RATCH AUSTRALIA CORPORATION

Mount Emerald Wind Farm

SHADOW FLICKER ASSESSMENT

AUGUST 2016

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RATCH Australia Corporation

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01	15/08/2016	Initial release
02	7/09/2016	Receptor distance clarification

AUTHOR, REVIEWER AND APPROVER DETAILS

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TABLE OF CONTENTS

ABBREVIATIONS

BoM	Bureau of Meteorology
d	day
h	hour
km	kilometre
kW, MW, GW	Kilowatt, Megawatt, Gigawatt
m	Minute
m/s	Metres per second
mAGL	Metres above ground level
mASL	Metres above sea level
MEWF	Mount Emerald Wind Farm
MWh	Megawatt hour
RATCH	RATCH Australia Corporation Limited
WTG	Wind Turbine Generator
WSP | PB	WSP | Parsons Brinckerhoff

EXECUTIVE SUMMARY

RATCH Australia Corporation Limited (RATCH) has requested WSP | Parsons Brinckerhoff (WSP | PB) to perform a shadow flicker assessment for the proposed Mount Emerald Wind Farm (MEWF). This report is a shadow flicker assessment of a single layout design consisting of two WTG models at a hub-height of 84 m and 90 m and the location of 123 receptors as specified by RATCH.

The shadow flicker assessment has been conducted using on-site monitored data (May 2010 – May 2016) from the 9530 monitoring tower as it records closest to the nominated hub heights. WSP | PB has used the sheared and long-term adjusted dataset from an energy yield assessment previously undertaken for this site as an input to determine the WTG orientation and operational hours.

The shadow flicker assessment conducted by WSP | PB consisted of a worst case and a realistic case for shadow flicker impact on each receptor. The realistic case was performed using conservative assumptions using monitored data from the Bureau of Meteorology to represent average sunlight hours per day; however, a number of parameters were still set at what are considered conservative values. Several sites were considered for realistic data, but the Walkamin Research Station (using mean daily data from 1968 to 2012) was selected as the most appropriate reference site to use in the realistic shadow flicker calculation due to its proximity to the MEWF site, geographic similarity and duration of recorded data.

However, the worst case assessment uses conservative model parameters that are very unlikely to occur in combination over annual timescales. The results show that for most residences, even under these conservative conditions, shadow flicker is below recommended levels of both aggregate annual hours and maximum daily hours of shadow flicker time.

Of the 123 receptors assessed, three have been predicted to experience levels of shadow flicker due to MEWF. However the draft National Wind Farm Development Guidelines – July 2010 [1] states that no shadow flicker assessment is required beyond 265 chord lengths from the WTGs, 1.06 km and the closest receptor is 1.6 km away from a MEWF WTG.

No receptors are expected to experience more than 7 hours of shadow flicker in the realistic case and for the worst case, no receptors are expected to experience over 12 hours of shadow flicker per year, as seen in Table ES.1 below. Appendix C provides a summary of the periods during which shadow flicker is expected at each of the three affected receptors.

Table ES.1 MEWF Shadow Flicker Results on affected receptors (UTM WGS84 Zone 55K)

RECEPTOR	GPS COORDINATES		WORST CASE SHADOW FLICKER HOURS PER YEAR	MAXIMUM SHADOW HOURS PER DAY	REALISTIC SHADOW FLICKER HOURS PER YEAR
	Easting	Northing	h/year	h/day	h/year
R05	325,084	8,099,119	5:23	0:15	3:01
R49	331,555	8,100,953	11:24	0:15	6:36
R78	327,662	8,103,902	4:14	0:12	2:04

The shadow hours per day provide an estimate of the maximum shadow experienced by a receptor on a single day of the year. There is no realistic and worst case scenarios associated with this parameter since, unlike shadow hours per year where the actual occurrence is cumulated over an entire year (and hence a range of environmental conditions), the shadow hours per day may well occur on a day that is conducive to the worst case for shadow flicker (i.e. assuming no cloud cover is present on the given day that this occurs).

Based on these results, the calculated levels of shadow flicker caused by MEWF on the receptors listed is substantially less than the limits prescribed by the appropriate guidelines for wind farm developments in Australia.

1 PROJECT BACKGROUND

RATCH Australia Corporation Limited (RATCH) has requested WSP | Parsons Brinckerhoff (WSP | PB) to conduct a shadow flicker assessment for the Mount Emerald Wind Farm (MEWF), located in Northern Queensland, southwest of Cairns. RATCH has nominated a layout consisting of 53 WTGs and two Vestas WTG models, detailed in Table 1.1, for evaluation and prediction of the shadow flicker at MEWF.

Table 1.1 WTG configurations evaluated for MEWF

MANUFACTURER	WTG MODEL	HUB HEIGHT	ROTOR DIAMETER	TURBINE CAPACITY	NUMBER OF WTGS	INSTALLED CAPACITY
Vestas	V117-3.45	90 mAGL	117 m	3.45 MW	37	127.65 MW
Vestas	V112-3.3	84 mAGL	112 m	3.3 MW	16	52.8 MW

Shadow flicker occurs when the sun passes behind the blades of a WTG casting an intermittent shadow. This affect is known to cause annoyance when this shadow is received at a dwelling. The severity and frequency of shadow flicker will decay with the distance from a WTG and if the location of a dwelling is within 2 km of a WTG, there is potential for this intermittent shadow to be frequent enough to cause annoyance.

An assessment using the draft National Wind Farm Development Guidelines – July 2010 [1] includes a worst case and realistic evaluation of shadow flicker to a distance of 265 times the maximum chord length from all WTGs, 1.06 km as this is the shadows become negligible at this distance. This assessment has evaluated shadow flicker on nearby receptors from MEWF to a distance of 2km.

This assessment has been conducted using a layout consisting of 53 WTGs, and the location of 123 shadow receptors (including surrounding dwellings), as specified by RATCH. It was found that no receptors are expected to exceed the recommended shadow flicker limits of the guidelines.

1.1 Description of shadow flicker

Shadow flicker is the fluctuating light levels caused by intermittent (moving or changing) shadows. If a location is in the shadow of a moving object, then there will be a momentary reduction in light intensity as the shadow passes by. This is most noticeable in an enclosed room that is lit by the sun, when the shadow falls across the window that is providing the light. Wind turbines can cause shadow flicker from the moving shadow of the wind turbine blades. Shadow flicker can also be caused by any moving objects that cast a shadow, such as vehicles or aeroplanes.

The rate of flicker for a three bladed, horizontal axis wind turbine is three times the rotational speed of the wind turbine rotor. For example a three bladed wind turbine with a rotor speed of 20 revolutions per minute (rpm) results in a flicker frequency of 1 Hertz (once per second). If the alternating light levels caused by the shadow flicker are of significant intensity and affect the whole light source of a room (i.e. the whole window is shadowed), it can disturb reading and other light-sensitive tasks, thus causing annoyance.

In order for a wind turbine to cause shadow flicker at a given location, the following conditions have to be satisfied. If any one of these conditions is not met, then shadow flicker will not occur, or will have a diminished impact, at that location.

- → The sun must be in the correct position in the sky to cast a shadow of the turbine onto the location. This will only occur for certain times of day and days of the year.
- → Wind direction will have an impact on shadow flicker impact, as the area of the shadow cast by the wind turbine will depend on which direction the wind turbine is pointing (yaw), which in turn is dependent on the wind direction.
- → There has to be unobstructed line of sight between the wind turbine and the location.

- The sun must not be significantly obscured by cloud or diffused by the atmosphere (significant diffusion typically occurs for angles of less than 3° above the horizon).
- The wind turbine has to be operating (i.e. the blades rotating).
- The dimension of the part of the blade causing the shadow has to be large enough to cast significant shadow. The largest dimension of blades is the chord near the root, which may be up to 3.5 m on large turbines, and the smallest is the depth of the blade near the tip, which may be 0.3 m or less. The latter is not sufficient to cast any noticeable shadow. If the blade is edge-on to the sun, then the shadow will be very small.
- The shadow must fall over most of a room's natural light source, i.e. window or skylight. If the windows are large (compared to the size of the shadow), or do not face the wind turbine, then the room's light levels will not vary significantly.

The sun's position varies with the time of day and the time of year. This means that the locations affected by shadow flicker from wind turbines vary with the time of day and time of the year.

The shadow flicker usually occurs to the east and west of the turbines or to the south if there is a large height difference between the turbines and the observer location.

Flicker effects will be strongest close to the WTGs, as the shadows cast by the rotating blades will be strongest. As the distance from the WTGs increases, the shadows cast by the rotor blades will become less distinct, reducing the impact of the flicker. At about 10 times the rotor diameter (1 km for a 100 m rotor diameter) the effect is reduced, and at a distance of 2 km the proportion of light blocked by the WTG blades becomes so small that flicker is not discernible. Therefore, WSP | PB has not evaluated shadow flicker beyond 2 km from any WTG at MEWF.

1.2 Scope of work

The scope undertaken in this assessment has been agreed between WSP | PB and RATCH in the email *Mt Emerald Shadow Flicker Report update* on 29 July 2016 [2], and is as follows:

- WSP | PB will perform a shadow flicker assessment based on:
  - A 53 WTG layout with two WTG models, as specified by RATCH;
  - Daily sunshine data from the closest or most applicable BoM site;
  - A list of coordinates of residences that RATCH wishes to be included in the assessment.
- WSP | PB will detail the results of this assessment in a single report, which will include:
  - A discussion of methodology and best practices;
  - A discussion on calculation inputs;
  - Documentation of the results for each residence for Worst Case Shadow Flicker per day and per year, and Realistic Shadow Flicker hours per year.

1.3 Input data

The following has been supplied by RATCH to produce the shadow flicker model:

- List of shadow receptors [3]
- 53-WTG layout [4]

From WSP | PB's previous involvement in the MEWF, additional inputs such as valid wind data and digital contours have been incorporated in the shadow flicker assessment.

2 METHODOLOGY

WSP | PB used WindPro v.3.0 to assess shadow flicker on supplied receptors at the MEWF. The model used for the calculation of flicker effects contains a mathematical model of the sun's position in the sky for a given location and time of year. Also contained in the model is information relating to the three-dimensional positions and sizes of the turbines and the locations where the flicker is to be calculated. This information is combined to calculate the times for which the turbine rotors will cast shadows over the locations of interest. Shadow flicker is assumed to occur when the centre of the sun passes behind any part of a turbine rotor.

A comparison between the realistic and worst case assessment assumptions are summarised in Table 2.1.

Table 2.1 Comparison of realistic and worst case scenario assumptions

	REALISTIC SCENARIO	WORST CASE SCENARIO
Sunlight cover	Data obtained from Walkamin Research Station (mean data from 1968 - 2012).	Direct sunlight during all daylight hours (i.e. no clouds are ever experienced over the wind farm site).
WTG operational hours	Operational hours based on power curve and 9530 mast data (May 2010 - May 2016); as a conservative measure, WSP | PB has not modified the power curve to account for hysteresis.	The wind turbines are always operating (i.e. it is always windy, and the turbines are never inoperable due to maintenance or faults).
WTG orientation	WTG orientation based on 9530 mast data (May 2010 - May 2016) [5].	The wind turbines are always turned in the horizontal plane to face the sun (i.e. the turbine rotor casts the maximum possible shadow).
WTG visibility	All the WTGs are visible except those screened by the topography.	
Maximum distance for influence	2 km	
Minimum sun height over horizon for influence	3°	
Dimensions of receptor window	Represented by a vertical rectangle facing each turbine; termed as a "Greenhouse" configuration, 10 m wide and 2 m high, centred 1.5 m off the ground (any shadow on any part of this rectangle is included in the count).	

In addition to the above assumptions, these calculations are based on the following WTG parameters:

- WTG rotor diameters 112 m and 117 m for corresponding V112 and V117 WTGs in the design layout
- WTG hub heights of 84 m and 90 m for corresponding V112 and V117 WTGs in the design layout
- WTG blade chord of 4 m (both WTG).

WSP | PB has considered a conservatively large receptor window of 10 m in width and 2 m in height to adequately include borderline situations where a receptor is just marginally exempt from experiencing the effects of shadow flicker. The Draft National Wind Farm Development Guidelines – July 2010 [1] suggest that the effects of shadow flicker are dependent on the blade dimensions and recommend an assessment distance of 265 times the maximum blade chord. Based on the maximum blade chord of 4 m, the assessment distance is 1.06 km; however, WSP | PB has used a more conservative assumption of 2 km in this assessment to account for the varying levels of human sensitivity to the intensity of shadow flicker.

The worst case assessment for each receptor results in the number of shadow flicker hours that the dwelling could potentially experience in a year. However, the occurrence of all these assumptions at one time is considered highly unlikely as cloud cover will occur over the project site, for example. Therefore, the worst case shadow flicker results serve as a starting point from which a more realistic situation is derived using measured data from reference sites recording sunlight information.

WSP | PB has applied a reduction factor to account for cloud cover at the MEWF to convert the worst case shadow flicker results to a more realistic annual estimate. This is based on recorded information on sunlight and cloud cover by the Bureau of Meteorology (BoM). The closest reference site is the Walkamin Research Station, located 6 km northeast of MEWF. This information is applied to the worst case shadow flicker assessment on a monthly average basis, measured using a Campbell-Stokes device. The average daily sunshine hours for Walkamin Research Station are shown in Table 2.2.

Table 2.2 Average sunshine hours per day on a monthly mean basis [6]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Walkamin Research Station (averaged between 1968 - 2012)	6.8	6.1	6.6	7.2	7.2	7.4	7.7	8.5	9.2	9.6	8.9	7.9

The cloud cover reduction factor is applied to the worst case results for the annual aggregate value only. The worst case shadow hours experienced in a day remains a realistic assumption as a dwelling may experience no cloud cover on the day of the year that has the maximum shadow flicker.

The location of the Walkamin Research Station relative to the MEWF site is shown in Figure 2.1.

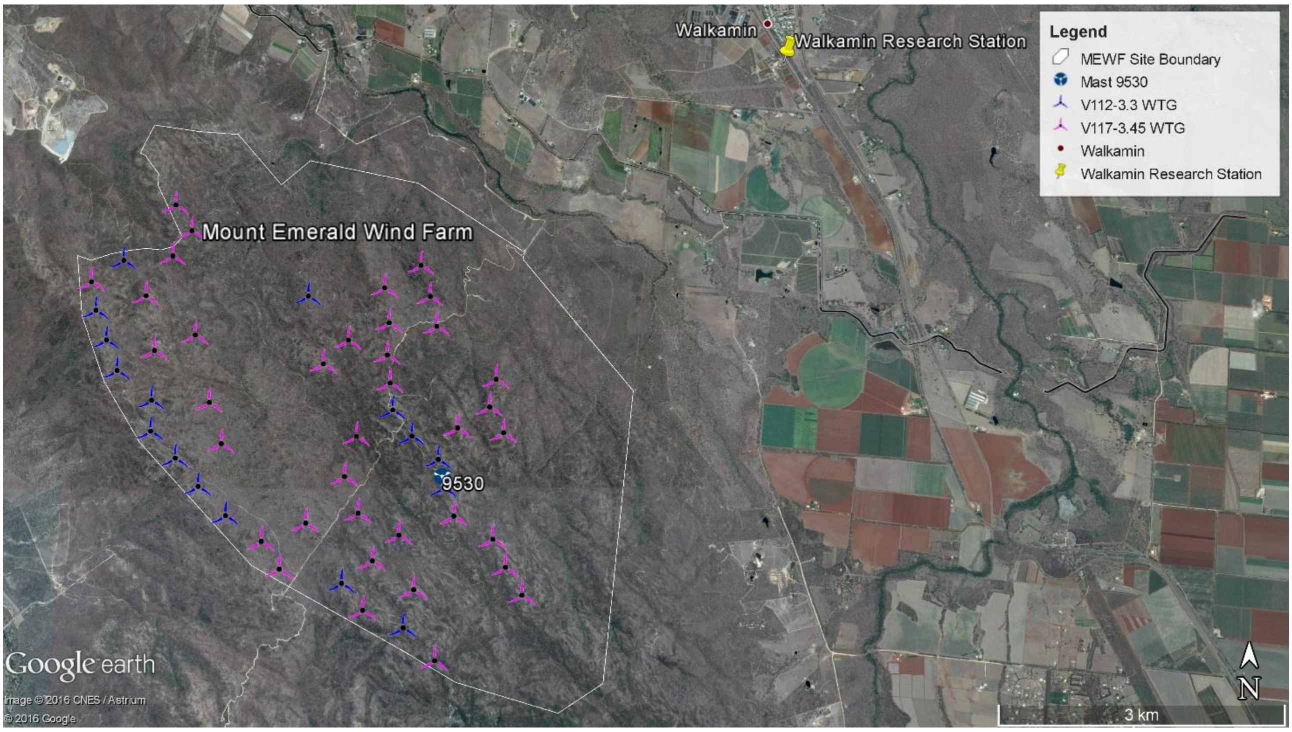

Figure 2.1 Location of Walkamin Research Station and wind monitoring mast 9530 relative to MEWF

As discussed above, wind speed and direction data recorded at the 9530 mast (May 2010 – May 2016) has been used as an input to this study [5]. The operational hours have been determined by applying the power curve to the wind speed data at the different hub heights, and the availability is estimated to be 97%. The operational hours per direction sector have been calculated by grouping the operational hours in 30 degree direction sectors.

The WTG power curves and operational hours per direction sector are presented in Appendix B and in Table 2.3 respectively.

Table 2.3 Operational hours per direction sector based on 9530 data

N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW	SUM
58	231	393	2,816	4,239	185	35	45	174	243	85	41	**8,545**

3 RESULTS

The results of the shadow flicker assessment including worst case results and realistic results using average sunshine statistics are shown below in Table 3.1.

It can be observed that none of the receptors are expected to experience shadow flicker for more than 30 hours per year in both the worst and realistic case scenarios, or 30 minutes per day in the worst case scenario. Based on these results, the calculated levels of shadow flicker caused by MEWF on the receptors listed are substantially less than the limits prescribed by the Draft National Wind Farm Development Guidelines [1]. The shadow flicker and receptor map is shown in Appendix A. Appendix C provides a summary of the periods during which shadow flicker is expected at each of the three affected receptors.

No receptors are within 265 chord lengths from the WTGs, 1.06 km. The closest receptor is 1.6 km away from a WTG.

Table 3.1 MEWF Shadow Flicker Results on each receptor location (UTM WGS84 Zone 55K)

RECEPTOR	GPS COORDINATES		WORST CASE SHADOW FLICKER HOURS PER YEAR	MAXIMUM SHADOW HOURS PER DAY	REALISTIC SHADOW FLICKER HOURS PER YEAR
	Easting	Northing	h/year	h/day	h/year
R01	327,108	8,094,240	0:00	0:00	0:00
R02	323,399	8,101,041	0:00	0:00	0:00
R03	322,551	8,100,377	0:00	0:00	0:00
R04	322,401	8,100,614	0:00	0:00	0:00
R05	325,084	8,099,119	5:23	0:15	3:01
R06	324,402	8,099,053	0:00	0:00	0:00
R07	324,438	8,098,311	0:00	0:00	0:00
R08	324,461	8,097,943	0:00	0:00	0:00
R09	324,552	8,097,638	0:00	0:00	0:00
R10	324,741	8,097,351	0:00	0:00	0:00
R11	325,824	8,096,858	0:00	0:00	0:00
R12	326,812	8,094,840	0:00	0:00	0:00
R13	322,913	8,101,970	0:00	0:00	0:00
R14	323,526	8,098,996	0:00	0:00	0:00
R15	322,190	8,101,228	0:00	0:00	0:00
R16	323,417	8,099,332	0:00	0:00	0:00
R17	321,385	8,101,835	0:00	0:00	0:00
R18	322,861	8,105,817	0:00	0:00	0:00

RECEPTOR	GPS COORDINATES		WORST CASE SHADOW FLICKER HOURS PER YEAR	MAXIMUM SHADOW HOURS PER DAY	REALISTIC SHADOW FLICKER HOURS PER YEAR
R19	323,237	8,105,869	0:00	0:00	0:00
R20	324,011	8,106,789	0:00	0:00	0:00
R21	327,346	8,105,105	0:00	0:00	0:00
R22	327,532	8,105,458	0:00	0:00	0:00
R23	327,320	8,105,720	0:00	0:00	0:00
R24	327,836	8,105,651	0:00	0:00	0:00
R25	328,105	8,105,059	0:00	0:00	0:00
R26	327,385	8,104,239	0:00	0:00	0:00
R27	328,640	8,104,706	0:00	0:00	0:00
R28	328,814	8,104,996	0:00	0:00	0:00
R29	329,227	8,104,783	0:00	0:00	0:00
R30	329,632	8,104,345	0:00	0:00	0:00
R31	329,738	8,105,254	0:00	0:00	0:00
R32	329,821	8,104,154	0:00	0:00	0:00
R33	329,870	8,104,536	0:00	0:00	0:00
R34	330,044	8,104,444	0:00	0:00	0:00
R35	330,166	8,103,957	0:00	0:00	0:00
R36	330,281	8,103,655	0:00	0:00	0:00
R37	330,744	8,104,165	0:00	0:00	0:00
R38	331,053	8,103,796	0:00	0:00	0:00
R39	331,012	8,103,431	0:00	0:00	0:00
R40	331,286	8,103,732	0:00	0:00	0:00
R41	331,610	8,103,457	0:00	0:00	0:00
R42	331,773	8,103,467	0:00	0:00	0:00
R43	331,900	8,103,216	0:00	0:00	0:00
R44	332,241	8,103,249	0:00	0:00	0:00
R45	332,142	8,103,035	0:00	0:00	0:00
R46	331,667	8,102,969	0:00	0:00	0:00
R47	331,836	8,102,949	0:00	0:00	0:00
R48	331,981	8,102,675	0:00	0:00	0:00
R49	331,555	8,100,953	11:24	0:15	6:36
R50	333,099	8,102,820	0:00	0:00	0:00

RECEPTOR	GPS COORDINATES		WORST CASE SHADOW FLICKER HOURS PER YEAR	MAXIMUM SHADOW HOURS PER DAY	REALISTIC SHADOW FLICKER HOURS PER YEAR
R51	333,372	8,102,564	0:00	0:00	0:00
R52	333,849	8,102,111	0:00	0:00	0:00
R53	333,977	8,101,981	0:00	0:00	0:00
R54	334,001	8,101,907	0:00	0:00	0:00
R55	334,143	8,101,119	0:00	0:00	0:00
R56	334,828	8,100,860	0:00	0:00	0:00
R57	332,290	8,102,160	0:00	0:00	0:00
R58	333,082	8,100,051	0:00	0:00	0:00
R59	332,424	8,099,580	0:00	0:00	0:00
R60	332,526	8,098,770	0:00	0:00	0:00
R61	333,441	8,099,268	0:00	0:00	0:00
R62	332,750	8,099,348	0:00	0:00	0:00
R63	333,180	8,098,115	0:00	0:00	0:00
R64	333,966	8,098,486	0:00	0:00	0:00
R65	334,769	8,098,473	0:00	0:00	0:00
R66	333,273	8,097,584	0:00	0:00	0:00
R67	333,769	8,097,741	0:00	0:00	0:00
R68	333,818	8,097,418	0:00	0:00	0:00
R69	333,759	8,097,284	0:00	0:00	0:00
R70	333,858	8,097,008	0:00	0:00	0:00
R71	333,837	8,096,819	0:00	0:00	0:00
R72	334,122	8,096,447	0:00	0:00	0:00
R73	334,300	8,097,467	0:00	0:00	0:00
R74	334,315	8,097,097	0:00	0:00	0:00
R75	334,312	8,096,814	0:00	0:00	0:00
R76	334,510	8,096,570	0:00	0:00	0:00
R77	333,420	8,095,349	0:00	0:00	0:00
R78	327,662	8,103,902	4:14	0:12	2:04
R79	326,084	8,095,615	0:00	0:00	0:00
R80	326,633	8,095,887	0:00	0:00	0:00
R81	322,227	8,102,228	0:00	0:00	0:00
R82	328,862	8,104,954	0:00	0:00	0:00

RECEPTOR	GPS COORDINATES		WORST CASE SHADOW FLICKER HOURS PER YEAR	MAXIMUM SHADOW HOURS PER DAY	REALISTIC SHADOW FLICKER HOURS PER YEAR
R83	331,064	8,103,659	0:00	0:00	0:00
R84	328,138	8,105,207	0:00	0:00	0:00
RANGEVIEW	335,269	8,097,070	0:00	0:00	0:00
WALKAMIN	332,711	8,105,470	0:00	0:00	0:00
R87	324,029	8,106,539	0:00	0:00	0:00
R88	325,804	8,107,243	0:00	0:00	0:00
R89	324,925	8,104,393	0:00	0:00	0:00
R90	323,839	8,105,103	0:00	0:00	0:00
R91	333,946	8,102,712	0:00	0:00	0:00
R92	334,049	8,103,397	0:00	0:00	0:00
R93	333,585	8,103,544	0:00	0:00	0:00
R94	333,738	8,103,749	0:00	0:00	0:00
R95	333,737	8,103,972	0:00	0:00	0:00
R96	333,543	8,104,296	0:00	0:00	0:00
R97	333,476	8,104,424	0:00	0:00	0:00
R98	333,652	8,104,597	0:00	0:00	0:00
R99	332,659	8,104,989	0:00	0:00	0:00
R100	332,380	8,105,473	0:00	0:00	0:00
R101	332,447	8,105,917	0:00	0:00	0:00
R102	333,013	8,104,126	0:00	0:00	0:00
R103	332,934	8,104,276	0:00	0:00	0:00
R104	332,397	8,104,339	0:00	0:00	0:00
R105	330,771	8,106,228	0:00	0:00	0:00
R106	330,687	8,106,366	0:00	0:00	0:00
R107	330,802	8,106,936	0:00	0:00	0:00
R108	331,175	8,107,484	0:00	0:00	0:00
R109	328,594	8,107,639	0:00	0:00	0:00
R110	328,212	8,107,130	0:00	0:00	0:00
R111	328,314	8,106,195	0:00	0:00	0:00
R112	327,666	8,106,205	0:00	0:00	0:00
R113	327,055	8,106,025	0:00	0:00	0:00
R114	327,675	8,108,169	0:00	0:00	0:00

RECEPTOR	GPS COORDINATES		WORST CASE SHADOW FLICKER HOURS PER YEAR	MAXIMUM SHADOW HOURS PER DAY	REALISTIC SHADOW FLICKER HOURS PER YEAR
R115	327,309	8,108,440	0:00	0:00	0:00
R116	324,316	8,109,076	0:00	0:00	0:00
R117	320,884	8,102,947	0:00	0:00	0:00
R118	321,231	8,101,117	0:00	0:00	0:00
R119	321,148	8,101,136	0:00	0:00	0:00
R120	321,240	8,101,684	0:00	0:00	0:00
R121	319,947	8,100,527	0:00	0:00	0:00
R122	333,913	8,094,653	0:00	0:00	0:00
R123	334,862	8,095,248	0:00	0:00	0:00

4 REFERENCES

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[6] Bureau of Meteorology, “Climate statistics for Australian locations; Walkamin Research Station,” 2013. [Online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_031108.shtml. [Accessed 7 3 2013].

[7] Vestas, “Performance Specification V112-3.3 MW 50/60 Hz 2016-06-08,” Vestas, Aarhus, Denmark, 2016.

[8] “Performance Specification V117-3.45 MW 50/60 Hz 0053-3711 V04 2016-05-06,” Vestas, Aarhus, Denmark, 2016.

Appendix A

SHADOW FLICKER MAPS

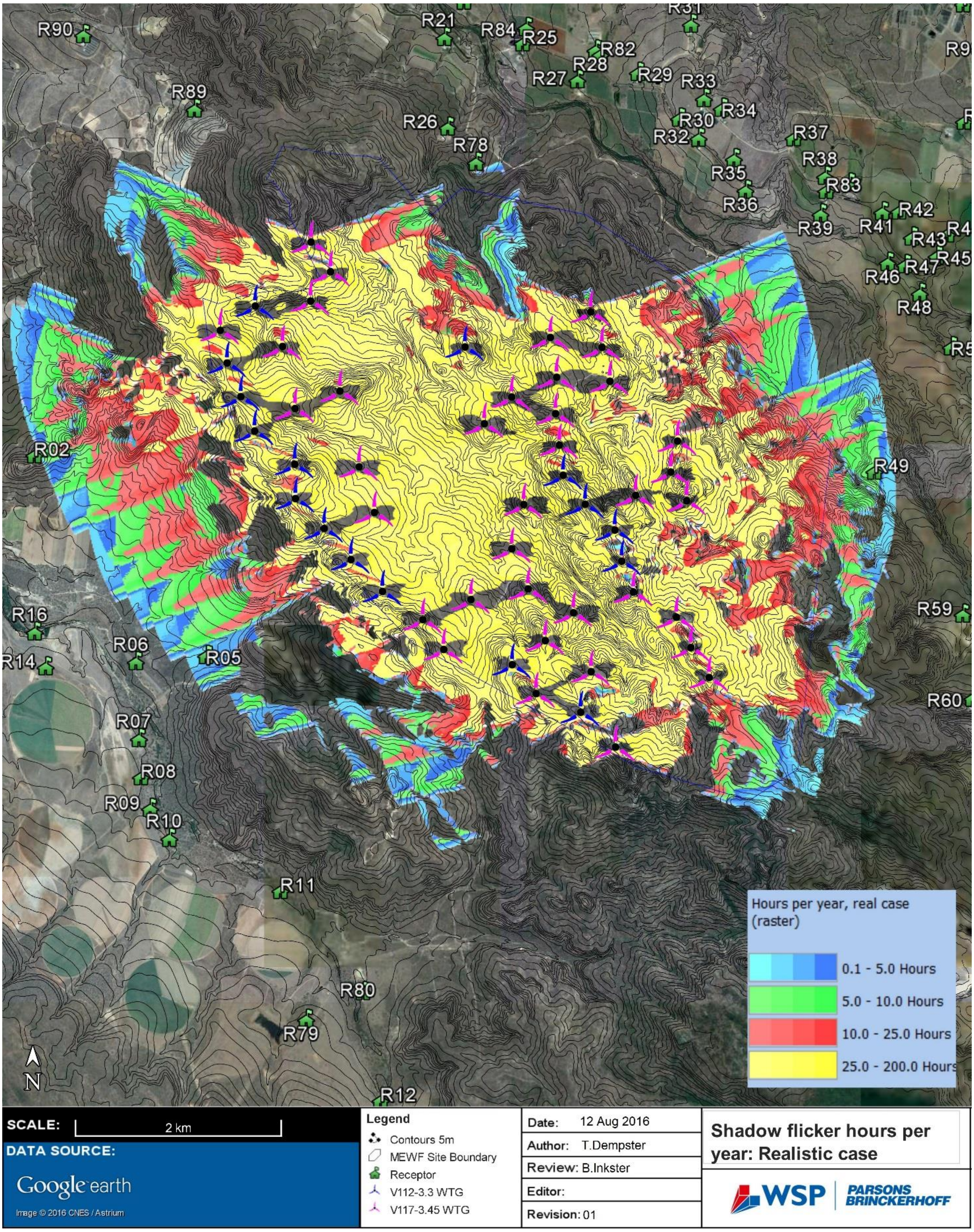

Figure A.1 MEWF shadow flicker map of realistic shadow flicker hours per year with receptor locations

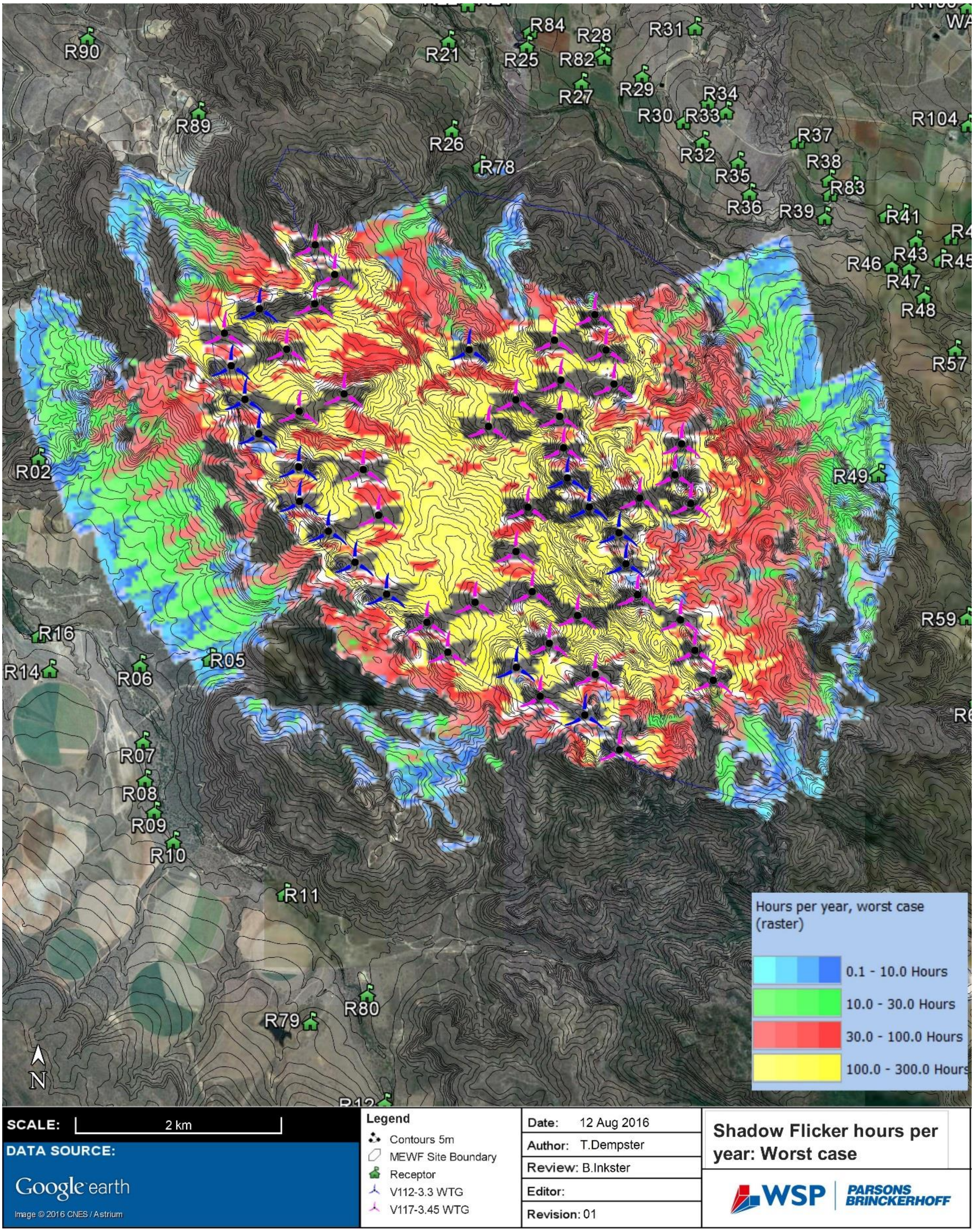

Figure A.2 MEWF shadow flicker map of worst case shadow flicker hours per year with receptor locations

Appendix B

WTG LAYOUT AND POWER CURVES

Table B.1 MEWF Vestas 53 WTG layout [4]

WTG ID	EASTING	NORTHING	ELEVATION	WTG CONFIGURATION	HUB HEIGHT
	UTM WGS84 Zone 54		mASL		mAGL
T03	326071	8103211	804.8	Vestas V117-3.45	90
T04	326263	8102926	795	Vestas V117-3.45	90
T05	326071	8102642	785.6	Vestas V117-3.45	90
T06	325535	8102589	808.7	Vestas V112-3.3	84
T07	325197	8102351	827.2	Vestas V117-3.45	90
T08	325266	8102037	842.8	Vestas V112-3.3	84
T09	325402	8101713	845.7	Vestas V112-3.3	84
T10	325539	8101383	859.8	Vestas V112-3.3	84
T11	325930	8101603	850	Vestas V117-3.45	90
T12	325803	8102201	815	Vestas V117-3.45	90
T13	326364	8101775	850	Vestas V117-3.45	90
T15	325931	8101065	890	Vestas V112-3.3	84
T16	325941	8100734	873.1	Vestas V112-3.3	84
T17	326222	8100448	851.5	Vestas V112-3.3	84
T18	326484	8100150	845.2	Vestas V112-3.3	84
T19	326793	8099845	846.3	Vestas V112-3.3	84
T20	327187	8099577	868.2	Vestas V117-3.45	90
T21	327392	8099290	860.2	Vestas V117-3.45	90
T22	327652	8099773	855	Vestas V117-3.45	90
T29	326556	8101046	820	Vestas V117-3.45	90
T30	326708	8100606	831.9	Vestas V117-3.45	90
T31	328045	8100267	817.6	Vestas V117-3.45	90
T32	328206	8099881	845	Vestas V117-3.45	90
T33	328648	8099655	850	Vestas V117-3.45	90
T34	328376	8099384	900	Vestas V117-3.45	90
T35	328058	8099149	930.5	Vestas V112-3.3	84
T36	328292	8098872	975	Vestas V117-3.45	90
T37	328824	8099088	902.9	Vestas V117-3.45	90
T38	328726	8098695	1000	Vestas V112-3.3	84
T39	329067	8098362	1030	Vestas V117-3.45	90
T44	329970	8099041	883.3	Vestas V117-3.45	90

WTG ID	EASTING	NORTHING	ELEVATION	WTG CONFIGURATION	HUB HEIGHT
T45	329790	8099328	911.7	Vestas V117-3.45	90
T46	329648	8099620	875	Vestas V117-3.45	90
T47	329228	8099859	892.5	Vestas V117-3.45	90
T48	329113	8100157	917.1	Vestas V112-3.3	84
T49	329043	8100457	925	Vestas V112-3.3	84
T50	329738	8100745	840	Vestas V117-3.45	90
T51	329581	8101021	809.7	Vestas V117-3.45	90
T52	329644	8101320	810	Vestas V117-3.45	90
T53	329242	8100793	855	Vestas V117-3.45	90
T54	328753	8100703	881.2	Vestas V112-3.3	84
T55	328157	8100695	810	Vestas V117-3.45	90
T56	328537	8100981	870	Vestas V112-3.3	84
T57	328498	8101272	845	Vestas V117-3.45	90
T58	328458	8101575	834.5	Vestas V117-3.45	90
T59	328466	8101926	820	Vestas V117-3.45	90
T60	328402	8102310	805	Vestas V117-3.45	90
T63	328792	8102560	820	Vestas V117-3.45	90
T64	328903	8102219	810	Vestas V117-3.45	90
T65	328983	8101892	805.5	Vestas V117-3.45	90
T66	328031	8101732	834.3	Vestas V117-3.45	90
T67	327768	8101472	808.2	Vestas V117-3.45	90
T69	327574	8102211	840	Vestas V112-3.3	84

Table B.2 WTG power curves used for assessment of MEWF

WIND SPEED	Vestas V112-3.3 (1.075 kg/m^3) [7]		Vestas V117-3.45 (1.075 kg/m^3) [8]	
m/s	Power (kW)	C_t	Power (kW)	C_t
0	0	-	0	-
1	0	-	0	-
2	0	-	0	-
3	4	0.895	15	0.876
3.5	40	0.889	62	0.851
4	101	0.87	126	0.837
4.5	176	0.841	202	0.827
5	265	0.84	292	0.827
5.5	368	0.843	402	0.827
6	490	0.837	535	0.823
6.5	635	0.832	692	0.819
7	806	0.825	877	0.819
7.5	1002	0.818	1088	0.81
8	1224	0.811	1330	0.801
8.5	1477	0.81	1603	0.798
9	1759	0.806	1911	0.799
9.5	2065	0.8	2244	0.792
10	2386	0.781	2588	0.768
10.5	2695	0.736	2914	0.716
11	2945	0.669	3177	0.648
11.5	3127	0.593	3354	0.573
12	3231	0.516	3427	0.494
12.5	3277	0.447	3446	0.424
13	3293	0.388	3450	0.367
13.5	3296	0.342	3450	0.324
14	3299	0.302	3450	0.286
14.5	3300	0.269	3450	0.255
15	3300	0.24	3450	0.228
15.5	3300	0.216	3450	0.205
16	3300	0.196	3450	0.186
16.5	3300	0.178	3450	0.169

WIND SPEED	Vestas V112-3.3 (1.075 kg/m^3) [7]		Vestas V117-3.45 (1.075 kg/m^3) [8]	
17	3300	0.163	3450	0.155
17.5	3300	0.149	3450	0.142
18	3300	0.137	3450	0.13
18.5	3300	0.127	3450	0.12
19	3300	0.117	3450	0.111
19.5	3300	0.108	3450	0.103
20	3300	0.101	3450	0.095
20.5	3300	0.094	3450	0.089
21	3300	0.088	3450	0.083
21.5	3300	0.083	3450	0.078
22	3300	0.078	3450	0.074
22.5	3300	0.073	3450	0.069
23	3300	0.068	3450	0.065
23.5	3300	0.064	3450	0.061
24	3300	0.061	3450	0.058
24.5	3300	0.058	3450	0.054
25	3300	0.055	3450	0.052

Appendix C

SHADOW FLICKER CALENDAR

Table C.1, Table C.2 and Table C.3 summarise the periods during which shadow flicker is expected at each of the affected receptors. As discussed in section 3 of the report, only three receptors are expected to experience shadow flicker.

Table C.1 Receptor R05 shadow flicker calendar

DATE	SUNRISE, TIME	SUNSET, TIME	SHADOW FLICKER TIME, START (WORST CASE)	SHADOW FLICKER TIME, END (WORST CASE)	FLICKER SOURCE	DISTANCE FROM FLICKER SOURCE	DURATION (WORST CASE)	DURATION (REALISTIC), ROUNDED TO CLOSEST MINUTE
Day-Month	hh:mm	hh:mm	hh:mm	hh:mm	WTG	km	hh:mm	hh:mm
3-May	6:32	18:00	7:27	7:30	T19	1.85	0:03	0:01
4-May	6:33	18:00	7:24	7:32	T19	1.85	0:08	0:04
5-May	6:33	17:59	7:22	7:33	T19	1.85	0:11	0:05
6-May	6:33	17:59	7:22	7:34	T19	1.85	0:12	0:06
7-May	6:33	17:58	7:21	7:34	T19	1.85	0:13	0:06
8-May	6:34	17:58	7:20	7:34	T19	1.85	0:14	0:07
9-May	6:34	17:57	7:21	7:35	T19	1.85	0:14	0:07
10-May	6:34	17:57	7:20	7:35	T19	1.85	0:15	0:07
11-May	6:35	17:57	7:20	7:35	T19	1.85	0:15	0:07
12-May	6:35	17:56	7:21	7:35	T19	1.85	0:14	0:07
13-May	6:35	17:56	7:22	7:34	T19	1.85	0:12	0:06
14-May	6:36	17:55	7:22	7:33	T19	1.85	0:11	0:05
15-May	6:36	17:55	7:23	7:33	T19	1.85	0:10	0:05
16-May	6:36	17:55	7:24	7:31	T19	1.85	0:07	0:03
27-Jul	6:47	18:04	7:37	7:41	T19	1.85	0:04	0:02
28-Jul	6:46	18:05	7:35	7:43	T19	1.85	0:08	0:04
29-Jul	6:46	18:05	7:33	7:44	T19	1.85	0:11	0:06
30-Jul	6:46	18:05	7:33	7:45	T19	1.85	0:12	0:06
31-Jul	6:45	18:06	7:31	7:45	T19	1.85	0:14	0:07
1-Aug	6:45	18:06	7:31	7:45	T19	1.85	0:14	0:08
2-Aug	6:44	18:06	7:31	7:46	T19	1.85	0:15	0:09
3-Aug	6:44	18:06	7:31	7:45	T19	1.85	0:14	0:08
4-Aug	6:44	18:07	7:31	7:45	T19	1.85	0:14	0:08
5-Aug	6:43	18:07	7:30	7:44	T19	1.85	0:14	0:08
6-Aug	6:43	18:07	7:31	7:44	T19	1.85	0:13	0:07
7-Aug	6:42	18:07	7:31	7:43	T19	1.85	0:12	0:07

DATE	SUNRISE, TIME	SUNSET, TIME	SHADOW FLICKER TIME, START (WORST CASE)	SHADOW FLICKER TIME, END (WORST CASE)	FLICKER SOURCE	DISTANCE FROM FLICKER SOURCE	DURATION (WORST CASE)	DURATION (REALISTIC), ROUNDED TO CLOSEST MINUTE
8-Aug	6:42	18:08	7:32	7:43	T19	1.85	0:11	0:06
9-Aug	6:41	18:08	7:33	7:41	T19	1.85	0:08	0:04
						Total duration (h:mm)	**5:23**	**3:01**

Table C.2 Receptor R49 shadow flicker calendar

DATE	SUNRISE, TIME	SUNSET, TIME	SHADOW FLICKER TIME, START (WORST CASE)	SHADOW FLICKER TIME, END (WORST CASE)	FLICKER SOURCE	DISTANCE FROM FLICKER SOURCE	DURATION (WORST CASE)	DURATION (REALISTIC), ROUNDED TO CLOSEST MINUTE
Day-Month	**hh:mm**	**hh:mm**	**hh:mm**	**hh:mm**	**WTG**	**km**	**hh:mm**	**hh:mm**
22-Feb	6:16	18:49	18:02	18:08	T50	2.13	0:06	0:02
23-Feb	6:16	18:49	17:59	18:09	T50	2.13	0:10	0:04
24-Feb	6:17	18:48	17:58	18:10	T50	2.13	0:12	0:05
25-Feb	6:17	18:47	17:57	18:11	T50	2.13	0:14	0:06
26-Feb	6:17	18:47	17:57	18:11	T50	2.13	0:14	0:06
27-Feb	6:18	18:46	17:56	18:11	T50	2.13	0:15	0:06
28-Feb	6:18	18:45	17:56	18:11	T50	2.13	0:15	0:06
1-Mar	6:18	18:45	17:56	18:10	T50	2.13	0:14	0:06
2-Mar	6:19	18:44	17:57	18:09	T50	2.13	0:12	0:05
3-Mar	6:19	18:43	17:59	18:08	T50	2.13	0:09	0:04
4-Mar	6:19	18:43	18:01	18:04	T50	2.13	0:03	0:01
17-Mar	6:22	18:33	17:52	18:00	T51	1.98	0:08	0:03
18-Mar	6:22	18:32	17:50	18:01	T51	1.98	0:11	0:05
19-Mar	6:23	18:31	17:49	18:01	T51	1.98	0:12	0:05
20-Mar	6:23	18:31	17:48	18:01	T51	1.98	0:13	0:06
21-Mar	6:23	18:30	17:48	18:02	T51	1.98	0:14	0:06
22-Mar	6:23	18:29	17:48	18:01	T51	1.98	0:13	0:06
23-Mar	6:23	18:28	17:48	18:00	T51	1.98	0:12	0:05
24-Mar	6:23	18:28	17:48	17:58	T51	1.98	0:10	0:04
25-Mar	6:24	18:27	17:50	17:56	T51	1.98	0:06	0:02

DATE	SUNRISE, TIME	SUNSET, TIME	SHADOW FLICKER TIME, START (WORST CASE)	SHADOW FLICKER TIME, END (WORST CASE)	FLICKER SOURCE	DISTANCE FROM FLICKER SOURCE	DURATION (WORST CASE)	DURATION (REALISTIC), ROUNDED TO CLOSEST MINUTE
7-Apr	6:26	18:17	17:35	17:42	T52	1.91	0:07	0:03
8-Apr	6:26	18:16	17:33	17:43	T52	1.91	0:10	0:05
9-Apr	6:26	18:15	17:31	17:44	T52	1.91	0:13	0:07
10-Apr	6:27	18:14	17:30	17:44	T52	1.91	0:14	0:07
11-Apr	6:27	18:14	17:29	17:43	T52	1.91	0:14	0:07
12-Apr	6:27	18:13	17:29	17:43	T52	1.91	0:14	0:07
13-Apr	6:27	18:12	17:29	17:43	T52	1.91	0:14	0:07
14-Apr	6:27	18:12	17:29	17:42	T52	1.91	0:13	0:07
15-Apr	6:28	18:11	17:30	17:40	T52	1.91	0:10	0:05
16-Apr	6:28	18:10	17:31	17:38	T52	1.91	0:07	0:03
27-Aug	6:30	18:11	17:33	17:40	T52	1.91	0:07	0:04
28-Aug	6:29	18:11	17:31	17:42	T52	1.91	0:11	0:07
29-Aug	6:28	18:12	17:30	17:43	T52	1.91	0:13	0:08
30-Aug	6:27	18:12	17:29	17:43	T52	1.91	0:14	0:08
31-Aug	6:27	18:12	17:29	17:43	T52	1.91	0:14	0:08
1-Sep	6:26	18:12	17:28	17:42	T52	1.91	0:14	0:09
2-Sep	6:25	18:12	17:29	17:43	T52	1.91	0:14	0:09
3-Sep	6:24	18:12	17:29	17:42	T52	1.91	0:13	0:08
4-Sep	6:24	18:12	17:30	17:40	T52	1.91	0:10	0:06
5-Sep	6:23	18:13	17:31	17:38	T52	1.91	0:07	0:04
18-Sep	6:12	18:14	17:39	17:42	T51	1.98	0:03	0:02
19-Sep	6:11	18:14	17:36	17:45	T51	1.98	0:09	0:06
20-Sep	6:10	18:14	17:34	17:45	T51	1.98	0:11	0:07
21-Sep	6:10	18:15	17:33	17:46	T51	1.98	0:13	0:08
22-Sep	6:09	18:15	17:33	17:47	T51	1.98	0:14	0:09
23-Sep	6:08	18:15	17:32	17:46	T51	1.98	0:14	0:09
24-Sep	6:07	18:15	17:32	17:45	T51	1.98	0:13	0:08
25-Sep	6:06	18:15	17:32	17:44	T51	1.98	0:12	0:08
26-Sep	6:05	18:15	17:33	17:43	T51	1.98	0:10	0:06
27-Sep	6:05	18:15	17:35	17:39	T51	1.98	0:04	0:02

DATE	SUNRISE, TIME	SUNSET, TIME	SHADOW FLICKER TIME, START (WORST CASE)	SHADOW FLICKER TIME, END (WORST CASE)	FLICKER SOURCE	DISTANCE FROM FLICKER SOURCE	DURATION (WORST CASE)	DURATION (REALISTIC), ROUNDED TO CLOSEST MINUTE
10-Oct	5:54	18:18	17:34	17:41	T50	2.13	0:07	0:04
11-Oct	5:54	18:18	17:31	17:42	T50	2.13	0:11	0:07
12-Oct	5:53	18:18	17:30	17:43	T50	2.13	0:13	0:08
13-Oct	5:52	18:18	17:29	17:44	T50	2.13	0:15	0:10
14-Oct	5:51	18:18	17:29	17:43	T50	2.13	0:14	0:09
15-Oct	5:51	18:19	17:29	17:44	T50	2.13	0:15	0:10
16-Oct	5:50	18:19	17:29	17:43	T50	2.13	0:14	0:09
17-Oct	5:49	18:19	17:29	17:42	T50	2.13	0:13	0:08
18-Oct	5:49	18:19	17:30	17:42	T50	2.13	0:12	0:08
19-Oct	5:48	18:20	17:31	17:40	T50	2.13	0:09	0:06
20-Oct	5:47	18:20	17:34	17:36	T50	2.13	0:02	0:01
						Total duration (h:mm)	**11:24**	**6:38**

Table C.3 Receptor R78 shadow flicker calendar

DATE	SUNRISE, TIME	SUNSET, TIME	SHADOW FLICKER TIME, START (WORST CASE)	SHADOW FLICKER TIME, END (WORST CASE)	FLICKER SOURCE	DISTANCE FROM FLICKER SOURCE	DURATION (WORST CASE)	DURATION (REALISTIC), ROUNDED TO CLOSEST MINUTE
Day-Month	**hh:mm**	**hh:mm**	**hh:mm**	**hh:mm**	**WTG**	**km**	**hh:mm**	**hh:mm**
1-Jan	5:49	18:56	18:01	18:09	T03	1.73	0:08	0:03
2-Jan	5:49	18:57	18:03	18:09	T03	1.73	0:06	0:02
3-Jan	5:50	18:57	18:06	18:08	T03	1.73	0:02	0:00
9-Dec	5:38	18:45	17:54	17:56	T03	1.73	0:02	0:01
10-Dec	5:38	18:45	17:52	17:58	T03	1.73	0:06	0:03
11-Dec	5:38	18:46	17:53	18:00	T03	1.73	0:07	0:03
12-Dec	5:39	18:46	17:52	18:01	T03	1.73	0:09	0:04
13-Dec	5:39	18:47	17:52	18:01	T03	1.73	0:09	0:04
14-Dec	5:39	18:47	17:52	18:03	T03	1.73	0:11	0:05
15-Dec	5:40	18:48	17:52	18:03	T03	1.73	0:11	0:05
16-Dec	5:40	18:49	17:53	18:04	T03	1.73	0:11	0:05

DATE	SUNRISE, TIME	SUNSET, TIME	SHADOW FLICKER TIME, START (WORST CASE)	SHADOW FLICKER TIME, END (WORST CASE)	FLICKER SOURCE	DISTANCE FROM FLICKER SOURCE	DURATION (WORST CASE)	DURATION (REALISTIC), ROUNDED TO CLOSEST MINUTE
17-Dec	5:40	18:49	17:53	18:05	T03	1.73	0:12	0:06
18-Dec	5:41	18:50	17:53	18:05	T03	1.73	0:12	0:06
19-Dec	5:41	18:50	17:54	18:06	T03	1.73	0:12	0:06
20-Dec	5:42	18:51	17:54	18:06	T03	1.73	0:12	0:06
21-Dec	5:42	18:51	17:55	18:07	T03	1.73	0:12	0:06
22-Dec	5:43	18:52	17:55	18:07	T03	1.73	0:12	0:06
23-Dec	5:43	18:52	17:56	18:08	T03	1.73	0:12	0:06
24-Dec	5:44	18:53	17:56	18:08	T03	1.73	0:12	0:06
25-Dec	5:44	18:53	17:57	18:09	T03	1.73	0:12	0:06
26-Dec	5:45	18:54	17:57	18:09	T03	1.73	0:12	0:06
27-Dec	5:45	18:54	17:58	18:10	T03	1.73	0:12	0:06
28-Dec	5:46	18:55	17:58	18:09	T03	1.73	0:11	0:05
29-Dec	5:47	18:55	17:59	18:10	T03	1.73	0:11	0:05
30-Dec	5:47	18:55	18:00	18:09	T03	1.73	0:09	0:04
31-Dec	5:48	18:56	18:01	18:10	T03	1.73	0:09	0:04
						Total duration (h:mm)	**4:14**	**2:06**