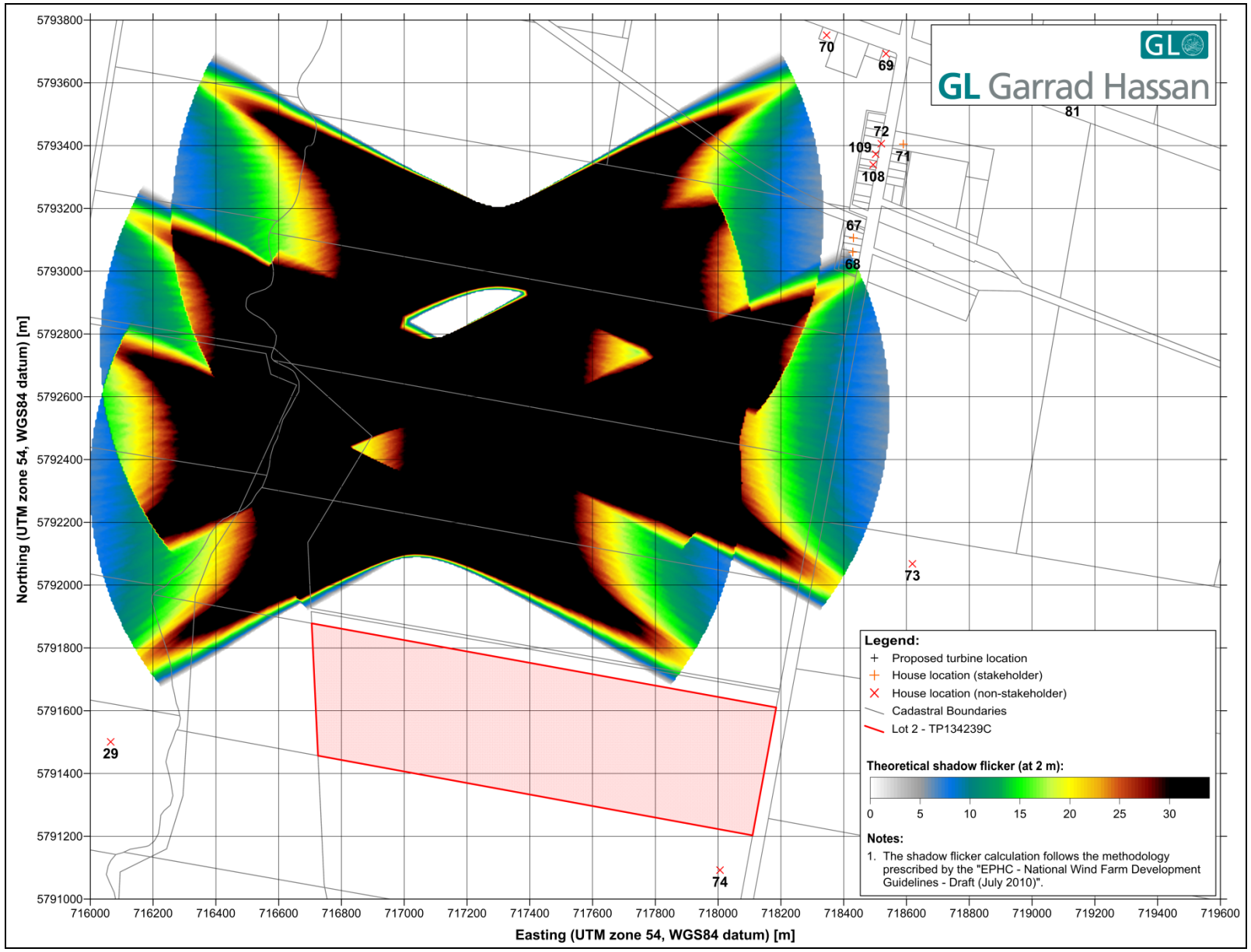

Figure 11. Theoretical shadow flicker map at 2m – Case A (Lot 2 – TP134239C area)

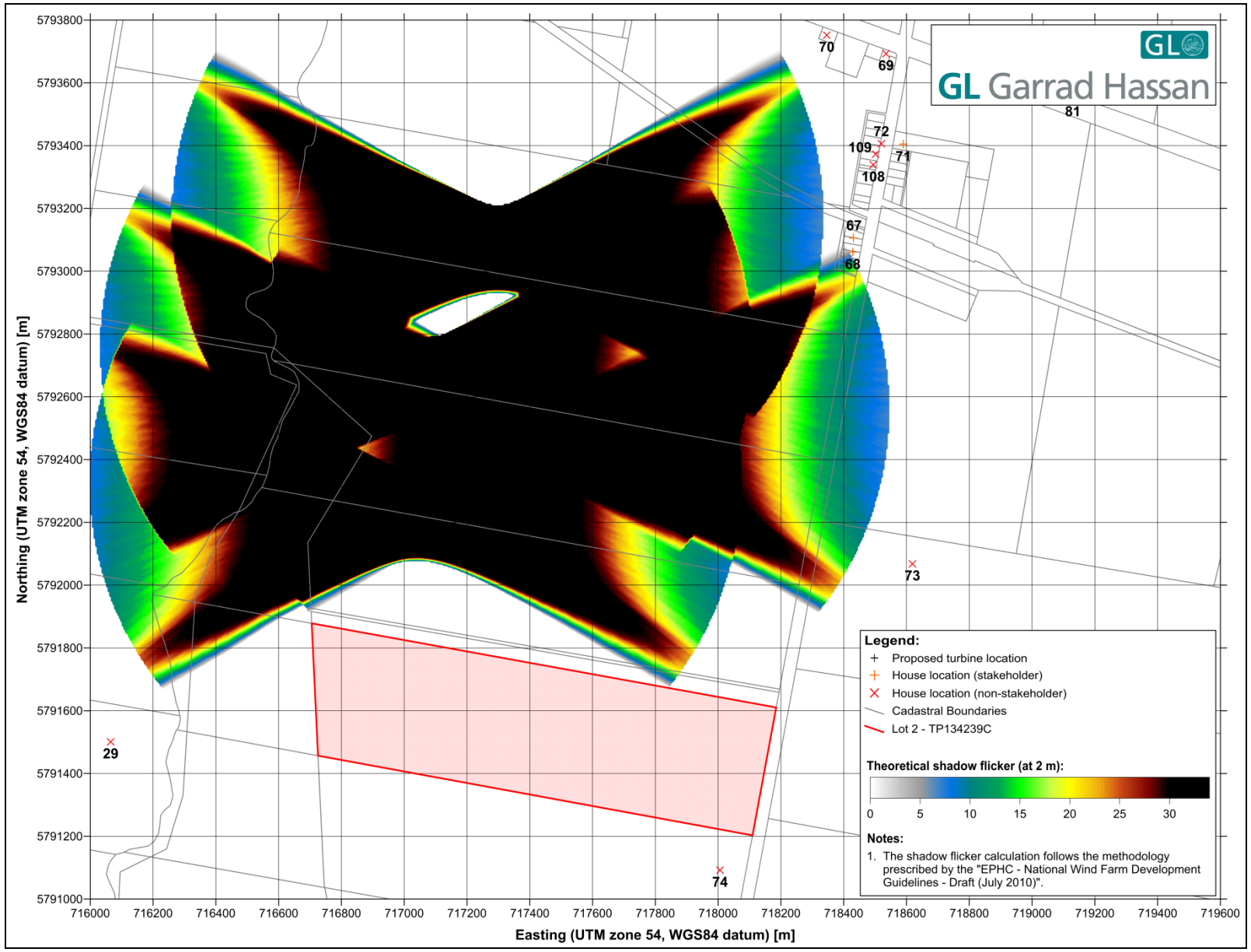

Figure 12. Theoretical shadow flicker map at 2m – Case B (Lot 2 – TP134239C area)

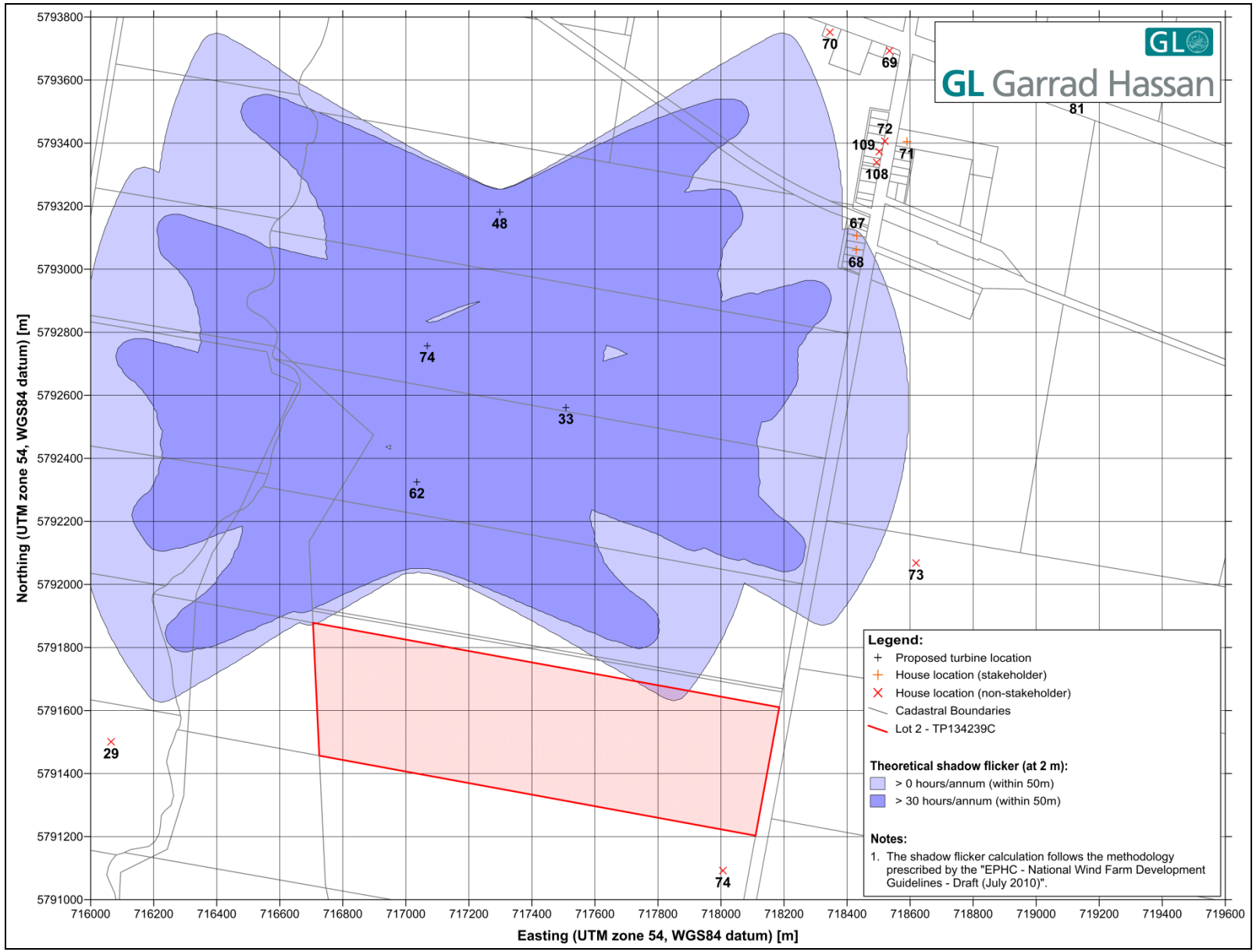

Figure 13. Theoretical shadow flicker contours at 2m – Case A (Lot 2 – TP134239C area)

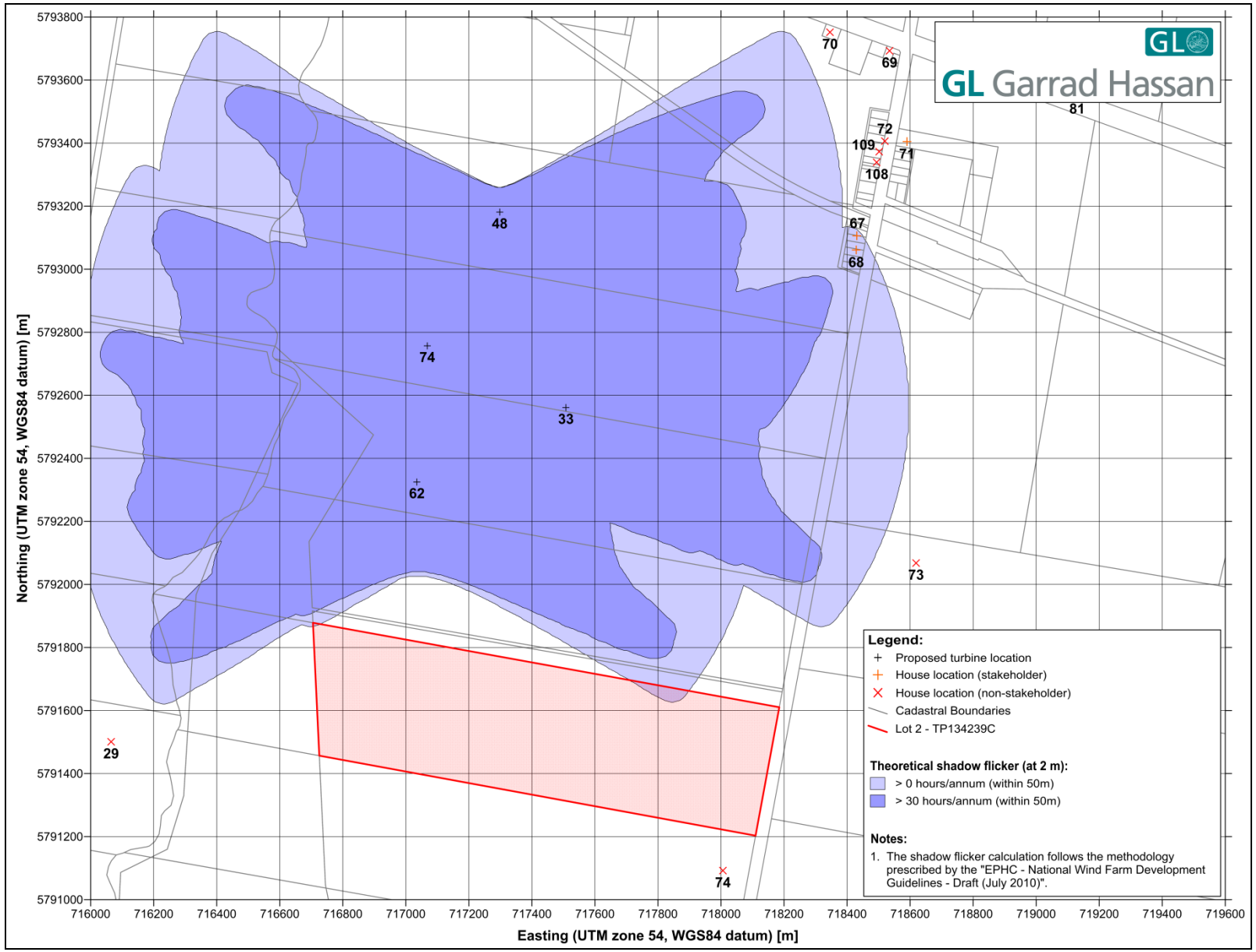

Figure 14. Theoretical shadow flicker contours at 2m – Case B (Lot 2 – TP134239C area)