SHADOW FLICKER ASSESSMENT FOR THE LAL LAL WIND FARM, VICTORIA

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1 EXECUTIVE SUMMARY

Garrad Hassan Pacific Pty Ltd (GH) has been commissioned by WestWind Energy (WE), to carry out an independent assessment of the shadow flicker durations for houses around the proposed Lal Lal Wind Farm site, based on a 64 turbine layout using Enercon E82 machines with an 85 m hub height. The proposed Lal Lal Wind Farm site is located approximately 17 km southeast of Ballarat in central Victoria.

As part of the guidelines for the development of wind farms in Victoria [1], the issue of shadow flicker is addressed where it is stated that:

> *"The shadow flicker experienced at any dwelling in the surrounding area must not exceed 30 hours per year as a result of the operation of the wind energy facility."*

Whilst the guidelines suggest that it is possible to determine the seasonal duration of shadow flicker, this is far from straightforward. The simplest method to calculate shadow flicker examines the quantity of shadow flicker from a purely geometrical standpoint. Such a style of calculation is the simplest, but tends to overestimate the number of hours of shadow flicker experienced at a dwelling [2, 3]. The variation of light intensity, the level of humidity and other dispersants in the air, incidence of cloud cover, and other factors all influence the quantity and intensity of shadow flicker experienced by a dwelling.

Analysis of the duration of shadow flicker has been conducted for houses around the proposed wind farm. The assessment has been conducted on simple geometric analyses with approximation of shadow diffusion with distance.

The estimation of shadow flicker involved using a list of nominated shadow flicker receptors (i.e. house locations) in combination with a proposed layout and turbine specification for the wind farm. Co-ordinates of the proposed layout and shadow flicker receptors have been supplied by WE [4]. This information was combined with supplied topographical data for the area to assess the likelihood and duration of shadow flicker experienced by houses on and around the site.

The modelling shows that there are no existing neighbours' residences that have modelled annual shadow flicker durations greater than 30 hours, and the maximum modelled annual shadow flicker duration at host landholder residences is 52 hours.

These figures do not include an allowance for the effect of cloud cover. Investigations into historical cloud cover observations indicate that the average cloud cover for the general region is approximately 60 % illustrating that the actual hours of shadow flicker around the proposed wind farm will be significantly less than the modelled hours.

The modelled shadow flicker hours assume that all the wind turbines are constantly yawed to the worst case position of facing into or away from the sun. A review of the likely site wind direction frequency data indicates that the greatest frequency that the wind blows to or from a single direction is in the order of 19 % further illustrating the conservatism of the modelling process.

The modelling process does not take into account any reduction due to the effect of any vegetation or other shielding effects around each house in calculating the number of shadow flicker hours, and may therefore be regarded as a conservative assessment.

2 DESCRIPTION OF THE PROPOSED WIND FARM SITE

2.1 Site description

The area proposed for potential wind farm development is located approximately 17 km southeast of Ballarat in central Victoria. The general location of the area of interest is shown in Figure 2.1. A more detailed contour map of the site region can be seen in Figure 2.2 which also includes proposed turbine locations.

The town of Ballarat is situated some 100 km northwest of Melbourne. The proposed wind farm is located in two sections, the higher 'Yendon' section in the north and the lower 'Elaine' section in the south. The wind farm is located on a moderately complex hill system that rises to an elevation of approximately 530 m in the north from approximately 400 m elevation in the south. Significant topographic features include tall hills of over 700 m in elevation located approximately 7, 5 and 4.5 km to the west, northwest and northeast of the site respectively.

The vegetation in the region is predominantly open farmland with some areas of natural vegetation and tree plantations, with the Lal Lal reservoir lying to the southeast of the Yendon section. Further to the southeast of the site lie the Brisbane Ranges and to the northeast the Wombat State Forest.

2.2 House locations

A list of co-ordinates of houses to be considered as shadow flicker receptors has been provided by WestWind [4]. Co-ordinates of receptors near to the wind farm, together with the identifiers which have been applied by WestWind, are shown in Table 2.1. The co-ordinates presented in this report are in MGA 1994 Datum, Zone 55H.

2.3 Proposed Wind Farm layout

WestWind have advised that the turbine specifications are for the Enercon E82 with a rotor diameter of 82 m and a hub height of 85 m [4]. Should an alternative machine for the site be considered which differs to these dimensions, the shadow flicker reported here should be re-analysed.

A list of co-ordinates of proposed turbine locations has been provided by WestWind [4]. These co-ordinates, together with the identifiers which have been supplied by WestWind are shown in Table 2.2.

3 BLADE GLINT

Blade glint is 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 [5]. The reflectiveness of the surface of the blades is also important, and this is to some extent influenced by colour and age of the blade. Matt surface finishes can be specified to minimise blade glint. Blade glint is an aspect which can be a potential distraction to drivers if roads are aligned towards turbines. The effect can be noticed over considerable distances, but is usually very minor.

Blade glint is not expected to be a problem with the proposed Lal Lal Wind Farm if an appropriate matt finish is specified for the turbine blades [1].

4 SHADOW FLICKER ASSESSMENT METHODOLOGY

Due to their height, wind turbines can cast shadows on the areas around them. Coupled with this, the moving blades create moving shadows. When viewed from a stationary position the moving shadows appear as a flicker giving rise to the phenomenon of ‘shadow flicker’. When the sun is low in the sky the length of the shadows increases, increasing the shadow flicker affected area around the wind turbine.

The number of annual hours of shadow flicker at a given location can be calculated using geometrical models incorporating data such as the sun path, the topographic variation and wind turbine details such as rotor diameter and hub height. In such models, the turbine rotor is modelled as a disc and assumed to be in the worst case alignment at all times (i.e. with the rotor plane always facing the sun). Further, the sun is assumed to be a point light source.

Shadow flicker calculated in this manner overestimates the number of annual hours of shadow flicker experienced at a specified location due to several reasons:

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

   A review of observed cloud cover data from the Bureau of Meteorology (BoM) station at Ballarat Aerodrome was undertaken to determine the likely level of cloud cover at the proposed Lal Lal Wind Farm. Based on the long-term historical data, an average cloud cover of approximately 60 % is observed for the region for both morning (9am) and evening (3pm). The location of Ballarat Aerodrome is shown in Figure 2.1.

2. The probability of wind turbines consistently yawing to the ‘worst case’ scenario where the wind turbine is facing into or away from the sun/turbine vector is significantly less than 1 (i.e. less than 100% of the time).

   Wind direction frequency data from a site on nearby Mt Mercer has been supplied to GH, which indicates that the frequency of time that the wind blows along any single direction axis is no greater than 19 %.

3. The amount of aerosols (moisture, dust, smoke, etc.) in the atmosphere has the ability to influence shadows cast.

   Firstly, the distance away from a wind turbine that shadows can be cast 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 of light between the light source (sun) and the receiver [2].

Secondly, the quantity of aerosols in the air is known to vary with time and thereby affecting the refraction of light. This in turn affects the intensity of direct light to cause shadows.

4. The modelling of the wind turbine blades as discs to determine shadow path overestimates the shadow flicker effect.

   The blades are of non-uniform width with the thickest viewable blade width (maximum chord) occurring closer to the hub and the thinnest being located at the tip of the blade. As outlined in point 3 above, the direct sunlight is diffused resulting in a maximum distance from the wind turbine that a shadow can be cast. This maximum distance is dependent on the human threshold for which variation in light intensity can be perceived [2]. When the blade tip causes shadow, the diffusion of direct sunlight means that the light variation threshold occurs closer to the wind turbine than when a shadow is caused by the maximum chord. That is, the maximum perceptible shadow length cast by the blade tip is less than by the maximum chord.

5. Modelling the sun as a point light source rather than a disc overestimates the shadow flicker effect.

   Firstly, situations arise where the light rays from different portions of the sun disc superimpose around a shadow resulting in light intensity variations less than human perception.

   Secondly, 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. However, when the sun is modelled as a point source, shadow flicker still arises.

6. The presence of vegetation or other obstacles acts to shield incidences of shadow flicker.

7. Periods where the wind turbine is not in operation due to low winds, high winds or operational and maintenance reasons, also reduces the likely occurrence of shadow flicker.

The modelling of shadow flicker has been conducted using simple geometric analyses using a digital topographical model for the site. The wind turbines have been modelled assuming all turbines are disc objects which are always facing the sun, which is the worst case with respect to shadow flicker. The sun has been assumed to be a point light source.

Due to points 3 and 4 above, an approximation for the maximum length of shadow flicker cast has been used. Guidance from the South Australian Government indicates that this distance is 500 m [6]. GH has adopted a more conservative approach to this and has applied a limit to the length that a shadow can be cast of 1 km [7].

No attempt has been made to account for the effects of cloud cover, nor to identify any vegetation or other shielding effects (other than terrain effects) around each house in calculating the number of shadow flicker hours presented in Section 5. Therefore, the modelling conducted here represents a conservative scenario and is believed to significantly overestimate the actual annual hours of shadow flicker experienced at a location.

5 RESULTS OF THE ANALYSIS

The results of the assessment of shadow flicker for the Lal Lal Wind Farm are shown in Table 2.1, and in the form of a shadow flicker map in Figure 5.1.

The modelling shows that there are no existing neighbours' residences that have modelled annual shadow flicker durations greater than 30 hours, and the maximum modelled annual shadow flicker duration at host landholder residences is 52 hours. These figures do not include allowances for the reduction due to the effects of cloud cover, nor for vegetation or other shielding effects (other than terrain effects) around each house in calculating the number of shadow flicker hours, and may therefore be regarded as a conservative assessment.

Based on information supplied by WestWind, Table 2.1 also indicates which of the houses are host landholders of the wind farm project [4].

REFERENCES

1 “Policy and planning guidelines for development of wind energy facilities in Victoria”, Sustainable Energy Authority Victoria, 2003.

2 Freund H-D., Kiel F.H., “Influences of the opaqueness of the atmosphere, the extension of the sun and the rotor blade profile on the shadow impact of wind turbines”, DEWI Magazin 20, Feb 2002.

3 Osten, T. & Pahlke T., “Shadow Impact on the surrounding of Wind Turbines”, DEWI Magazin 13., Aug 1998.

4 Email from G. Flynn of WestWind to D. Price of GH, 15 January 2008.

5 Energy-Wise Renewables “Guidelines for Renewable Energy Developments - Wind Energy”, Energy Efficiency and Conservation Authority New Zealand, June 1995.

6 Planning SA, Planning Bulletin "Wind Farms, Draft for Consultation”, South Australian Government, 2002.

7 http://www.windpower.org/en/tour/env/shadow/shadow2.htm

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House Identifier	Easting [m]	Northing [m]	Occupant status	Average Shadow Flicker [hours/annum]
N31ac	239908	5831068	Host	14
L17aa	237170	5817965	Host	42
J17aa	235026	5817386	Host	44
L17ab	237848	5817275	Host	52
L18aa	237913	5818705	Neighbour	11
H18aa	233189	5818529	Neighbour	17
K31aa	236084	5831076	Host	7
M29aa	238304	5829565	Neighbour	0
N31ab	239974	5831555	Neighbour	0
L19ab	237955	5819290	Neighbour	0
K34aa	236991	5834590	Neighbour	19
M18ab	238248	5818860	Neighbour	0
K15aa	236990	5815534	Neighbour	0
M18ac	238584	5818659	Neighbour	0
K31ab	236079	5831300	Host	0
J17ab	235924	5817263	Neighbour	0
M19aa	238239	5819045	Neighbour	0
P30aa	241097	5830670	Neighbour	0
N31aa	239957	5831913	Neighbour	0
J31aa	235760	5831259	Host	0
P30ad	241181	5830156	Neighbour	0
I14aa	234270	5814032	Neighbour	0
H13aa	233813	5813799	Neighbour	0
N32aa	239820	5832252	Neighbour	0
N32ab	239795	5832616	Neighbour	0
N32ac	239798	5832667	Neighbour	0
K35aa	236884	5835273	Neighbour	0
N33aa	239635	5833198	Neighbour	0
P29aa	241371	5829923	Neighbour	0
P31aa	241214	5831184	Neighbour	0
G17aa	232365	5817016	Neighbour	0
L28aa	237867	5828259	Neighbour	0
P30ac	241481	5830456	Neighbour	0
M18aa	238991	5818801	Neighbour	0
P31ad	241352	5831017	Neighbour	0
I19aa	234650	5819546	Neighbour	0
J27aa	235611	5827300	Neighbour	0
M35aa	238613	5835432	Neighbour	0
M15ab	238142	5815735	Neighbour	0
N33ab	239461	5833716	Neighbour	0
M16aa	238711	5816662	Neighbour	0
H14aa	232224	5814915	Neighbour	0
J27ac	235470	5827188	Neighbour	0
I34aa	234437	5834986	Neighbour	0
L27aa	237982	5827972	Neighbour	0
L20aa	237780	5820400	Neighbour	0
M20aa	238027	5820287	Neighbour	0
I34ab	234231	5834755	Neighbour	0
I19ab	234381	5819964	Neighbour	0
L20ab	237875	5820448	Neighbour	0

Table 2.1 House locations within 2 km of the Lal Lal Wind Farm. (Continued).

House Identifier	Easting [m]	Northing [m]	Occupant status	Average Shadow Flicker [hours/annum]
L35aa	237151	5835770	Neighbour	0
J35ab	235079	5835665	Neighbour	0
J35ac	235054	5835659	Neighbour	0
M15aa	238182	5815469	Neighbour	0
L15ab	237993	5815237	Neighbour	0
M20ab	238366	5820167	Neighbour	0
J14aa	235220	5814078	Neighbour	0
M19ab	238798	5819663	Neighbour	0
I35aa	234925	5835662	Neighbour	0
P30ab	241778	5830993	Neighbour	0
L15aa	237993	5815139	Neighbour	0
J35aa	235100	5835764	Neighbour	0
N16ab	239115	5816724	Neighbour	0
I30aa	234380	5830417	Neighbour	0
P31ac	241554	5831622	Neighbour	0
I35ab	234605	5835627	Neighbour	0
H20aa	233938	5820296	Host	0
M20ak	238110	5820583	Neighbour	0
P31ab	241297	5831922	Neighbour	0
M20aj	238027	5820643	Neighbour	0
N34aa	239792	5834345	Neighbour	0
L14ac	238074	5814991	Neighbour	0
L15ac	238074	5814990	Neighbour	0
M36aa	238329	5836132	Neighbour	0
I27af	234434	5827306	Neighbour	0

Table 2.1 House locations within 2 km of the Lal Lal Wind Farm. (Concluded).

Wind Turbine Identifier	Easting [m]	Northing [m]
YSWT01	235749	5834082
YSWT02	236288	5834090
YSWT03	237834	5834197
YSWT04	236751	5833682
YSWT05	237479	5833611
YSWT06	237872	5833859
YSWT07	236422	5833305
YSWT08	236950	5833099
YSWT09	237383	5833222
YSWT10	236427	5832689
YSWT11	236867	5832295
YSWT12	237362	5832449
YSWT13	237778	5832435
YSWT14	237721	5831776
YSWT15	237577	5831353
YSWT16	238492	5832517
YSWT17	238292	5832087
YSWT18	238663	5831719
YSWT19	238151	5831503
YSWT20	237011	5830822
YSWT21	236257	5830315
YSWT22	236743	5830314
YSWT23	236485	5829872
YSWT24	236209	5829599
YSWT25	237009	5829643
YSWT26	235996	5829179
YSWT27	236816	5829207
YSWT28	235859	5828710
YSWT29	236585	5828803
YSWT30	237553	5830953
YSWT31	237935	5831086
YSWT32	239265	5831110
YSWT33	237473	5830494
YSWT34	238063	5830698
YSWT35	238489	5830840
YSWT36	239624	5830764
YSWT37	238726	5830234
YSWT38	239378	5830392
YSWT39	240083	5830399
YSWT40	239743	5830040

Table 2.2 Proposed layout of the Lal Lal Wind Farm (Yendon section).

Wind Turbine Identifier	Easting [m]	Northing [m]
ESWT01	233500	5817822
ESWT02	233855	5818367
ESWT03	234084	5817161
ESWT04	234351	5817454
ESWT05	234648	5817731
ESWT06	235025	5817868
ESWT07	236483	5818385
ESWT08	236876	5818621
ESWT09	237209	5818874
ESWT10	234095	5815947
ESWT11	234393	5816255
ESWT12	234695	5816555
ESWT13	234986	5816872
ESWT14	234746	5815979
ESWT15	235337	5816007
ESWT16	236903	5817482
ESWT17	236754	5816449
ESWT18	237003	5816752
ESWT19	237212	5817071
ESWT20	237353	5817401
ESWT21	237579	5817722
ESWT22	237798	5818054
ESWT23	233785	5815068
ESWT24	233936	5815414

Table 2.2 Proposed layout of the Lal Lal Wind Farm (Elaine section).

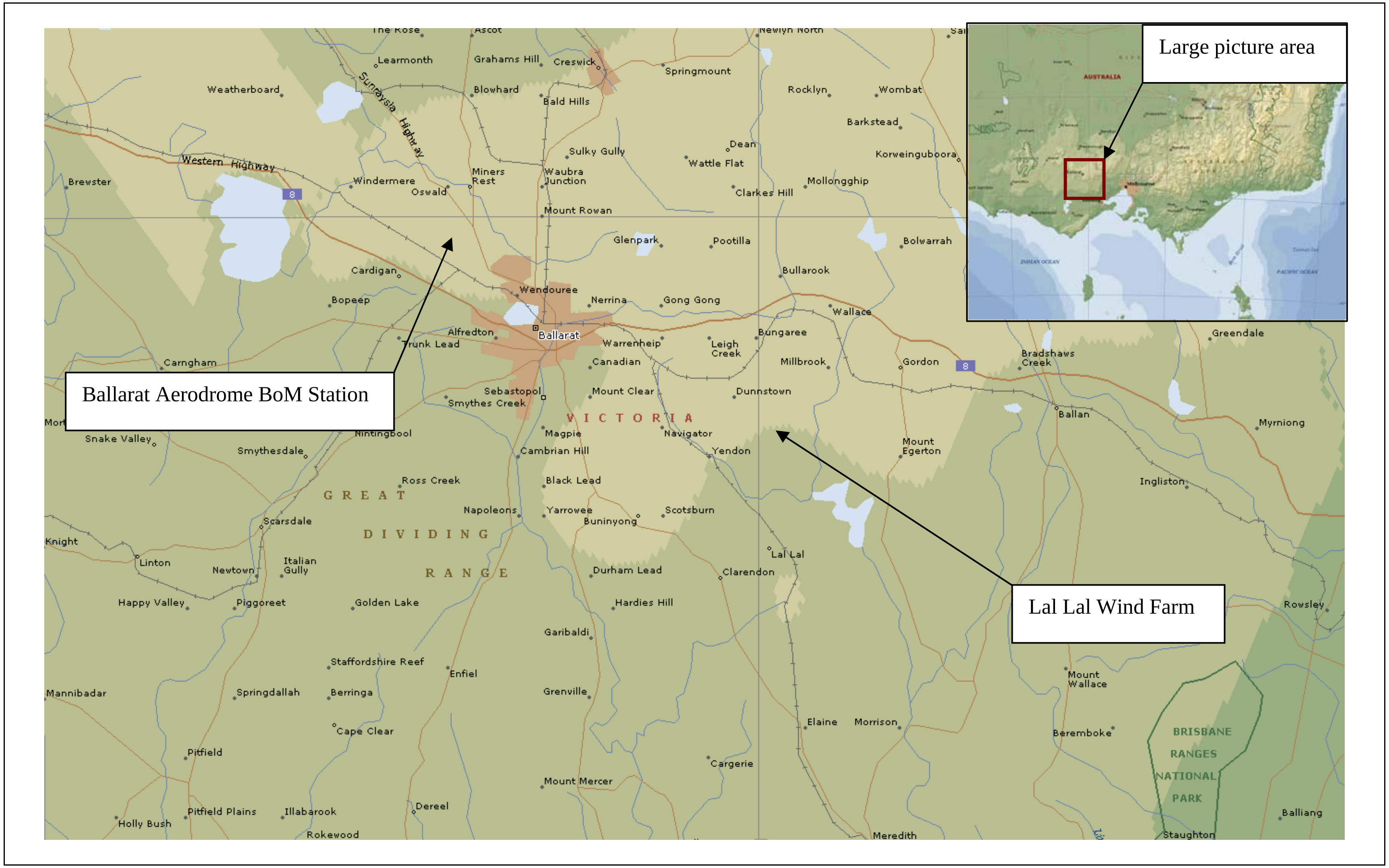

Figure 2.1 Location of the proposed Lal Lal Wind Farm.

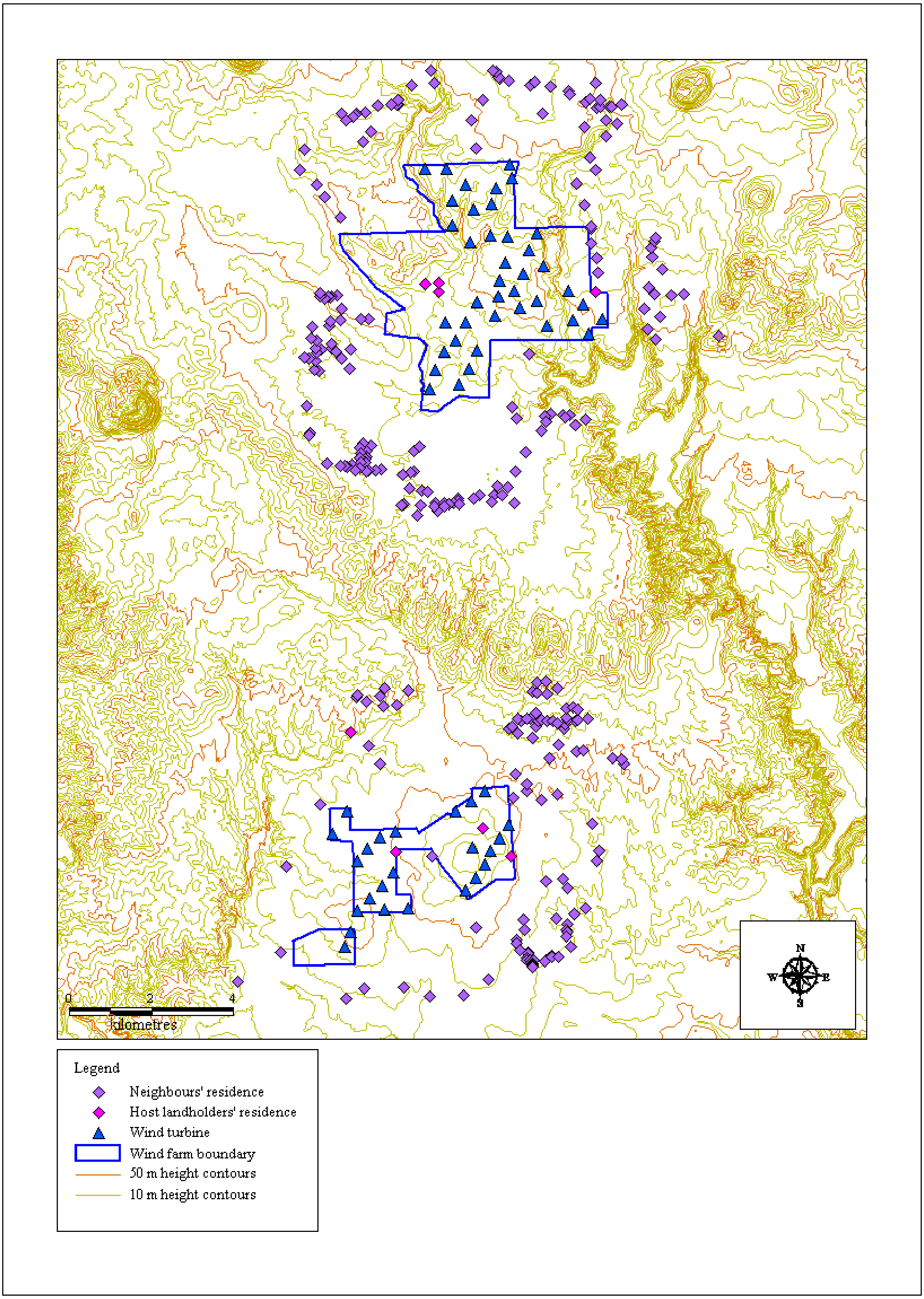

Figure 2.2 Site layout of the Lal Lal Wind Farm.

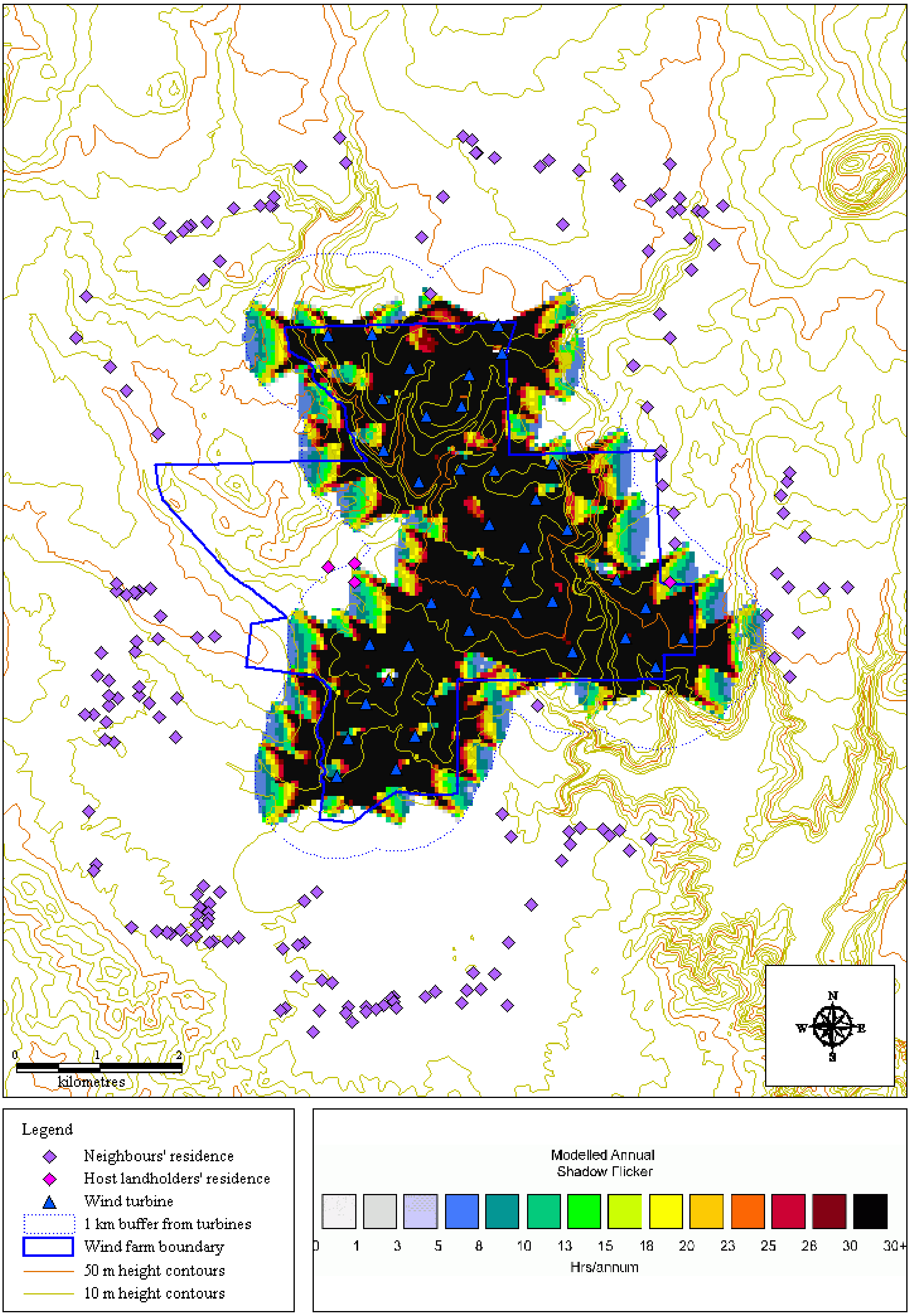

Figure 5.1 **Map of modelled hours of annual shadow flicker at the proposed Lal Lal Wind Farm (Yendon section).**

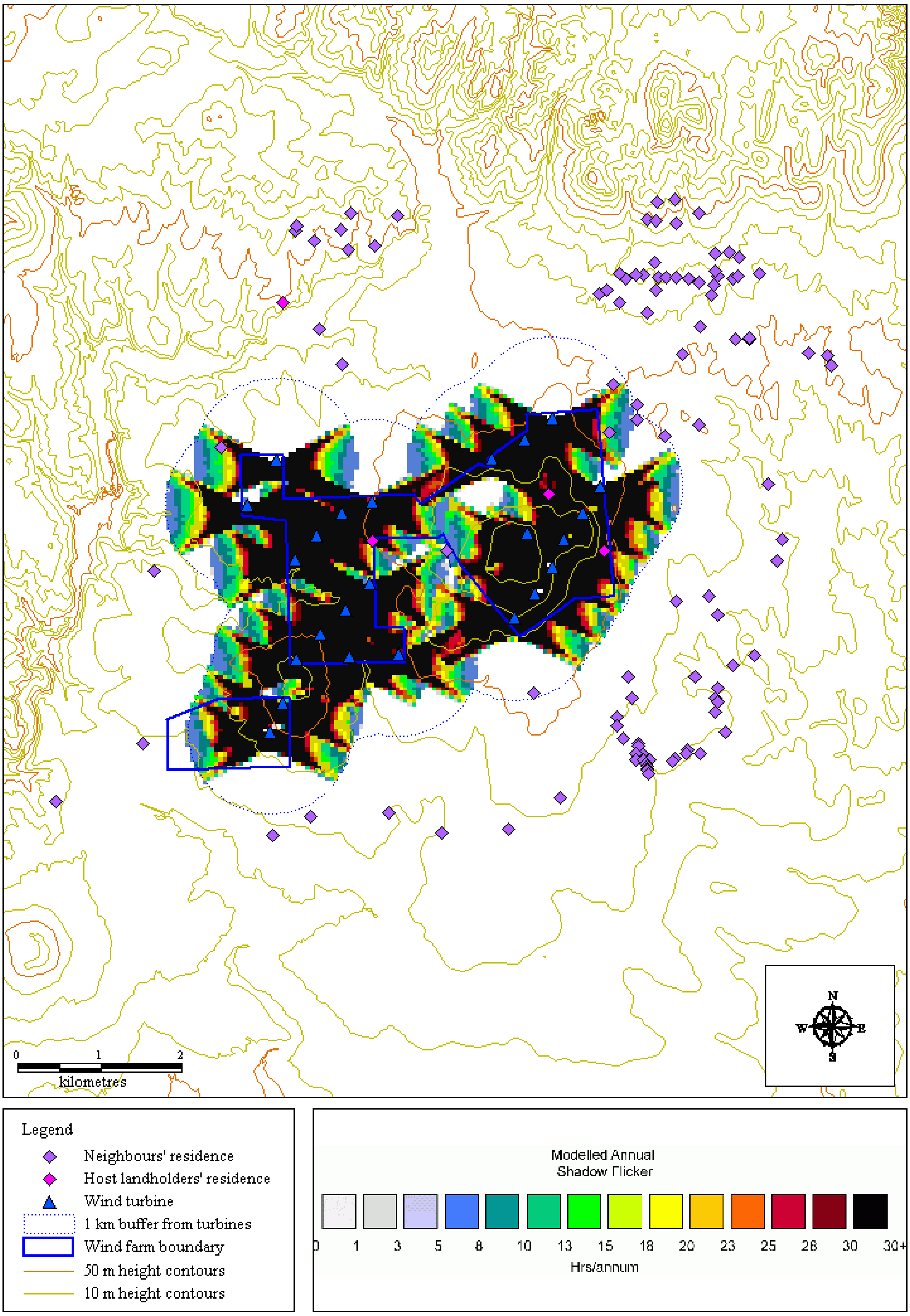

Figure 5.1 **Map of modelled hours of annual shadow flicker at the proposed Lal Lal Wind Farm (Elaine section).**