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1 EXECUTIVE SUMMARY

Garrad Hassan Pacific Pty Ltd (GH) has been commissioned by Stockyard Hill Wind Farm Pty Ltd (SYHWF) to carry out an independent assessment of the shadow flicker durations for sites around the Stockyard Hill Wind Farm based on a 242 wind turbine layout. The results of the work are reported here.

As part of the guidelines for the development of wind farms in Victoria [1], the issue of shadow flicker is addressed and 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.”

It is generally accepted that shadow flicker from wind turbines does not occur for distances greater than approximately 1 km, and this assumption has been applied in this assessment.

Determining the annual duration of shadow flicker 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 over-estimate the number of hours of shadow flicker experienced at a dwelling [1,2]

There are a number of reasons why the theoretical duration of shadow flicker provides a conservative assessment. Calculation of the theoretical duration of shadow flicker is usually undertaken based on simplifying assumptions regarding operation of the turbines;

- The modelled shadow flicker hours assumes that the wind turbine is constantly yawed to the worst case position of facing into or away from the sun, and hence in the worst-case orientation for casting shadows;
- Periods where the wind turbine is not rotating due to low winds are not considered.

There are also local environmental factors which can reduce the incidence of shadow flicker relative to the theoretical values;

- Periods when there are clouds between the sun and observer;
- The modelling process does not take into account any reduction due to the effect of any vegetation or other shielding effects.

Independent analysis of duration of shadow flicker has been conducted for dwellings neighbouring the proposed Stockyard Hill Wind Farm by means of a simple geometric analysis, together with an assessment of the probable degree of conservatism attached to the assessment.

The modelling shows that there are 5 receptors that may be subject to theoretical duration of shadow flicker greater than 30 hours per annum based on the ‘worst case’ analysis. After application of an adjustment factor for turbine orientation, the number of receptors which may be exposed to durations of shadow flicker greater than 30 hours per annum is reduced to 2. It is understood that both of these are landowners with an interest in the project.

Note that the modelling process does not take into account any reduction due to the effects of cloud cover, low wind speed, vegetation or other shielding effects around each house in calculating the number of shadow flicker hours, and therefore the adjusted values may still be regarded as a conservative assessment.

2 DESCRIPTION OF THE PROPOSED WIND FARM SITE

Site description

The Stockyard Hill Wind Farm site is located approximately 45 km west of Ballarat, 5 km south of Beaufort and 4 km north of Skipton in inland Victoria

Figure 2.1 shows the general location of the Stockyard Hill Wind Farm site. The land surrounding the site is predominantly cleared land used for farming with scattered windbreaks and residential plantings near houses and sheds. Topography of the site appears to be characterised by moderate slopes and rolling hills, having been formed by ancient volcanic lava flows. The site includes Stockyard Hill, the remnants of an extinct volcano with Black Lake in its crater. There are also numerous stony rises and outcrops.

House locations

A list of co-ordinates of buildings within and surrounding the site has been provided by SYHWF [3]. Co-ordinates of receptors (ie buildings) within 1km of the wind farm, together with the identifier that has been applied by SYHWF, are shown in Table 2.1.

The co-ordinates presented in this report are in WGS 1984, Zone 54.

Proposed Wind Farm layout

SYHWF has advised that the proposed turbine model for the project is to have a rotor diameter of 92 m and a proposed hub height of 80 m.

A list of co-ordinates of proposed turbine locations has been provided by SYHWF [3]. These co-ordinates, together with the identifiers which have been supplied by SYHWF are shown in Table 2.2.

Figure 2.2 shows the proposed turbine layout and surrounding house locations.

3 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 over the wind farm site, and wind turbine details such as rotor diameter and hub height. In such models, the wind turbine rotor is modelled as a disc and assumed to be in the worst case position (i.e. perpendicular) relative to the sun-turbine vector. Further, the sun is assumed to be a point light source.

To illustrate typical results, an indicative theoretical shadow flicker map for a flat area in the Western Victoria region is shown in Figure 3.1. The geometry of the shadow flicker map can be characterised as butterfly shaped 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.

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.
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 less than 1 (i.e. less than 100% of the time).

It is noted that the diagram shown in Figure 3.1 has been generated assuming that the indicative turbine is always pointing towards or away from the sun-turbine vector. Wind direction frequency data at the site has been provided by SYHWF in the form of a site wind rose [4] and this is shown overlaid on the indicative shadow flicker map, binned into 30 degree direction bins.

It can be seen that the frequency of time that the wind blows from any given direction is no greater than 13 %, and orientation of the rotor other than directly pointing at the sun will reduce the projected shadow, and hence the incidence of shadow flicker.

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 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 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 has an effect similar to that of point 4 above.

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 shields 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. This is specific to the operational control of particular turbine types.

The modelling of shadow flicker has been conducted using simple geometric analysis. The wind turbine has been modelled assuming all wind turbines are disc objects positioned in 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 recommends that this distance is 500 m [5]. GH has adopted a more conservative approach to this and has assumed that the length to which a shadow can be cast is 1 km [6].

No attempt has been made to account for the effects of cloud cover, or to identify any vegetation or other shielding effects around each house in calculating the number of shadow flicker hours presented in Section 4. Therefore, the modelling conducted here represents a conservative scenario and is believed to significantly overestimate the actual annual hours of shadow flicker which will be experienced.

4 RESULTS OF THE ANALYSIS

The results of the assessment of shadow flicker for the Stockyard Hill Wind Farm are presented in the form of a shadow flicker map in Figure 4.1. The shadow flicker results for each receptor identified to GH are also listed in Table 4.1.

The assessment of theoretical shadow flicker hours shows that 5 of the receptors identified by SYHWF could theoretically experience more than the recommended limit of 30 shadow flicker hours per year.

Approximation of the degree of conservatism due to the 'worst case' assumption on rotor orientation was undertaken using the representative wind rose supplied by SYHWF [4]. By combining the probability of occurrence of various wind directions with the reduction in shadow flicker resulting from orientation of turbines to these wind directions, the probable degree of conservatism in the theoretical assessment has been determined. These calculations have been completed based on 30 degree direction bins.

The results of this modified analysis are also presented in Table 4.1 and show that only 2 of the 5 locations identified in the 'worst case' analysis are likely to experience more than the recommended limit of 30 shadow flicker hours per year. It is understood that both of these are participating landowners with an interest in the project.

Note that the modified modelling process does not take into account any reduction due to the effects of cloud cover, low wind speed, vegetation or other shielding effects around each house in calculating the number of shadow flicker hours, and therefore the adjusted values may still be regarded as a conservative assessment.

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 Magazine No. 20, February 2002, pp43-51.
- 3 Email communication from P. Lausberg of SYHWF to G. Slack of GH, 16th December 2008.
- 4 “Wind Analysis and Modelling Services for Windpower Pty Ltd : Waubra Region, Victoria”, Windlab Systems, 13 November 2007.
- 5 Planning SA, Planning Bulletin "Wind Farms, Draft for Consultation", South Australian Government, 2002.
- 6 <http://www.windpower.org/en/tour/env/shadow/shadow2.htm>

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House Identifier	Easting [m]	Northing [m]	Status
I5	714345	5849628	Participating Landowner
H10	709858	5848031	Participating Landowner
I18	711488	5845324	Participating Landowner
M12	706893	5836340	Participating Landowner
N28	714106	5831545	Participating Landowner
M20	708373	5832651	Participating Landowner
B42	698409	5850996	Participating Landowner
B41	698995	5852322	Participating Landowner
B38	695961	5853202	Participating Landowner
B39	697017	5851896	Participating Landowner
H14	706705	5846346	Participating Landowner
H27	705091	5843052	Participating Landowner
H32	705384	5841864	Participating Landowner
H30	704506	5841547	Participating Landowner
H29	703243	5842092	Participating Landowner
H25	701380	5842799	Participating Landowner
M5	701154	5837552	Participating Landowner
L8	699647	5837851	Participating Landowner
L7	698979	5837874	Participating Landowner
I33	710107	5842201	Participating Landowner
M6	701684	5836660	Participating Landowner

Table 2.1 House locations in close proximity to the Stockyard Hill Wind Farm turbines [3].

Turbine ID	Easting [m]	Northing [m]	Turbine No.	Easting [m]	Northing [m]
T1	696868	5853108	T26	700719	5850678
T2	696940	5852658	T27	704743	5850634
T3	703137	5852595	T28	700334	5850585
T4	697977	5852393	T29	701504	5850526
T5	699853	5852249	T30	704408	5850488
T6	703358	5852221	T31	701076	5850248
T7	697402	5852197	T32	701279	5849847
T8	703914	5852121	T33	708019	5849599
T9	702772	5852079	T34	714043	5849567
T10	699612	5852021	T35	700972	5849481
T11	704373	5851985	T36	700098	5849408
T12	700171	5851968	T37	711039	5849388
T13	701767	5851942	T38	700601	5849317
T14	700767	5851938	T39	710215	5849187
T15	701128	5851910	T40	712257	5849155
T16	702178	5851857	T41	709859	5848959
T17	700484	5851844	T42	700501	5848954
T18	701444	5851769	T43	708113	5848895
T19	702955	5851498	T44	707007	5848842
T20	699335	5851479	T45	706620	5848796
T21	701247	5851435	T46	711066	5848788
T22	699165	5851229	T47	713633	5848786
T23	701015	5851115	T48	707436	5848739
T24	702970	5850998	T49	700754	5848595
T25	701247	5850798	T50	709894	5848580

Table 2.2 Proposed turbine layout for the Stockyard Hill Wind Farm site [3]. (Cont.)

Turbine ID	Easting [m]	Northing [m]	Turbine No.	Easting [m]	Northing [m]
T51	707730	5848580	T103	703947	5841234
T52	712461	5848570	T104	703257	5841109
T53	710545	5848561	T105	704798	5841050
T54	713408	5848438	T106	701156	5841036
T55	711018	5848407	T107	701787	5840921
T56	708245	5848375	T108	705680	5840909
T57	707949	5848373	T109	706628	5840817
T58	706735	5848344	T110	702393	5840813
T59	712142	5848334	T111	704465	5840771
T60	707816	5847982	T112	703908	5840683
T61	708355	5847951	T113	706235	5840579
T62	709347	5847730	T114	703538	5840538
T63	706988	5847683	T115	702966	5840440
T64	709896	5847674	T116	706679	5840407
T65	706695	5847427	T117	701229	5840325
T66	706210	5847386	T118	704395	5840267
T67	707298	5847319	T119	703841	5840175
T68	705785	5847306	T120	701949	5840148
T69	705309	5847200	T121	706398	5840097
T70	706124	5846908	T122	698261	5840040
T71	704536	5846907	T123	707435	5839998
T72	704978	5846875	T124	702672	5839840
T73	705044	5846510	T125	699006	5839809
T74	709968	5845121	T126	700843	5839741
T75	710638	5844993	T127	704210	5839691
T76	711338	5844676	T128	706636	5839597
T77	709978	5844414	T129	703356	5839589
T78	711801	5844214	T130	701542	5839580
T79	710846	5844106	T131	698132	5839579
T80	704433	5844074	T132	709773	5839551
T81	712367	5844039	T133	704699	5839506
T82	713222	5843935	T134	710967	5839388
T83	705723	5843873	T135	707737	5839332
T84	705120	5843800	T136	702230	5839323
T85	711549	5843735	T137	707171	5839321
T86	712122	5843643	T138	699985	5839305
T87	701948	5843413	T139	705925	5839135
T88	711108	5843206	T140	703950	5839231
T89	704326	5843181	T141	700575	5839230
T90	703129	5843074	T142	699342	5839207
T91	703682	5843074	T143	706426	5839169
T92	712003	5843027	T144	704893	5839135
T93	710992	5842642	T145	710352	5839098
T94	702005	5842614	T146	705373	5839071
T95	703975	5842584	T147	709017	5839030
T96	704597	5842272	T148	702781	5838952
T97	702236	5842078	T149	698031	5838889
T98	701711	5841977	T150	703558	5838882
T99	701240	5841808	T151	699851	5838823
T100	706148	5841419	T152	705730	5838811
T101	702617	5841384	T153	708406	5838791
T102	706458	5841239	T154	700519	5838761

Table 2.2 Proposed turbine layout for Stockyard Hill Wind Farm site [3]. (Cont.)

Turbine ID	Easting [m]	Northing [m]	Turbine No.	Easting [m]	Northing [m]
T155	701240	5838729	T199	712328	5833462
T156	698666	5838721	T200	713064	5833447
T157	702175	5838677	T201	710814	5833400
T158	706335	5838641	T202	713599	5833261
T159	704389	5838612	T203	711328	5833175
T160	707073	5838598	T204	714855	5833146
T161	709963	5838589	T205	713165	5833124
T162	707777	5838541	T206	711830	5833093
T163	699236	5838531	T207	713877	5832973
T164	709217	5838444	T208	712890	5832884
T165	705112	5838387	T209	712436	5832864
T166	705704	5838264	T210	713448	5832852
T167	710799	5838258	T211	715370	5832803
T168	700234	5838255	T212	709619	5832669
T169	701018	5838210	T213	713943	5832540
T170	708409	5838167	T214	715999	5832529
T171	706272	5838075	T215	709211	5832495
T172	709022	5837844	T216	713462	5832416
T173	701707	5837833	T217	713058	5832406
T174	706974	5837671	T218	707680	5832300
T175	707730	5837532	T219	712599	5832185
T176	708459	5837359	T220	709670	5831931
T177	700362	5837333	T221	708102	5831897
T178	706275	5837332	T222	709130	5831881
T179	699666	5837240	T223	712047	5831876
T180	706790	5836978	T224	708475	5831779
T181	699893	5836919	T225	712595	5831692
T182	700861	5836863	T226	713177	5831549
T183	708860	5836858	T227	708948	5831449
T184	707586	5836817	T228	710165	5831431
T185	708224	5836622	T229	711479	5831186
T186	707748	5836010	T230	710695	5831051
T187	706052	5835487	T231	709457	5831044
T188	712785	5834669	T232	712488	5830972
T189	706060	5834634	T233	713258	5830831
T190	706670	5834548	T234	709919	5830710
T191	713251	5834205	T235	713814	5830566
T192	714223	5834160	T236	710777	5830549
T193	712655	5834138	T237	711537	5830409
T194	712261	5833993	T238	714641	5830405
T195	713665	5833810	T239	712357	5830193
T196	712709	5833724	T240	713134	5830081
T197	711241	5833645	T241	713824	5829942
T198	714421	5833566	T242	714525	5829811

Table 2.2 Proposed turbine layout for Stockyard Hill Wind Farm site [3]. (Concluded)

House Identifier	THEOERTICAL MAXMUM	ADJUSTED FOR WIND ROSE	
	Hours per Year	Hours per Year	Reduction [%]
I5	122	78	37%
H10	17	11	38%
I18	14	8	42%
M12	40	25	37%
N28	7	4	45%
M20	25	15	38%
B42	12	7	40%
B41	27	14	45%
B38	9	5	47%
B39	57	38	35%
H27	11	6	45%
H32	13	8	41%
H30	5	1	77%
H29	25	17	33%
H25	27	16	41%
M5	39	24	39%
L8	37	25	34%
I33	10	6	41%
M6	10	6	44%

Table 4.1 Modelled shadow flicker durations for receptors in the vicinity of the proposed Stockyard Hill Wind Farm site.



Figure 2.1 Location of the proposed Stockyard Hill Wind Farm site.

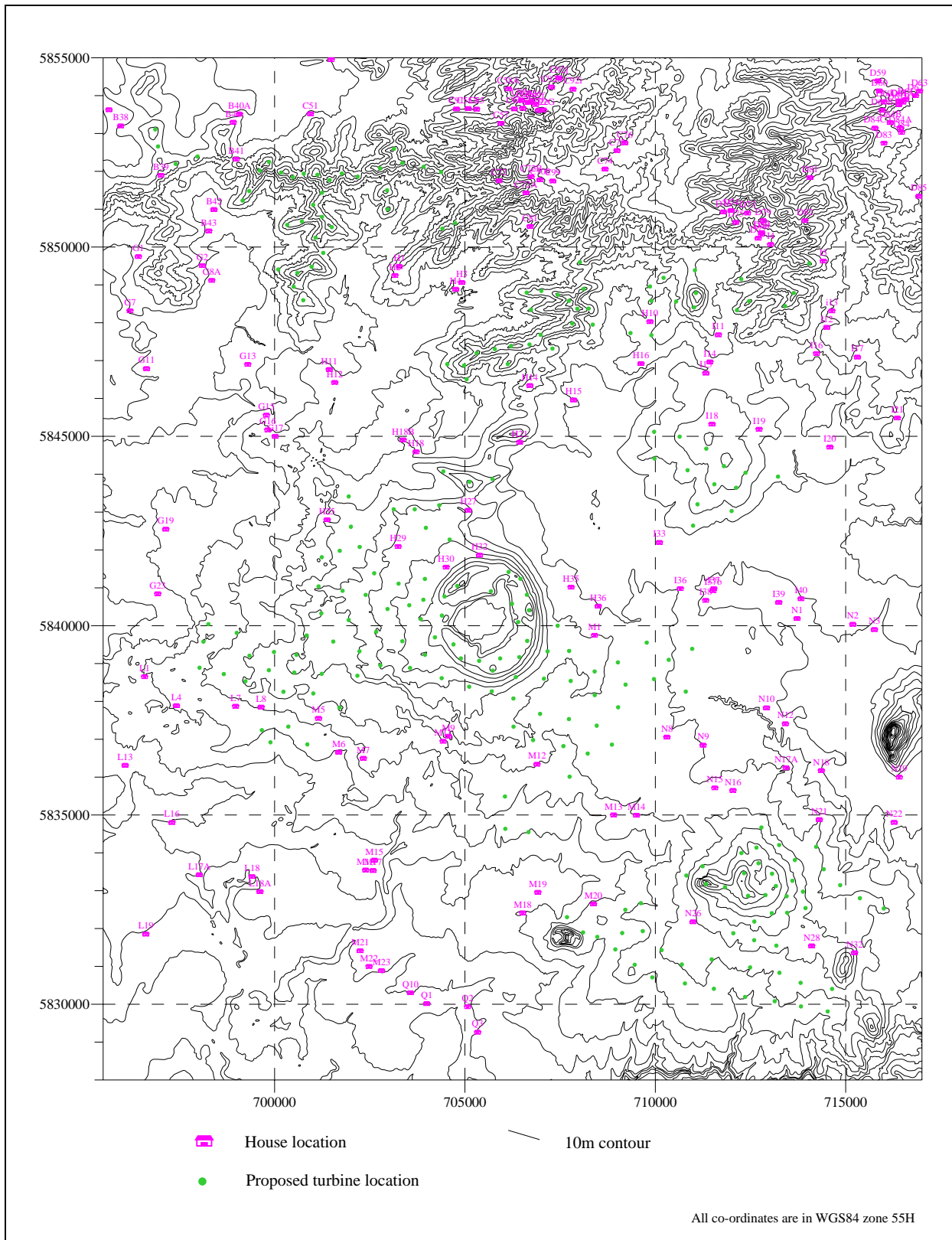


Figure 2.2 Proposed Stockyard Hill wind farm layout showing houses in the vicinity of the turbines.

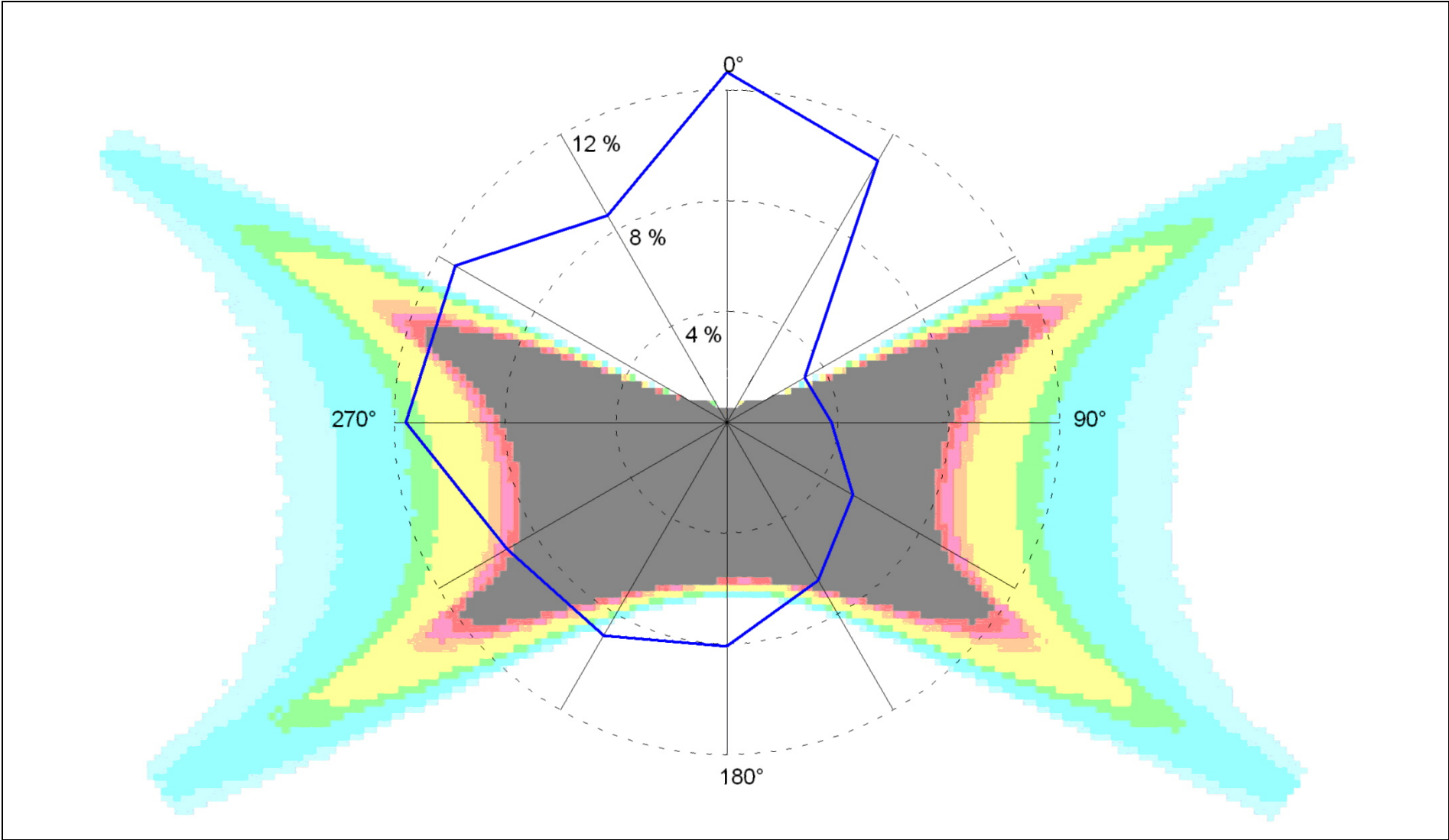


Figure 3.1 Indicative shadow flicker map with wind direction frequency overlain

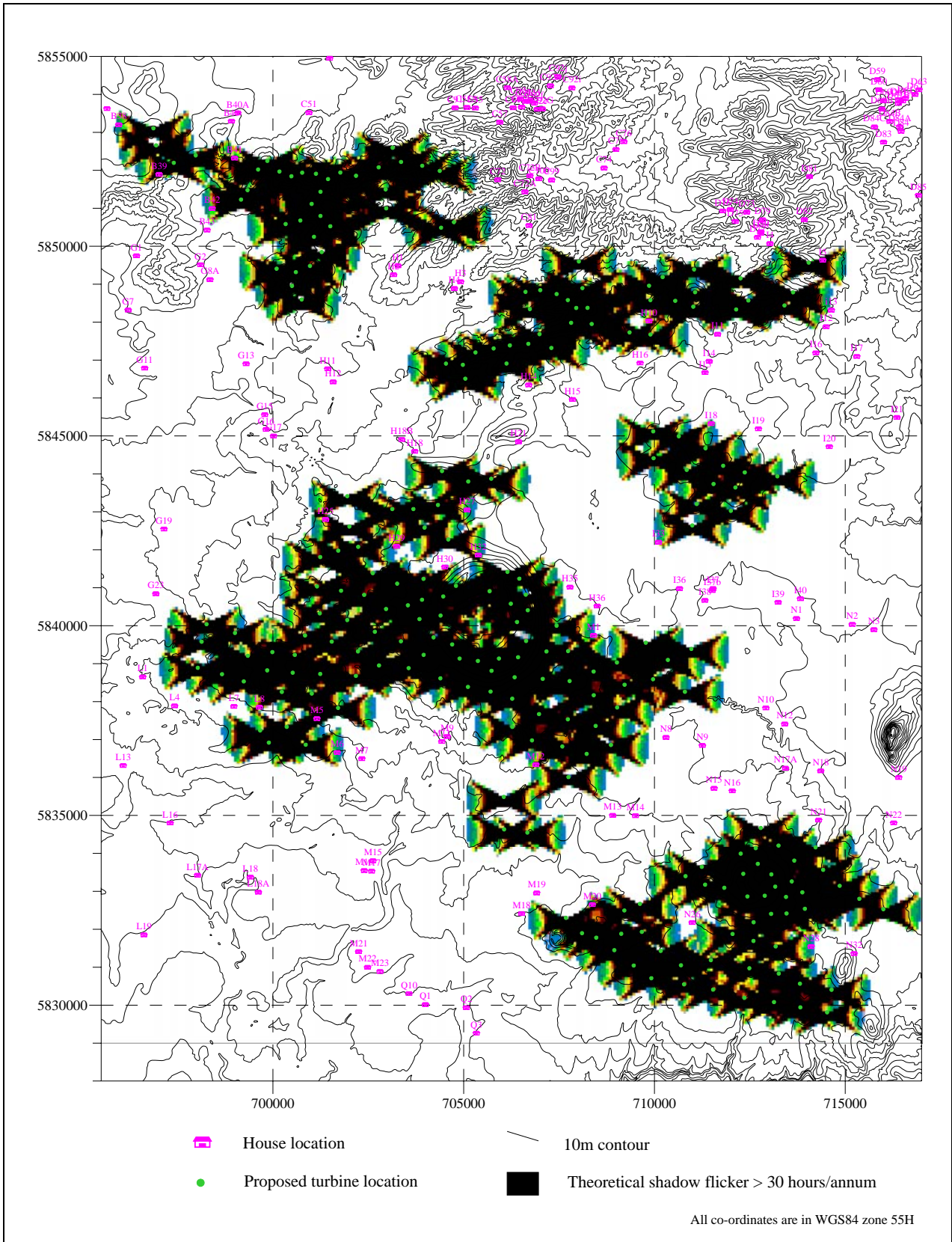


Figure 4.1 Modelled hours of annual shadow flicker at the Stockyard Hill Wind Farm.