DNV·GL

## STOCKYARD HILL WIND FARM

# Shadow Flicker and Blade Glint Assessment

## Stockyard Hill Wind Farm Pty Ltd

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# Table of contents

# EXECUTIVE SUMMARY

Stockyard Hill Wind Farm Pty Ltd ("SHWFPL") (a subsidiary of Origin Energy) is developing a wind farm project in south-west Victoria, known as the Stockyard Hill Wind Farm ("SHWF").

Planning Permit No. PL-SP/05/0548 (Pyrenees Planning Scheme) ("the Permit") was issued by the Minister for Planning in October 2010 to enable the use and development of the SHWF Wind Energy Facility ("WEF").

SHWFPL has now decided to progress the preparation of an application to amend the Permit to seek approval for taller turbines to achieve more efficient generation of energy. Additionally, as a result of the proposed taller turbines and to ensure the Permit reflects current standards, guidelines and departments, there are a number of other amendments proposed as part of the application.

DNV GL has been commissioned by SHWFPL to independently assess the expected annual shadow flicker duration in the vicinity of the SHWF WEF and any associated impact of blade glint, with the purpose of accompanying an application to amend the Permit.

This document provides an assessment of the overall impact of proposed amended WEF, whilst describing the resulting change in potential impact from the permitted WEF.

## Regulatory Requirements

Shadow flicker involves the modulation of light levels resulting from the periodic passage of a rotating wind turbine blade between the sun and an observer. The Victorian Planning Guidelines [1] 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 [2] 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. Condition 17 of the Permit also specifies a shadow flicker limit of 30 hours per year at any dwelling in the vicinity of the WEF, although this does not apply to dwellings where the landowner has agreed to accept shadow flicker durations in excess of this limit.

The Victorian Planning Guidelines refer to the Draft National Guidelines for guidance on the methodology for assessing shadow flicker durations. This assessment was based on the methodology recommended by the Draft National Guidelines. Calculations were carried out assuming houses had either one or two stories with window heights of either 2 m or 6 m, respectively. The relevant shadow flicker duration at a dwelling was taken as the maximum calculated duration occurring within 50 m of the dwelling.

Blade glint involves the reflection of light from a turbine blade, and can be seen by an observer as a periodic flash of light coming from the wind turbine. The Draft National Guidelines note that blade glint is not generally a problem provided that non-reflective coatings are used for the surface of the blades, and Condition 4(g) of the Permit specifies that the wind turbines must be of non-reflective finish and colour.

## Approach

SHWFPL has asked DNV GL to assess the shadow flicker based upon two layouts provided for the SHWF WEF: a 'permitted' layout consisting of 157 wind turbines, as shown in Figure 3, and an 'amended' layout consisting of 149 wind turbines with a larger turbine type, also shown in Figure 3.

An example turbine model with a hub height of 80 m and rotor diameter of 104 m has been considered for the permitted WEF, while a turbine model with a hub height of 110 m and rotor diameter of 140 m has been considered for the amended WEF. These dimensions represent the maximum overall tip height within the maximum blade/rotor and tower hub height dimensions [6, 7]. There are 46 dwellings located

within 1.5km of the SHWF WEF as outlined in Table 4, 29 of which are participant dwellings and two of which are proponent dwellings, as defined in Section 2.1.

SHWFPL has informed DNV GL that 27 neighbouring participant dwellings have agreed to accept shadow flicker durations above 30 hours per year, as shown in Table 4, and a further two dwellings require no shadow flicker limit due to either being owned by SHWFPL or having contractual arrangements in place such that the building will not be used as a residential dwelling for the operational life of the WEF. DNV GL has assumed that the shadow flicker limits provided by SHWFPL apply to the theoretical shadow flicker only and that the limit on the actual shadow flicker is one-third of the agreed limit, which is consistent with the approach taken by the Draft National Guidelines. For dwellings where no agreement has been obtained, the recommended and specified shadow flicker limits described above have been applied.

The theoretical shadow flicker durations at dwellings (sensitive locations) within and neighbouring the SHWF WEF have been determined using a purely geometric analysis which takes into account the relative position of the sun throughout the year, the wind turbines at the site, local topography and the viewer. The actual shadow flicker duration likely to be experienced at each dwelling has then been predicted by estimating the possible reduction in shadow flicker duration due to turbine orientation and cloud cover.

## Assessment Findings

The results of this assessment are summarised in the following table.

**Summary of shadow flicker assessment results for the proposed SHWF WEF**

| Predicted shadow flicker within 50 m of dwelling | Number of dwellings affected | | | | Anticipated change |
|---|---|---|---|---|---|
| | Permitted Layout | | Amended Layout | | |
| | Total | Dwellings with agreed limit > 30 hours/year | Total | Dwellings with agreed limit > 30 hours/year | |
| *Predicted theoretical shadow flicker (recommended/specified limit: 30 hours/year)* | | | | | |
| Above recommended limit | 6 | 6 | 8 | 8 | Number of dwellings increased by two |
| Above agreed or recommended limit, whichever is greater | 2 | 2 | 1 | 1 | Number of dwellings decreased by one |
| *Predicted actual shadow flicker (recommended limit: 10 hours/year)* | | | | | |
| Above recommended limit | 3 | 3 | 2 | 2 | Number of dwellings decreased by one |
| Above one-third of agreed limit or recommended limit, whichever is greater | 1 | 1 | 0 | 0 | Number of dwellings decreased by one |

As the calculation of the predicted actual shadow flicker duration does not take into account any reduction due to low wind speed, vegetation, or other shielding effects around each house in calculating the number of shadow flicker hours, the values presented may still be regarded as conservative. Moreover, if the turbine selected for the site has dimensions smaller than those considered here, but still within the turbine envelope specified in Section 2.2, shadow flicker durations in the vicinity of the site are likely to be lower than those predicted. The effects of shadow flicker can also be reduced through a number of mitigation measures, if required, to ensure compliance with Condition 17 of the Permit.

# Conclusion

A shadow flicker assessment has been carried out at all dwelling locations within 1.5 km of the proposed SHWF WEF. The results show that, for the amended WEF, eight dwellings are predicted to experience theoretical shadow flicker durations that exceed the limit recommended by the current guidelines and specified in Condition 17 of the Permit. However, all of these dwellings have agreed to accept shadow flicker durations above the limit specified in the Permit. Similarly, two dwellings are predicted to experience actual shadow flicker durations from the amended WEF in excess of the limit recommended in the guidelines, however both of these dwellings have agreed to accept a theoretical shadow flicker limit above that specified in the Permit. Taking these landowner agreements into account, the theoretical shadow flicker durations for the amended WEF are predicted to exceed the applicable limits at only one dwelling, which is a participant dwelling with respect to shadow flicker, while the predicted actual shadow flicker durations are within the applicable limits for all dwelling locations.

These results correspond to an increase in the number of dwellings predicted to experience theoretical shadow flicker durations above the recommended limits by two compared to the permitted WEF, but a decrease in the number of dwellings predicted to experience theoretical shadow flicker durations above the applicable limits once landowner agreements are taken into account by one. The number of dwellings predicted to experience actual shadow flicker above the applicable limits is also decreased by one.

Since a non-reflective finish is proposed for the blades of the wind turbines, as specified by Condition 4(g) of the Permit, blade glint is not expected to be an issue for either the permitted or the amended WEF.

# 1 INTRODUCTION

## 1.1 Project Background

Stockyard Hill Wind Farm Pty Ltd ("SHWFPL") (a subsidiary of Origin Energy) is developing a wind farm project in south-west Victoria, known as the Stockyard Hill Wind Farm (SHWF).

The project has three components - a wind energy facility ("WEF"), a grid connection (approximately 75 km of overhead powerlines and a terminal station), and a quarry. This document relates to the WEF component of the project.

Planning Permit No. PL-SP/05/0548 (Pyrenees Planning Scheme) ("the Permit") was issued by the Minister for Planning on 26 October 2010 to enable the use and development of the SHWF WEF.

SHWFPL has now decided to progress the preparation of an application to amend the Permit under Section 97I of the *Planning and Environment Act 1987*.

The primary driver for the amendment application is to seek approval for taller turbines to achieve more efficient generation of energy.

The application to amend the Permit must consider the anticipated difference in environmental, social, and economic impact (whether an increase or decrease from the permitted project) as a result of the proposed amendments.

## 1.2 Purpose of Document

This document was prepared with the purpose of accompanying an application to amend the Permit, including the assessment of the expected annual shadow flicker duration and any associated impact of blade glint.

This document provides an assessment of the overall impact of proposed amended WEF, whilst also describing the resulting change in potential impact from the permitted WEF.

# 2 THE PROJECT

## 2.1 WEF Site

The WEF site is located in the Pyrenees Shire Council, approximately 150 km west northwest of Melbourne and approximately 35 km west of Ballarat, as shown in Figure 1. The closest townships to the WEF site include Beaufort (approximately 4.5 km north of the site) and Skipton (approximately 4 km south of the site).

The site comprises approximately 155.3 km$^2$ (approximately 45.8 km$^2$ less than the permitted project) and is generally bound by Eurambeen-Streatham Road and Beaufort-Carranballac Road to the west, Stockyard Hill Road and Mt Emu Settlement Road in the south, Mount Emu Creek in the east and Ballrogan Road, Long Gully Road, and Dalgleishs Road in the north. Skipton Road bisects the subject site.

There are 46 dwellings, or 'receptors', located within 1.5 km of the SHWF WEF. The coordinates of dwellings in the vicinity of the Project are presented in Table 4 and are shown in Figure 3 to Figure 12[1]. Any dwelling located on land listed in the Address of Land in the Permit, or where the landowner has a written agreement with SHWFPL relating to their land and dealing with noise or shadow flicker from the permitted wind turbines, is identified in Table 4 and Figure 3 to Figure 12 as a participant dwelling. Any dwelling that is currently owned by SHWFPL or under option to be purchased by SHWFPL is identified as a proponent dwelling.

The SHWF WEF includes a mixture of flat and undulating terrain with hills. The land at the site is mainly used for wheat farming and sheep grazing. There are extensive areas of forestry in the far north of the site, as well as some smaller patches in the east and south. Topography in the general region is dominated by the mountains of the Great Dividing Range which lie to the north and west of the site, with the westernmost part of the Great Dividing Range, the Grampians National Park, lying approximately 60 km to the west of the site.

The northern sections of the site contain the highest concentration of hills with elevations varying from approximately 330 m to 430 m. The central and southern areas of the site contain flatter terrain; however, there are some isolated hills. The centre of the site contains the topographical feature known as Stockyard Hill which is a circular area of elevated land containing a depressed area in the centre known as Black Lake. The south-eastern section of the site contains some notable areas of elevated topography including Monmot Hill and Nanimia Hill. Elevations across the central and southern areas of the site are very similar to the northern area, varying from approximately 320 m to 440 m. Significant areas of state forest are located to the immediate north of the site and approximately 12 km to the southeast.

The elevation contours for the Project are displayed in Figure 3[2].

## 2.2 Permitted and Amended WEF

The Permit was issued by the Minister for Planning in October 2010 to enable the use and development of the SHWF WEF, including up to 157 turbine sites (with a maximum tower height of 80 m, maximum

[1] It should be noted that DNV GL has not carried out a detailed and comprehensive survey of house locations in the area and is relying on information provided by SHWFPL [8].
[2] Detailed elevation data for the area within the WEF boundary has been provided to DNV GL by SHWFPL [9].

blade length of 52 m, and a maximum tip height of 132 m). The Permit is subject to 48 conditions, including the following Condition 17 (which relates to Blade Shadow Flicker[3]):

> *"Shadow flicker from the wind energy facility must not exceed 30 hour per annum at any dwelling existing at the date of the permit.*
>
> *This condition does not apply to any dwelling where a landowner has agreed to the exceedance (This exemption will be given effect through an agreement with the landowner that will apply to any occupant of the dwelling)."*

The amendment is proposed to enable physical changes to the project and amendments to the Permit conditions. The amendments to the Permit, which relate to Shadow Flicker and Blade Glint include:

- Turbine dimensions – a maximum hub height of 120 m and rotor diameter of 140 m, and overall tip height not exceeding 180m.
- Layout – ultimate design for up to 149 wind turbine locations, consisting of the following changes:
    - relocation of three turbines onto three new titles within the centre of the WEF site (adjoining existing permitted address of lands);
    - addition of four new turbine locations within the existing permit address of lands; and
    - deletion of 12 turbine locations.

No amendments are proposed to either Condition 4(g) or Condition 17 of the Permit.

A map of the site is shown in Figure 3, and the coordinates of the permitted and amended turbine locations are presented in Table 5 and Table 6.

[3] There are no permit conditions which relate to Blade Glint, however the Permit does specify that wind turbines must be of non-reflective finish and colour (Condition 4(g)).

# 3 REGULATORY REQUIREMENTS

## 3.1 Shadow Flicker

The Victorian Planning Guidelines [1] currently state;

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

In addition, the EPHC Draft National Wind Farm Development Guidelines released in July 2010 [2] include recommendations for shadow flicker limits relevant to wind farms in Australia.

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

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

These limits are assumed to apply to a single dwelling, and it is noted that there is no requirement under either the Victorian Planning Guidelines or Draft National Guidelines to assess shadow flicker durations at locations other than in the vicinity of dwellings.

The Draft National Guidelines provide background information, a proposed methodology and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm.

The impact of shadow flicker is typically only significant up to a distance of around 10 rotor diameters from a turbine [10] or approximately 800 m to 1400 m for modern wind turbines (which typically have rotor diameters of 80 m to 140 m). Beyond this distance limit the shadow is diffused such that the variation in light levels is not likely to be sufficient to cause annoyance. This issue is discussed in the Draft National Guidelines where it is stated that:

> *"Shadow flicker can theoretically extend many kilometres from a wind turbine. However the intensity of the shadows decreases with distance. While acknowledging that different individuals have different levels of sensitivity and may be annoyed by different levels of shadow intensity, these guidelines limit assessment to moderate levels of intensity (i.e., well above the minimum theoretically detectable threshold) commensurate with the nature of the impact and the environment in which it is experienced."*

The Draft National Guidelines therefore suggest a distance equivalent to 265 maximum blade chords[4] as an appropriate limit, which corresponds to approximately 800 m to 1325 m for modern wind turbines (which typically have maximum blade chord lengths of 3 m to 5 m).

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

## 3.2 Blade Glint

The Draft National Guidelines provide guidance on blade glint and state that:

> *"The sun's light may be reflected from the surface of wind turbine blades. Blade Glint has the potential to annoy people. All major wind turbine manufacturers currently finish their blades with a low reflectivity treatment. This prevents a potentially annoying reflective glint from the surface of the blades and the possibility of a strobing reflection when the turbine blades are spinning. Therefore the risk of blade glint from a new development is considered to be very low."*

# 4 APPROACH

SHWFPL has commissioned DNV GL to complete this assessment based upon two layouts provided for the SHWF WEF: the 'permitted' layout consisting of 157 wind turbines as shown in Figure 3, and an 'amended' layout consisting of 149 wind turbines with a larger turbine type, also shown in Figure 3.

For the purpose of this assessment, an example turbine model with a hub height of 80 m and rotor diameter of 104 m has been considered for the permitted WEF, and a larger turbine model with a hub height of 110 m and rotor diameter of 140 m has been considered for the amended WEF. These dimensions represent the maximum overall tip height within the maximum blade/rotor and tower hub height dimensions.

The results generated based on these turbine configurations will be conservative for all turbine configurations with dimensions that remain inside the turbine envelope by satisfying all of the following criteria:

- a rotor diameter of 140 m or less for the amended layout or 104 m or less for the permitted layout;
- a maximum blade chord of 5.2 m for the amended layout or 3.9 m for the permitted layout;
- an upper blade tip height of 180 m or less for the amended layout or 132 m or less for the permitted layout; and
- a lower tip height of 40 m or greater for the amended layout or 28 m for the permitted layout.

## 4.1 Shadow Flicker

### 4.1.1 Overview

Shadow flicker may occur under certain combinations of geographical position and time of day, when the sun passes behind the rotating blades of a wind turbine and casts a moving shadow over neighbouring areas. When viewed from a stationary position the moving shadows cause periodic flickering of the light from the sun, giving rise to the phenomenon of 'shadow flicker'.

The effect is most noticeable inside buildings, where the flicker appears through a window opening. The likelihood and duration of the effect depends upon a number of factors, including:

- Direction of the property relative to the turbine;
- Distance from the turbine (the further the observer is from the turbine, the less pronounced the effect will be);
- Wind direction (the shape of the shadow will be determined by the position of the sun relative to the blades which will be oriented to face the wind);
- Turbine height and rotor diameter;
- Time of year and day (the position of the sun in the sky);
- Weather conditions (cloud cover reduces the occurrence of shadow flicker).

### 4.1.2 Theoretical Modelled 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 a WEF, and wind turbine details such as rotor diameter and hub height.

The wind turbines have been modelled assuming they are spherical objects, which is equivalent to assuming the turbines are always oriented perpendicular to the sun-turbine vector. This assumption will mean the model calculates the maximum duration for which there is potential for shadow flicker to occur.

In line with the methodology proposed in the Draft National Guidelines, DNV GL has assessed the shadow flicker at the 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 6 m, to represent second floor windows. The shadow receptors are simulated as fixed points, representing the worst case scenario, as real windows would be facing a particular direction. The shadow flicker calculations for dwelling locations have been carried out with a temporal resolution of 1 minute; if shadow flicker is predicted to occur in any 1-minute period, the model records this as 1 minute of shadow flicker. The shadow flicker map was generated using a temporal resolution of 5 minutes to reduce computational requirements to acceptable levels.

As part of the shadow flicker assessment, it is necessary to make an assumption regarding the maximum length of a shadow cast by a wind turbine that is likely to cause annoyance due to shadow flicker. The UK wind industry considers that 10 rotor diameters is appropriate [10], while the Draft National Guidelines suggest a distance equivalent to 265 maximum blade chords as an appropriate limit. For the permitted WEF, which is modelled using the 3.4M104 with a 104 m rotor diameter and a maximum blade chord of 3.85 m, DNV GL has implemented a maximum shadow length of 10 rotor diameters or 1040 m, which is the more conservative assumption. For the amended WEF, which is modelled with the 3.4M140 with a 140 m rotor diameter and a maximum blade chord of 4.15 m, DNV GL has implemented a maximum shadow length of 10 rotor diameters or 1400 m, which again represents the more conservative assumption.

The model also makes the following assumptions and simplifications:

- There are clear skies every day of the year;
- The blades of the turbines are always perpendicular to the direction of the line of sight from the location of interest to the sun;
- The turbines are always rotating.

The first two of these items are addressed in the calculation of the predicted actual shadow flicker duration as described in Section 4.1.4. The third item means that the results generated by the model may be slightly conservative as there will be some periods of time when the turbines are not rotating, but is unlikely to have a significant impact on the results.

The settings used to execute the model can be seen in Table 7.

To illustrate typical results, an indicative shadow flicker map for a turbine located in a relatively flat area is shown in Figure 2. The geometry of the shadow flicker map can be characterised as a butterfly shape, with the four protruding lobes corresponding to slowing of solar north-south travel around the summer and winter solstices for morning and evening. The lobes to the north of the indicative turbine location result from the summer solstice and conversely the lobes to the south result from the winter solstice. The lobes to the west result from morning sun while the lobes to the east result from evening sun. When the sun is low in the sky, the length of shadows cast by the turbine increases, increasing the area around the turbine affected by shadow flicker.

### 4.1.3 Factors Affecting 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, including:

1. The wind turbine will not always be oriented such that its rotor is in the worst case position (i.e. perpendicular to the sun-turbine vector). Any other rotor orientation will reduce the area of the projected shadow and hence the shadow flicker duration.

   The wind speed frequency distribution or wind rose at the site can be used to determine probable turbine orientation and to calculate the resulting reduction in shadow flicker duration.

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

   Cloud cover measurements recorded at nearby meteorological stations may be used to estimate probable levels of cloud cover and to provide an indication of the resulting reduction in shadow flicker duration.

3. Aerosols (moisture, dust, smoke, etc.) in the atmosphere have the ability to influence shadows cast by a wind turbine.

   The length of the shadow cast by a wind turbine is dependent on the degree that direct sunlight is diffused, which is in turn dependent on the amount of dispersants (humidity, smoke, and other aerosols) in the path between the light source (sun) and the receiver.

4. The modelling of the wind turbine rotor as a sphere rather than individual blades results in an overestimate of shadow flicker duration.

   Turbine blades are of non-uniform thickness with the thickest part of the blade (maximum chord) close to the hub and the thinnest part (minimum chord) at the tip. Diffusion of sunlight, as discussed above, results in a limit to the maximum distance that a shadow can be perceived. This maximum distance will also be dependent on the thickness of the turbine blade, and the human threshold for perception of light intensity variation. As such, a shadow cast by the blade tip will be shorter than the shadow cast by the thickest part of the blade.

5. The analysis does not consider that when the sun is positioned directly behind the wind turbine hub, there is no variation in light intensity at the receiver location and therefore no shadow flicker.

6. The presence of vegetation or other physical barriers around a shadow receptor location may shield the view of the wind turbine, and therefore reduce the incidence of shadow flicker.

7. Periods where the wind turbine is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce the annual shadow flicker duration.

### 4.1.4 Predicted Actual Duration

As discussed above in Section 4.1.3, there are a number of factors which may reduce the incidence of shadow flicker, such as cloud cover and variation in turbine orientation, that are not taken into account in the calculation of the theoretical shadow flicker duration. Exclusion of these factors means that the theoretical calculation is likely to be conservative. An attempt has been made to quantify the likely reduction in shadow flicker duration due to these effects and therefore produce a prediction of the actual shadow flicker duration likely to be experienced at a dwelling.

Cloud cover is typically measured in 'oktas' or eighths of the sky covered with cloud. DNV GL has obtained data from several Bureau of Meteorology (BoM) stations. Those that were deemed appropriate for use were located a distance of approximately 28 km to 32 km from the site [11, 12], with twice daily approximations of the percentage of cloud cover visible across the sky. The results show that the average annual cloud cover values obtained from readings at 9 am and 3 pm for the two available stations, at Ararat and Ballarat, range between 3.7 and 6.0 oktas. On an average day, 5.1/8 or approximately 63% of the sky in the vicinity of the wind farm is covered with clouds. Although it is not possible to definitively calculate the effect of cloud cover on shadow flicker duration, a reduction in the shadow flicker duration proportional to the amount of cloud cover is a reasonable assumption. An assessment of the likely reduction in shadow flicker duration due to cloud cover was conducted on a monthly basis, which indicated that a reduction of 50% to 72% is expected at the affected dwellings.

Similarly, turbine orientation can have an impact on the shadow flicker duration. The shadow flicker impact is greatest when the turbine rotor plane is approximately perpendicular to a line joining the sun and an observer, and a minimum when the rotor plane is approximately parallel to a line joining the sun and an observer. A wind direction frequency distribution previously derived by DNV GL from data collected by masts on site was used to estimate the reduction in shadow flicker duration due to rotor orientation. The measured wind rose is shown overlaid on the indicative shadow flicker map in Figure 2. An assessment of the likely reduction in shadow flicker duration due to variation in turbine orientation was conducted on an annual basis, which indicated that a reduction of 29% to 87% can be expected at the affected dwelling locations.

It should be noted that the method prescribed by the Draft National Guidelines for assessing actual shadow flicker duration recommends that only reductions due to cloud cover, and not turbine orientation, be included. However, DNV GL considers that this additional reduction due to turbine orientation is appropriate as the projected area of the turbine, and therefore the expected shadow flicker duration, is reduced when the turbine rotor is not perpendicular to the line joining the sun and dwelling.

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in calculating the shadow flicker duration. Similarly, turbine shutdown has not been considered. It is therefore likely that the adjusted shadow flicker durations presented here can still be regarded as a conservative assessment.

### 4.1.5 Limits

As discussed in Section 3.1, the Victorian Planning Guidelines [1] recommend a shadow flicker limit of 30 hours per year in the area immediately surrounding a dwelling. In addition, the Draft National Guidelines [2] 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. Condition 17 of the Permit issued for the use and development of the SHWF WEF also specifies a shadow flicker limit of 30 hours per year at any dwelling in the vicinity of the WEF, although this condition does not apply to dwellings where the landowner has agreed to accept shadow flicker durations in excess of this limit.

SHWFPL has informed DNV GL that, in accordance with Condition 17 of the Permit, a number of landowners have agreed to accept a shadow flicker limit of greater than 30 hours per year. The agreed shadow flicker limits for these dwellings, as provided by SHWFPL, are shown in in Table 4. SHWFPL have also advised that several dwellings in the vicinity of the WEF are not subject to shadow flicker limits, as a consequence of being owned by SHWFPL or having contractual arrangements in place stating that the building will not be used as a residential dwelling for the operational life of the WEF. Those dwellings that require no shadow flicker limit are identified in Table 4, but have not been considered in this assessment.

For the purpose of this assessment, DNV GL has assumed that the agreed limits provided by SHWFPL apply to the theoretical shadow flicker duration only, and that the limit on the actual shadow flicker for these dwellings is equal to one-third of the agreed limit. This is consistent with the approach taken by the Draft National Guidelines, where the recommended limit on the actual shadow flicker duration of 10 hours per year is one-third of the recommended limit on the theoretical shadow flicker duration.

For dwellings where no shadow flicker agreement has been obtained, the limit on the theoretical shadow flicker duration has been maintained at 30 hours per year as recommended by the Victorian Guidelines and specified in Condition 17 of the Permit, and the limit on the actual shadow flicker duration has been maintained at 10 hours per year as recommended by the Draft National Guidelines.

## 4.2 Blade Glint

Blade glint involves the regular reflection of the sun off rotating turbine blades. Its occurrence depends on a combination of circumstances arising from the orientation of the nacelle, angle of the blade, and the angle of the sun. The reflectiveness of the surface of the blades is also important. As discussed, blade glint is not generally a problem for modern wind turbines, provided the blades are coated with a non-reflective paint.

# 5 ASSESSMENT

## 5.1 Shadow Flicker

A shadow flicker assessment was carried out at all dwelling locations, or 'receptors', located within 1.5 km of the proposed SHWF WEF, as outlined in Table 4.

The theoretical predicted shadow flicker durations at all dwellings identified to be affected by shadow flicker are presented in Table 8 and Table 9. The maximum predicted theoretical shadow flicker durations within 50 m of these receptors are also presented in these tables. Results are displayed only for dwellings that are predicted to receive shadow flicker from either of the two turbine layouts considered. The results are presented in the form of shadow flicker maps at 2 m and 6 m above ground for the permitted WEF and the amended WEF in Figure 4, Figure 5, Figure 8, and Figure 9 respectively. Additionally, the results are presented in the form of shadow flicker duration contours in Figure 6, Figure 7, Figure 10, and Figure 11. The difference in 'allowable' shadow flicker duration (less than 30 hours per year) between the previously permitted layout and the current amended layout at a height of 2 m is displayed in Figure 12.

The results indicate that several dwellings in the vicinity of the SHWF WEF, including 17 dwellings for the permitted WEF and 21 dwellings for the amended WEF, are predicted to experience some shadow flicker based on the methodology recommended by the Draft National Guidelines. A number of these dwellings are predicted to experience a theoretical shadow flicker duration in excess of the limit of 30 hours per year within 50 m of the dwelling location recommended by the Victorian Planning Guidelines and specified in Condition 17 of the Permit, as summarised in Table 1 below. However, all dwellings where the recommended or specified limits have been exceeded have entered into agreements with SHWFPL to accept shadow flicker durations above the specified limit, as allowed by the Permit. The agreed shadow flicker limits are presented in Table 8 and Table 9. Taking these landowner agreements into account, the theoretical shadow flicker durations are predicted to exceed the applicable limits at two dwellings for the permitted WEF (dwellings B127 and B169) but only one dwelling for the amended WEF (dwelling B140), which has been identified as a participant and has agreed to accept a shadow flicker duration greater than the specified limit.

**Table 1 Number of dwellings predicted to experience theoretical shadow flicker above the applicable limits for the permitted and amended SHWF WEF**

| Predicted theoretical shadow flicker within 50 m of dwelling | Permitted Layout | | Amended Layout | |
|---|---|---|---|---|
| | Total number of dwellings | Number of dwellings with agreed limit > 30 hours/year | Total number of dwellings | Number of dwellings with agreed limit > 30 hours/year |
| Above recommended limit (> 30 hours/year) | 6 | 6 | 8 | 8 |
| Above agreed limit or recommended limit, whichever is greater | 2 | 2 | 1 | 1 |

An assessment of the level of conservatism associated with the theoretical results has been conducted by calculating the possible reduction in shadow flicker duration due to turbine orientation (based on the wind rose measured at the site) and cloud cover. These adjusted results are presented as predicted actual shadow flicker durations in Table 8 and Table 9. Consideration of turbine orientation and cloud cover reduces the predicted shadow flicker duration by 70% to 96% at the dwellings affected by shadow flicker.

After reductions due to turbine orientation and cloud cover are taken into account, several dwellings are predicted to experience an actual shadow flicker duration greater than the limit of 10 hours per year within 50 m of the dwelling location recommended by the Draft National Guidelines, as summarised in Table 2 below. However, for both the permitted and amended WEF, all dwellings where the recommended limit is exceeded have entered into agreements with SHWFPL to accept shadow flicker durations above than the limit specified in Condition 17 of the Permit for theoretical shadow flicker duration. As discussed in Section 4.1.5, it has been assumed that the limit on the predicted actual shadow flicker duration for these dwellings can be taken as one-third of the agreed limit, which, for the shadow flicker limits provided by SHWFPL and shown in Table 4, is equal to double the recommended limit of 10 hours per year. Based on this assumption, the predicted actual shadow flicker duration is still greater than the assumed limit at one dwelling location for the permitted WEF, but is within the applicable limits at all dwelling locations for the amended WEF.

**Table 2 Number of dwellings predicted to experience actual shadow flicker above the applicable limits for the permitted and amended SHWF WEF**

| Predicted actual shadow flicker within 50 m of dwelling | Permitted Layout | | Amended Layout | |
|---|---|---|---|---|
| | Total number of dwellings | Number of dwellings with agreed limit > 30 hours/year | Total number of dwellings | Number of dwellings with agreed limit > 30 hours/year |
| Above recommended limit (> 10 hours/year) | 3 | 3 | 2 | 2 |
| Above one-third of agreed limit or recommended limit, whichever is greater | 1 | 1 | 0 | 0 |

Compared to the permitted WEF, the amended WEF increases the number of dwellings that are predicted to experience theoretical shadow flicker durations above the limit recommended by the Draft National Guidelines and specified in Condition 17 of the Permit. This is suggested by Figure 12, which shows that the overall area affected by shadow flicker is greater for the amended WEF than for the permitted WEF as a consequence of the larger turbines proposed for the amended WEF. However, the shadow flicker duration in some areas is reduced or eliminated due to the relocation or removal of turbines, and the amended WEF decreases the number of dwellings that are expected to experience theoretical shadow flicker durations that exceed the applicable limit once landowner agreements to accept shadow flicker durations above the specified limit have been taken into account. When reductions due to turbine orientation and cloud cover are considered, the amended WEF also decreases the number of dwellings that are predicted to experience actual shadow flicker durations above the limit recommended by the Draft National Guidelines. Based on the assumption that the predicted actual shadow flicker limit can be taken as equal to one-third of the theoretical shadow flicker limit, it is expected that the actual shadow flicker durations for the amended WEF will be within those allowed by Condition 17 the Permit at all dwellings.

If shadow flicker presents a problem, its effects can be reduced through a number of measures to ensure compliance with Condition 17 of the Permit. These include 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, or micrositing of turbines.

## 5.2 Blade Glint

As discussed in Section 4.2, blade glint is not generally a problem for modern wind turbines provided that the blades are coated with a non-reflective paint. Since Condition 4(g) of the Permit specifies that the wind turbines for the SHWF WEF must be of non-reflective finish and colour, and no amendments are proposed to this condition, it is expected that any blade glint associated with the amended WEF will be the same as for the permitted WEF.

# 6 CONCLUSION

An analysis has been conducted to determine the annual duration of shadow flicker experienced at dwellings in the vicinity of the SHWF WEF, based on the methodology proposed in the Draft National Guidelines. The results of the assessment are presented in the form of shadow flicker maps, in Figure 4 to Figure 11. The shadow flicker results for each house location predicted to be affected by shadow flicker are also listed in Table 8 and Table 9, and are summarised in Table 3 below.

**Table 3 Summary of shadow flicker assessment results for the proposed SHWF WEF**

| Predicted shadow flicker within 50 m of dwelling | Number of dwellings affected | | | | Anticipated change |
|---|---|---|---|---|---|
| | Permitted Layout | | Amended Layout | | |
| | Total | Dwellings with agreed limit > 30 hours/year | Total | Dwellings with agreed limit > 30 hours/year | |
| Any shadow flicker (> 0 hours/year) | 17 | 17 | 21 | 18 | Number of dwellings increased by four |
| *Predicted theoretical shadow flicker (recommended/specified limit: 30 hours/year)* | | | | | |
| Above recommended limit | 6 | 6 | 8 | 8 | Number of dwellings increased by two |
| Above agreed or recommended limit, whichever is greater | 2 | 2 | 1 | 1 | Number of dwellings decreased by one |
| *Predicted actual shadow flicker (recommended limit: 10 hours/year)* | | | | | |
| Above recommended limit | 3 | 3 | 2 | 2 | Number of dwellings decreased by one |
| Above one-third of agreed limit or recommended limit, whichever is greater | 1 | 1 | 0 | 0 | Number of dwellings decreased by one |

Compared to the permitted WEF, the amended WEF increases by two the number of dwellings that are predicted to experience theoretical shadow flicker durations above the limit recommended by the Victorian Planning Guidelines and specified in Condition 17 of the Permit. However, the number of dwellings that are expected to experience theoretical shadow flicker durations above the applicable limits once landowner agreements are taken into account decreases by one. The amended WEF also decreases by one the number of dwellings that are predicted to experience actual shadow flicker durations above the applicable limits, both before and after the relevant landowner agreements are considered.

It should be noted that the calculation of predicted actual shadow flicker duration does not take into account any reduction in shadow flicker hours due to low wind speed, vegetation, or other shielding effects. Therefore, the values presented may still be regarded as a conservative assessment.

If shadow flicker presents a problem, mitigation strategies to reduce the duration of shadow flicker experienced at a dwelling and ensure compliance with Condition 17 of the Permit can include: installation of screening structures or planting of trees to block shadows cast by the turbines, use of turbine control strategies which shut down turbines when shadow flicker is likely to occur, or relocation of turbines.

Blade glint is not likely to be an issue for either the permitted or amended WEF, as non-reflective coatings are proposed to be used on the turbine blades in accordance with Condition 4(g) of the Permit.

# 7 REFERENCES


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3. "Influences of the opaqueness of the atmosphere, the extension of the sun and the rotor blade profile on the shadow impact of wind turbines", Freund H-D, Kiel F.H., DEWI Magazine No. 20, Feb 2002, pp43-51.
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12. "Climate statistics for Australian locations – Ballarat Aerodrome", Bureau of Meteorology, viewed 19 November 2015, http://www.bom.gov.au/climate/averages/tables/cw_089002_All.shtml

# List of Tables



# List of Figures

**Table 4 Dwelling locations within 1.5 km of turbines at the proposed SHWF WEF [8] – continued**

| House ID[1] | Easting[2] [m] | Northing[2] [m] | Status | Shadow Flicker Limit[3] | Distance to nearest turbine (permitted layout) [km] | Distance to nearest turbine (amended layout) [km] |
|---|---|---|---|---|---|---|
| B027 | 713027 | 5850072 | Non-participant | 30 hours | 1198 | 1220 |
| B028 | 712786 | 5850338 | Non-participant | 30 hours | 1298 | 1319 |
| B029 | 712701 | 5850234 | Non-participant | 30 hours | 1169 | 1190 |
| B030 | 712790 | 5850384 | Non-participant | 30 hours | 1342 | 1363 |
| *B053* | *711656* | *5847683* | *Participant* | *60 hours* | *812* | *1034* |
| **B057** | **709858** | **5848031** | **Proponent** | **No limit** | **360** | **193** |
| *B058* | *709623* | *5846924* | *Participant* | *60 hours* | *799* | *1013* |
| B061 | 711434 | 5846970 | Non-participant | 30 hours | 1498 | 1718 |
| *B064* | *710107* | *5842201* | *Participant* | *60 hours* | *987* | *976* |
| *B080* | *714306* | *5834879* | *Participant* | *60 hours* | *725* | *831* |
| B083 | 712039 | 5835649 | Non-participant | 30 hours | 1232 | 1759 |
| *B097* | *708404* | *5839745* | *Participant* | *60 hours* | *784* | *636* |
| B098 | 708496 | 5840559 | Non-participant | 30 hours | 1444 | 1356 |
| *B102* | *715232* | *5831362* | *Participant* | *60 hours* | *1126* | *1222* |
| *B103* | *714106* | *5831545* | *Participant* | *60 hours* | *927* | *1245* |
| *B104* | *710991* | *5832179* | *Participant* | *60 hours* | *1053* | *1158* |
| B110 | 705895 | 5851752 | Non-participant | 30 hours | 1536 | 1305 |
| *B112* | *704918* | *5849066* | *Participant* | *60 hours* | *1512* | *1412* |
| B114 | 703278 | 5849485 | Non-participant | 30 hours | 1510 | 1497 |
| B118 | 698274 | 5850428 | Non-participant | 30 hours | 1197 | 1579 |
| *B119* | *698409* | *5850995* | *Participant (shadow flicker only)* | *60 hours* | *789* | *1123* |
| *B120* | *699102* | *5852320* | *Participant* | *60 hours* | *590* | *590* |
| B122 | 698915 | 5853297 | Non-participant | 30 hours | 1302 | 1280 |
| *B124* | *695961* | *5853202* | *Participant* | *60 hours* | *909* | *1008* |
| B125 | 695651 | 5853628 | Non-participant | 30 hours | 1321 | 1366 |
| *B127* | *696999* | *5851953* | *Participant* | *60 hours* | *471* | *694* |
| *B140* | *706705* | *5846346* | *Participant* | *60 hours* | *808* | *833* |
| B141 | 707855 | 5845963 | Non-participant | 30 hours | 1467 | 1445 |
| *B143* | *703669* | *5844423* | *Participant* | *60 hours* | *838* | *1234* |
| *B144* | *703729* | *5844762* | *Participant* | *60 hours* | *983* | *1506* |
| *B145* | *705091* | *5843052* | *Participant* | *60 hours* | *774* | *865* |
| *B146* | *705384* | *5841864* | *Participant* | *60 hours* | *885* | *1033* |
| **B148** | **703243** | **5842092** | **Proponent** | **No limit** | **881** | **367** |
| *B149* | *701380* | *5842799* | *Participant* | *60 hours* | *651* | *973* |
| *B168* | *701154* | *5837552* | *Participant* | *60 hours* | *673* | *959* |
| *B169* | *699647* | *5837851* | *Participant (noise only)* | *30 hours* | *675* | *845* |
| *B170* | *699004* | *5837890* | *Participant* | *60 hours* | *683* | *876* |

[1] Participant dwellings are indicated by *underlined italic text*. Proponent dwellings are indicated by **bold text**
[2] Coordinate system: MGA Zone 54, GDA94 datum.
[3] Limits provided by SHWFPL, and assumed to apply to theoretical shadow flicker duration only. Dwellings with no limit have not been considered in this assessment. See Section 4.1.5 for further details.

**Table 4 Dwelling locations within 1.5 km of turbines at the proposed SHWF WEF - concluded**

| House ID[1] | Easting[2] [m] | Northing[2] [m] | Status | Shadow Flicker Limit[3] | Distance to nearest turbine (permitted layout) [km] | Distance to nearest turbine (amended layout) [km] |
|---|---|---|---|---|---|---|
| *B171* | *697423* | *5837889* | *Participant* | *60 hours* | *1474* | *1621* |
| *B203* | *701684* | *5836682* | *Participant* | *60 hours* | *841* | *885* |
| *B245* | *701784* | *5837154* | *Participant* | *60 hours* | *966* | *1101* |
| *B318* | *710635* | *5849884* | *Participant (noise only)* | *30 hours* | *640* | *858* |
| *B322* | *715703* | *5831166* | *Participant* | *60 hours* | *1305* | *1416* |
| B328 | 712415 | 5850552 | Non-participant | 30 hours | 1409 | 1428 |
| *B343* | *697991* | *5838011* | *Participant* | *60 hours* | *980* | *1170* |
| *B345* | *705393* | *5841802* | *Participant* | *60 hours* | *923* | *1071* |
| B366 | 705718 | 5852253 | Non-participant | 30 hours | 1368 | 1178 |

[1] Participant dwellings are indicated by *underlined italic text*. Proponent dwellings are indicated by **bold text**
[2] Coordinate system: MGA Zone 54, GDA94 datum.
[3] Limits provided by SHWFPL, and assumed to apply to theoretical shadow flicker duration only. Dwellings with no limit have not been considered in this assessment. See Section 4.1.5 for further details.

**Table 5 Permitted turbine layout for the SHWF WEF [4] - continued**

| Turbine ID | Easting[1] [m] | Northing[1] [m] | Base Elevation [m] | Turbine ID | Easting[1] [m] | Northing[1] [m] | Base Elevation [m] |
|---|---|---|---|---|---|---|---|
| T1 | 696868 | 5853108 | 363 | T64 | 709896 | 5847674 | 371 |
| T2 | 696940 | 5852658 | 353 | T65 | 706695 | 5847427 | 397 |
| T3 | 703137 | 5852595 | 403 | T66 | 706210 | 5847386 | 401 |
| T4 | 697977 | 5852393 | 361 | T67 | 707298 | 5847319 | 375 |
| T6 | 703358 | 5852221 | 403 | T68 | 705785 | 5847306 | 394 |
| T7 | 697402 | 5852197 | 364 | T69 | 705309 | 5847200 | 389 |
| T8 | 703914 | 5852120 | 395 | T70 | 706124 | 5846908 | 388 |
| T9 | 702772 | 5852079 | 403 | T71 | 704536 | 5846907 | 357 |
| T10 | 699612 | 5852021 | 387 | T72 | 704978 | 5846874 | 380 |
| T11 | 704373 | 5851985 | 399 | T74 | 709981 | 5845071 | 364 |
| T16 | 702178 | 5851857 | 390 | T75 | 710638 | 5844993 | 373 |
| T19 | 702955 | 5851498 | 378 | T76 | 711338 | 5844676 | 381 |
| T20 | 699335 | 5851479 | 355 | T77 | 709978 | 5844414 | 359 |
| T22 | 699165 | 5851229 | 349 | T78 | 711801 | 5844214 | 380 |
| T24 | 702970 | 5850998 | 369 | T79 | 710846 | 5844106 | 366 |
| T27 | 704743 | 5850634 | 393 | T80 | 704433 | 5844074 | 375 |
| T30 | 704408 | 5850488 | 388 | T81 | 712367 | 5844039 | 370 |
| T33 | 708019 | 5849599 | 390 | T82 | 713221 | 5843935 | 353 |
| T37 | 711039 | 5849388 | 392 | T84 | 704924 | 5843925 | 387 |
| T39 | 710215 | 5849187 | 389 | T85 | 711549 | 5843735 | 372 |
| T40 | 712257 | 5849155 | 408 | T86 | 712122 | 5843643 | 371 |
| T41 | 709859 | 5848959 | 373 | T87 | 701948 | 5843413 | 354 |
| T43 | 708113 | 5848895 | 401 | T88 | 711108 | 5843206 | 363 |
| T44 | 707007 | 5848842 | 386 | T89 | 704326 | 5843181 | 378 |
| T45 | 706620 | 5848796 | 377 | T90 | 703129 | 5843074 | 377 |
| T46 | 711066 | 5848788 | 425 | T91 | 703682 | 5843074 | 387 |
| T48 | 707436 | 5848739 | 400 | T92 | 712003 | 5843027 | 356 |
| T50 | 709894 | 5848580 | 371 | T93 | 710992 | 5842642 | 355 |
| T51 | 707730 | 5848580 | 410 | T94 | 702005 | 5842614 | 361 |
| T52 | 712461 | 5848570 | 403 | T95 | 703975 | 5842584 | 386 |
| T53 | 710545 | 5848561 | 383 | T96 | 704597 | 5842272 | 388 |
| T55 | 711018 | 5848407 | 415 | T97 | 702236 | 5842078 | 367 |
| T56 | 708245 | 5848375 | 387 | T98 | 701711 | 5841977 | 361 |
| T57 | 707949 | 5848373 | 406 | T99 | 701240 | 5841808 | 356 |
| T58 | 706735 | 5848344 | 369 | T101 | 702617 | 5841384 | 376 |
| T59 | 712142 | 5848334 | 391 | T103 | 703947 | 5841234 | 393 |
| T60 | 707816 | 5847982 | 400 | T104 | 703257 | 5841109 | 386 |
| T61 | 708355 | 5847951 | 366 | T106 | 701156 | 5841036 | 363 |
| T62 | 709347 | 5847730 | 363 | T107 | 701787 | 5840921 | 373 |
| T63 | 706988 | 5847683 | 392 | T110 | 702393 | 5840813 | 378 |

[1] Coordinate system: MGA zone 54, GDA94 datum.

**Table 5 Permitted turbine layout for the SHWF WEF – concluded**

| Turbine ID | Easting[1] [m] | Northing[1] [m] | Base Elevation [m] | Turbine ID | Easting[1] [m] | Northing[1] [m] | Base Elevation [m] |
|---|---|---|---|---|---|---|---|
| T111 | 704465 | 5840771 | 422 | T195 | 713665 | 5833810 | 363 |
| T112 | 703908 | 5840683 | 399 | T196 | 712709 | 5833724 | 394 |
| T114 | 703538 | 5840538 | 393 | T197 | 711241 | 5833645 | 374 |
| T115 | 702966 | 5840440 | 387 | T198 | 714421 | 5833566 | 348 |
| T117 | 701229 | 5840325 | 361 | T199 | 712328 | 5833462 | 414 |
| T119 | 703841 | 5840174 | 404 | T200 | 713064 | 5833446 | 397 |
| T120 | 701949 | 5840148 | 372 | T201 | 710814 | 5833400 | 358 |
| T122 | 698261 | 5840040 | 334 | T202 | 713599 | 5833261 | 374 |
| T124 | 702672 | 5839840 | 381 | T203 | 711328 | 5833175 | 420 |
| T125 | 699006 | 5839809 | 340 | T204 | 714854 | 5833145 | 343 |
| T126 | 700843 | 5839741 | 362 | T205 | 713165 | 5833124 | 398 |
| T129 | 703356 | 5839589 | 388 | T206 | 711830 | 5833093 | 404 |
| T130 | 701542 | 5839580 | 366 | T207 | 713877 | 5832973 | 361 |
| T131 | 698132 | 5839579 | 342 | T208 | 712890 | 5832883 | 398 |
| T132 | 709657 | 5839599 | 357 | T209 | 712436 | 5832864 | 412 |
| T135 | 707737 | 5839332 | 364 | T210 | 713448 | 5832852 | 378 |
| T136 | 702230 | 5839323 | 371 | T211 | 715370 | 5832803 | 350 |
| T138 | 699985 | 5839305 | 356 | T212 | 709619 | 5832669 | 340 |
| T141 | 700575 | 5839230 | 365 | T213 | 713943 | 5832540 | 362 |
| T142 | 699342 | 5839207 | 350 | T214 | 715999 | 5832529 | 349 |
| T147 | 709017 | 5839030 | 359 | T215 | 709211 | 5832495 | 337 |
| T148 | 702781 | 5838952 | 381 | T216 | 713462 | 5832416 | 369 |
| T149 | 698237 | 5839117 | 339 | T217 | 713058 | 5832406 | 380 |
| T151 | 699851 | 5838823 | 353 | T219 | 712599 | 5832185 | 373 |
| T154 | 700519 | 5838761 | 364 | T220 | 709670 | 5831931 | 338 |
| T155 | 701240 | 5838729 | 362 | T223 | 712047 | 5831876 | 364 |
| T156 | 698666 | 5838721 | 346 | T225 | 712595 | 5831692 | 364 |
| T157 | 702175 | 5838677 | 369 | T226 | 713177 | 5831549 | 363 |
| T163 | 699236 | 5838531 | 350 | T229 | 711479 | 5831186 | 352 |
| T168 | 700233 | 5838255 | 354 | T232 | 712488 | 5830972 | 351 |
| T169 | 701018 | 5838210 | 354 | T233 | 713258 | 5830831 | 355 |
| T173 | 701717 | 5838266 | 358 | T235 | 713814 | 5830566 | 355 |
| T177 | 700362 | 5837333 | 333 | T238 | 714641 | 5830405 | 353 |
| T179 | 699904 | 5837228 | 329 | T239 | 712357 | 5830193 | 337 |
| T182 | 700861 | 5836863 | 331 | T240 | 713134 | 5830081 | 347 |
| T188 | 712785 | 5834669 | 368 | T241 | 713824 | 5829942 | 347 |
| T191 | 713251 | 5834205 | 362 | T242 | 714525 | 5829811 | 342 |
| T192 | 714223 | 5834160 | 350 | | | | |
| T193 | 712655 | 5834138 | 385 | | | | |
| T194 | 712261 | 5833993 | 384 | | | | |

[1] Coordinate system: MGA zone 54, GDA94 datum.

**Table 6 Amended turbine layout for the SHWF WEF [5] - continued**

| Turbine ID | Easting[1] [m] | Northing[1] [m] | Base Elevation [m] | Turbine ID | Easting[1] [m] | Northing[1] [m] | Base Elevation [m] |
|---|---|---|---|---|---|---|---|
| A1 | 701970 | 5851867 | 394 | F7 | 697918 | 5839649 | 328 |
| A2 | 702658 | 5852068 | 405 | G1 | 702406 | 5840754 | 379 |
| A3 | 702934 | 5851497 | 379 | G2 | 702091 | 5840217 | 374 |
| A4 | 703087 | 5852543 | 409 | G3 | 701554 | 5839757 | 366 |
| A5 | 703596 | 5852201 | 410 | G4 | 701578 | 5839096 | 364 |
| A6 | 704067 | 5852005 | 416 | G5 | 701099 | 5838869 | 363 |
| A7 | 704594 | 5851892 | 426 | G6 | 700212 | 5838479 | 356 |
| A8 | 699612 | 5852021 | 387 | G7 | 699336 | 5838700 | 349 |
| A9 | 699390 | 5851545 | 356 | H1 | 702753 | 5839828 | 383 |
| A10 | 698013 | 5852388 | 360 | H2 | 702915 | 5838918 | 379 |
| A11 | 697535 | 5852650 | 345 | H3 | 702311 | 5839261 | 373 |
| A12 | 696914 | 5852640 | 353 | H4 | 702305 | 5838649 | 367 |
| A13 | 696970 | 5853262 | 353 | H5 | 701753 | 5838374 | 360 |
| A14 | 702961 | 5850946 | 368 | H6 | 700028 | 5837050 | 327 |
| A15 | 704533 | 5850422 | 405 | H7 | 700797 | 5836663 | 329 |
| B1 | 702763 | 5841264 | 380 | I1 | 703046 | 5840522 | 389 |
| B2 | 703420 | 5841212 | 388 | I2 | 703567 | 5840557 | 393 |
| B3 | 703485 | 5841740 | 387 | I3 | 703965 | 5841397 | 393 |
| B4 | 703968 | 5842414 | 386 | I4 | 704651 | 5840903 | 436 |
| B5 | 704476 | 5842359 | 387 | I5 | 704140 | 5840608 | 401 |
| B6 | 704167 | 5843295 | 370 | I6 | 703881 | 5839976 | 400 |
| B7 | 704971 | 5843907 | 388 | I7 | 703445 | 5839409 | 392 |
| C1 | 702454 | 5841969 | 372 | J1 | 710426 | 5848610 | 375 |
| C2 | 702900 | 5842225 | 373 | J2 | 710225 | 5849113 | 387 |
| C3 | 703463 | 5842528 | 382 | J3 | 711174 | 5848720 | 428 |
| C4 | 703683 | 5843029 | 388 | J4 | 711186 | 5849226 | 392 |
| C5 | 703127 | 5842919 | 378 | J5 | 712244 | 5849137 | 409 |
| C6 | 702608 | 5842843 | 366 | J6 | 712356 | 5848444 | 401 |
| C7 | 701943 | 5843592 | 353 | K1 | 709970 | 5847874 | 371 |
| D1 | 702129 | 5841376 | 369 | K2 | 709861 | 5848586 | 371 |
| D2 | 701795 | 5841798 | 361 | K3 | 709736 | 5849070 | 368 |
| D3 | 701242 | 5841562 | 358 | K4 | 708283 | 5848579 | 371 |
| D4 | 699605 | 5839811 | 347 | K5 | 708248 | 5849092 | 380 |
| D5 | 699070 | 5839935 | 340 | K6 | 708058 | 5849561 | 392 |
| E1 | 701107 | 5840803 | 361 | L1 | 709263 | 5847903 | 364 |
| E2 | 701345 | 5840315 | 364 | L2 | 708463 | 5847573 | 366 |
| E3 | 700969 | 5839898 | 364 | L3 | 708518 | 5848087 | 365 |
| E4 | 700750 | 5839386 | 358 | L4 | 707943 | 5847939 | 395 |
| E5 | 699995 | 5839374 | 354 | L5 | 707771 | 5848564 | 414 |
| E6 | 698674 | 5839618 | 341 | L6 | 707279 | 5848336 | 388 |
| E7 | 698244 | 5840083 | 334 | L7 | 706700 | 5848304 | 368 |
| F1 | 701686 | 5840831 | 373 | M1 | 707415 | 5847830 | 392 |
| F2 | 700448 | 5838975 | 365 | M2 | 707000 | 5847645 | 394 |
| F3 | 699878 | 5838908 | 353 | M3 | 707325 | 5847306 | 374 |
| F4 | 699322 | 5839251 | 351 | M4 | 706643 | 5847404 | 397 |
| F5 | 698765 | 5838888 | 346 | M5 | 706178 | 5847399 | 399 |
| F6 | 698366 | 5839207 | 341 | M6 | 705657 | 5847248 | 391 |

[1] Coordinate system: MGA zone 54, GDA94 datum.

**Table 6 Amended turbine layout for the SHWF WEF - concluded**

| Turbine ID | Easting[1] [m] | Northing[1] [m] | Base Elevation [m] | Turbine ID | Easting[1] [m] | Northing[1] [m] | Base Elevation [m] |
|---|---|---|---|---|---|---|---|
| M7 | 706020 | 5846821 | 381 | R6 | 713443 | 5834084 | 361 |
| N1 | 710101 | 5844908 | 365 | S1 | 711819 | 5832989 | 395 |
| N2 | 709880 | 5844452 | 360 | S2 | 711409 | 5833292 | 412 |
| N3 | 710626 | 5844786 | 372 | S3 | 711050 | 5833660 | 365 |
| N4 | 710355 | 5844267 | 361 | S4 | 710612 | 5833401 | 352 |
| N5 | 709710 | 5839595 | 356 | S5 | 709511 | 5832837 | 336 |
| N6 | 709035 | 5838816 | 358 | S6 | 709045 | 5832608 | 334 |
| N7 | 707918 | 5839334 | 363 | T1 | 712356 | 5832208 | 373 |
| O1 | 710924 | 5844017 | 365 | T2 | 712485 | 5831487 | 361 |
| O2 | 711505 | 5843838 | 373 | T3 | 712393 | 5830780 | 348 |
| O3 | 712086 | 5843715 | 372 | T4 | 712323 | 5830287 | 341 |
| O4 | 711783 | 5843045 | 356 | T5 | 711536 | 5830952 | 347 |
| O5 | 711274 | 5843205 | 364 | T6 | 709467 | 5831817 | 336 |
| O6 | 710958 | 5842681 | 356 | U1 | 712846 | 5832338 | 380 |
| P1 | 711386 | 5844646 | 380 | U2 | 713076 | 5830672 | 352 |
| P2 | 711996 | 5844324 | 381 | U3 | 712910 | 5830158 | 346 |
| P3 | 712567 | 5844036 | 366 | U4 | 713649 | 5830388 | 352 |
| P4 | 713180 | 5844022 | 354 | U5 | 713936 | 5829969 | 349 |
| Q1 | 712736 | 5832837 | 401 | U6 | 714438 | 5829859 | 342 |
| Q2 | 713114 | 5833173 | 397 | U7 | 714540 | 5830355 | 351 |
| Q3 | 713566 | 5833496 | 372 | V1 | 713303 | 5832554 | 377 |
| Q4 | 713904 | 5833871 | 358 | V2 | 713580 | 5832976 | 374 |
| Q5 | 714394 | 5834054 | 348 | V3 | 714056 | 5833144 | 356 |
| R1 | 712247 | 5832704 | 399 | V4 | 714504 | 5833560 | 346 |
| R2 | 712275 | 5833249 | 420 | V5 | 714973 | 5833364 | 342 |
| R3 | 712257 | 5833760 | 393 | V6 | 715577 | 5832941 | 348 |
| R4 | 712717 | 5834028 | 389 | V7 | 716240 | 5832587 | 344 |
| R5 | 713079 | 5833676 | 388 | | | | |

[1] Coordinate system: MGA zone 54, GDA94 datum.

**Table 7 Shadow flicker model settings for theoretical shadow flicker calculation**

| Model Setting | Value |
|---|---|
| Maximum shadow length | 1040 m (permitted layout)<br>1400 m (amended layout) |
| Year of calculation | 2027 |
| Minimum elevation of the sun | 3° |
| Time step | 1 min<br>(5 min for map) |
| Rotor modelled as | Sphere<br>(Disc for turbine orientation reduction calculation) |
| Sun modelled as | Disc |
| Offset between rotor and tower | None |
| Receptor height (single storey) | 2 m |
| Receptor height (double storey) | 6 m |
| Locations used for determining maximum shadow flicker within 50 m of each dwelling[1] | 25 m grid centred on house location |

[1] In addition to the 25 m resolution grid points, points were added every 45° on a 50 m radius circle centred on the house location.

**Table 8 Theoretical and predicted actual annual shadow flicker durations for dwellings affected by shadow flicker with the permitted layout configuration - continued**

| House ID[1] | Easting[2] [m] | Northing[2] [m] | Applicable shadow flicker limit (theoretical) [hr/yr] | Contributing Turbines | Theoretical Annual | | | | Predicted Actual Annual[4] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | At Dwelling[3] [hr/yr] | | Max Within 50 m of Dwelling[3] [hr/yr] | | At Dwelling[3] [hr/yr] | | Max Within 50 m of Dwelling[3] [hr/yr] | |
| | | | | | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m | SF at 2m | SF at 6 m |
| *B058* | *709623* | *5846924* | *60* | - | - | - | - | - | - | - | - | - |
| *B064* | *710107* | *5842201* | *60* | *T93* | *16.9* | *16.3* | *25.4* | *24.6* | *2.9* | *2.8* | *4.0* | *3.9* |
| *B097* | *708404* | *5839745* | *60* | *T135* | *0.0* | *0.0* | *3.5* | *3.9* | *0.0* | *0.0* | *0.3* | *0.4* |
| *B103* | *714106* | *5831545* | *60* | *T226* | *10.3* | *9.8* | *11.8* | *11.3* | *2.1* | *2.0* | *2.4* | *2.3* |
| *B104* | *710991* | *5832179* | *60* | - | - | - | - | - | - | - | - | - |
| B110 | 705895 | 5851752 | 30 | - | - | - | - | - | - | - | - | - |
| *B119* | *698409* | *5850995* | *60* | *T20, T22* | *19.1* | *19.2* | *46.1* | *47.8* | *3.9* | *3.9* | *8.3* | *8.4* |
| *B120* | *699102* | *5852320* | *60* | *T10* | *0.0* | *0.0* | *35.5* | *37.5* | *0.0* | *0.0* | *8.5* | *9.2* |
| *B124* | *695961* | *5853202* | *60* | *T1* | *14.0* | *13.8* | *15.7* | *15.4* | *3.1* | *3.0* | *3.5* | *3.4* |
| B125 | 695651 | 5853628 | 30 | - | - | - | - | - | - | - | - | - |
| *B127* | *696999* | *5851953* | *60* | *T4, T7* | *91.8* | *90.2* | *113.7* | *112.4* | *16.2* | *16.0* | *20.7* | *20.3* |
| *B140* | *706705* | *5846346* | *60* | *T70* | *0.0* | *0.0* | *17.7* | *15.9* | *0.0* | *0.0* | *2.7* | *2.3* |
| *B143* | *703669* | *5844423* | *60* | *T80* | *35.0* | *35.1* | *40.2* | *40.7* | *9.3* | *9.4* | *10.7* | *10.8* |
| *B145* | *705091* | *5843052* | *60* | *T89* | *15.2* | *14.6* | *17.3* | *16.6* | *3.2* | *3.1* | *3.6* | *3.5* |
| *B146* | *705384* | *5841864* | *60* | *T96* | *16.6* | *15.7* | *21.6* | *20.8* | *2.8* | *2.7* | *3.5* | *3.3* |

[1] Participant dwellings are indicated by *underlined italic text*.
[2] Coordinate system: MGA Zone 54, GDA94 datum.
[3] Dwellings identified in Table 4 with no shadow flicker limit have been omitted from this table. Dwellings predicted to experience zero hours of shadow flicker from both of the assessed layouts have also been omitted. Shadow flicker durations above the stated limits (for theoretical shadow flicker durations) or one-third of the stated limits (for predicted actual shadow flicker durations) are highlighted in red. See Section 4.1.5 for further details.
[4] Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.

**Table 8 Theoretical and predicted actual annual shadow flicker durations for dwellings affected by shadow flicker with the permitted layout configuration - concluded**

| House ID[1] | Easting[2] [m] | Northing[2] [m] | Applicable shadow flicker limit (theoretical) [hr/yr] | Contributing Turbines | Theoretical Annual | | | | Predicted Actual Annual[4] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | At Dwelling[3] [hr/yr] | | Max Within 50 m of Dwelling[3] [hr/yr] | | At Dwelling[3] [hr/yr] | | Max Within 50 m of Dwelling[3] [hr/yr] | |
| | | | | | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m |
| *B149* | *701380* | *5842799* | *60* | *T94* | *34.2* | *32.5* | *54.9* | *53.4* | *8.2* | *7.9* | *13.1* | *12.6* |
| *B168* | *701154* | *5837552* | *60* | *T177* | *17.7* | *16.5* | *24.3* | *22.6* | *4.3* | *4.0* | *5.8* | *5.5* |
| *B169* | *699647* | *5837851* | *30* | *T168* | *44.9* | *43.6* | *53.4* | *52.8* | *8.1* | *7.8* | *9.7* | *9.5* |
| *B170* | *699004* | *5837890* | *60* | - | - | - | - | - | - | - | - | - |
| *B203* | *701684* | *5836682* | *60* | *T182* | *14.0* | *13.2* | *15.8* | *15.2* | *2.8* | *2.7* | *3.2* | *3.1* |
| *B245* | *701784* | *5837154* | *60* | *T182* | *12.6* | *11.8* | *17.6* | *16.3* | *3.1* | *2.9* | *4.2* | *3.9* |
| *B345* | *705393* | *5841802* | *60* | *T96* | *18.7* | *17.9* | *26.6* | *25.2* | *3.0* | *2.8* | *4.4* | *4.2* |
| B366 | 705718 | 5852253 | 30 | - | - | - | - | - | - | - | - | - |

[1] Participant dwellings are indicated by *underlined italic text*.
[2] Coordinate system: MGA Zone 54, GDA94 datum.
[3] Dwellings identified in Table 4 with no shadow flicker limit have been omitted from this table. Dwellings predicted to experience zero hours of shadow flicker from both of the assessed layouts have also been omitted. Shadow flicker durations above the stated limits (for theoretical shadow flicker durations) or one-third of the stated limits (for predicted actual shadow flicker durations) are highlighted in red. See Section 4.1.5 for further details.
[4] Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.

**Table 9 Theoretical and predicted actual annual shadow flicker durations for dwellings affected by shadow flicker with the amended layout configuration - continued**

| House ID[1] | Easting[2] [m] | Northing[2] [m] | Applicable shadow flicker limit (theoretical) [hr/yr] | Contributing Turbines | Theoretical Annual | | | | Predicted Actual Annual[4] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | At Dwelling[3] [hr/yr] | | Max Within 50 m of Dwelling[3] [hr/yr] | | At Dwelling[3] [hr/yr] | | Max Within 50 m of Dwelling[3] [hr/yr] | |
| | | | | | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m | SF at 2m | SF at 6 m |
| *B058* | *709623* | *5846924* | *60* | *L2* | *16.1* | *15.8* | *20.8* | *20.3* | *2.7* | *2.6* | *3.3* | *3.2* |
| *B064* | *710107* | *5842201* | *60* | *O6* | *44.8* | *44.2* | *51.9* | *51.1* | *7.1* | *7.1* | *9.0* | *8.9* |
| *B097* | *708404* | *5839745* | *60* | *N5* | *9.4* | *9.0* | *10.6* | *10.1* | *2.1* | *2.0* | *2.4* | *2.3* |
| *B103* | *714106* | *5831545* | *60* | - | - | - | - | - | - | - | - | - |
| *B104* | *710991* | *5832179* | *60* | *R1, T1* | *24.2* | *24.0* | *26.5* | *26.3* | *4.7* | *4.7* | *5.1* | *5.0* |
| B110 | 705895 | 5851752 | 30 | A7 | 10.2 | 10.0 | 11.2 | 10.9 | 2.2 | 2.1 | 2.4 | 2.3 |
| *B119* | *698409* | *5850995* | *60* | *A9* | *29.2* | *29.9* | *41.0* | *41.4* | *4.9* | *5.0* | *7.0* | *7.1* |
| *B120* | *699102* | *5852320* | *60* | *A8, A10* | *14.7* | *14.4* | *58.1* | *59.8* | *3.1* | *3.0* | *12.4* | *13.0* |
| *B124* | *695961* | *5853202* | *60* | *A12, A13* | *23.2* | *23.6* | *37.2* | *37.0* | *4.4* | *4.5* | *8.0* | *8.0* |
| B125 | 695651 | 5853628 | 30 | A13 | 13.2 | 12.7 | 14.6 | 14.2 | 3.2 | 3.1 | 3.5 | 3.4 |
| *B127* | *696999* | *5851953* | *60* | *A10* | *19.4* | *18.8* | *22.6* | *22.0* | *3.6* | *3.5* | *4.0* | *3.9* |
| *B140* | *706705* | *5846346* | *60* | *M6, M7* | *61.3* | *60.1* | *68.0* | *66.9* | *11.0* | *10.8* | *12.0* | *11.8* |
| *B143* | *703669* | *5844423* | *60* | *B7* | *0.0* | *0.0* | *28.5* | *28.2* | *0.0* | *0.0* | *7.1* | *6.9* |
| *B145* | *705091* | *5843052* | *60* | *B4, B6, C4* | *19.1* | *18.4* | *30.2* | *29.4* | *3.8* | *3.7* | *6.1* | *6.0* |
| *B146* | *705384* | *5841864* | *60* | *B5* | *25.1* | *24.6* | *34.6* | *33.9* | *4.3* | *4.2* | *5.4* | *5.3* |

[1] Participant dwellings are indicated by *underlined italic text*.
[2] Coordinate system: MGA Zone 54, GDA94 datum.
[3] Dwellings identified in Table 4 with no shadow flicker limit have been omitted from this table. Dwellings predicted to experience zero hours of shadow flicker from both of the assessed layouts have also been omitted. Shadow flicker durations above the stated limits (for theoretical shadow flicker durations) or one-third of the stated limits (for predicted actual shadow flicker durations) are highlighted in red. See Section 4.1.5 for further details.
[4] Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.

**Table 9 Theoretical and predicted actual annual shadow flicker durations for dwellings affected by shadow flicker with the amended layout configuration - concluded**

| House ID[1] | Easting[2] [m] | Northing[2] [m] | Applicable shadow flicker limit (theoretical) [hr/yr] | Contributing Turbines | Theoretical Annual | | | | Predicted Actual Annual[4] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | At Dwelling[3] [hr/yr] | | Max Within 50 m of Dwelling[3] [hr/yr] | | At Dwelling[3] [hr/yr] | | Max Within 50 m of Dwelling[3] [hr/yr] | |
| | | | | | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m | SF at 2 m | SF at 6 m |
| *B149* | *701380* | *5842799* | *60* | *C6* | *11.6* | *11.2* | *12.7* | *12.3* | *2.4* | *2.3* | *2.7* | *2.6* |
| *B169* | *699647* | *5837851* | *30* | *-* | *-* | *-* | *-* | *-* | *-* | *-* | *-* | *-* |
| *B168* | *701154* | *5837552* | *60* | *H6* | *20.5* | *20.0* | *27.8* | *26.9* | *5.9* | *5.7* | *7.3* | *7.1* |
| *B170* | *699004* | *5837890* | *60* | *G6* | *16.8* | *16.5* | *20.7* | *20.4* | *2.9* | *2.8* | *3.4* | *3.4* |
| *B203* | *701684* | *5836682* | *60* | *H7* | *24.0* | *23.4* | *27.4* | *26.7* | *5.1* | *5.0* | *5.9* | *5.8* |
| *B245* | *701784* | *5837154* | *60* | *H7* | *13.0* | *12.8* | *25.2* | *24.7* | *2.6* | *2.6* | *7.0* | *6.9* |
| *B345* | *705393* | *5841802* | *60* | *B5* | *30.9* | *30.2* | *37.4* | *36.4* | *4.8* | *4.7* | *6.4* | *6.1* |
| B366 | 705718 | 5852253 | 30 | A7 | 16.7 | 15.6 | 23.5 | 21.8 | 4.0 | 3.8 | 5.6 | 5.2 |

[1] Participant dwellings are indicated by *underlined italic text*.
[2] Coordinate system: MGA Zone 54, GDA94 datum.
[3] Dwellings identified in Table 4 with no shadow flicker limit have been omitted from this table. Dwellings predicted to experience zero hours of shadow flicker from both of the assessed layouts have also been omitted. Shadow flicker durations above the stated limits (for theoretical shadow flicker durations) or one-third of the stated limits (for predicted actual shadow flicker durations) are highlighted in red. See Section 4.1.5 for further details.
[4] Considering likely reductions in shadow flicker duration due to cloud cover and turbine orientation.

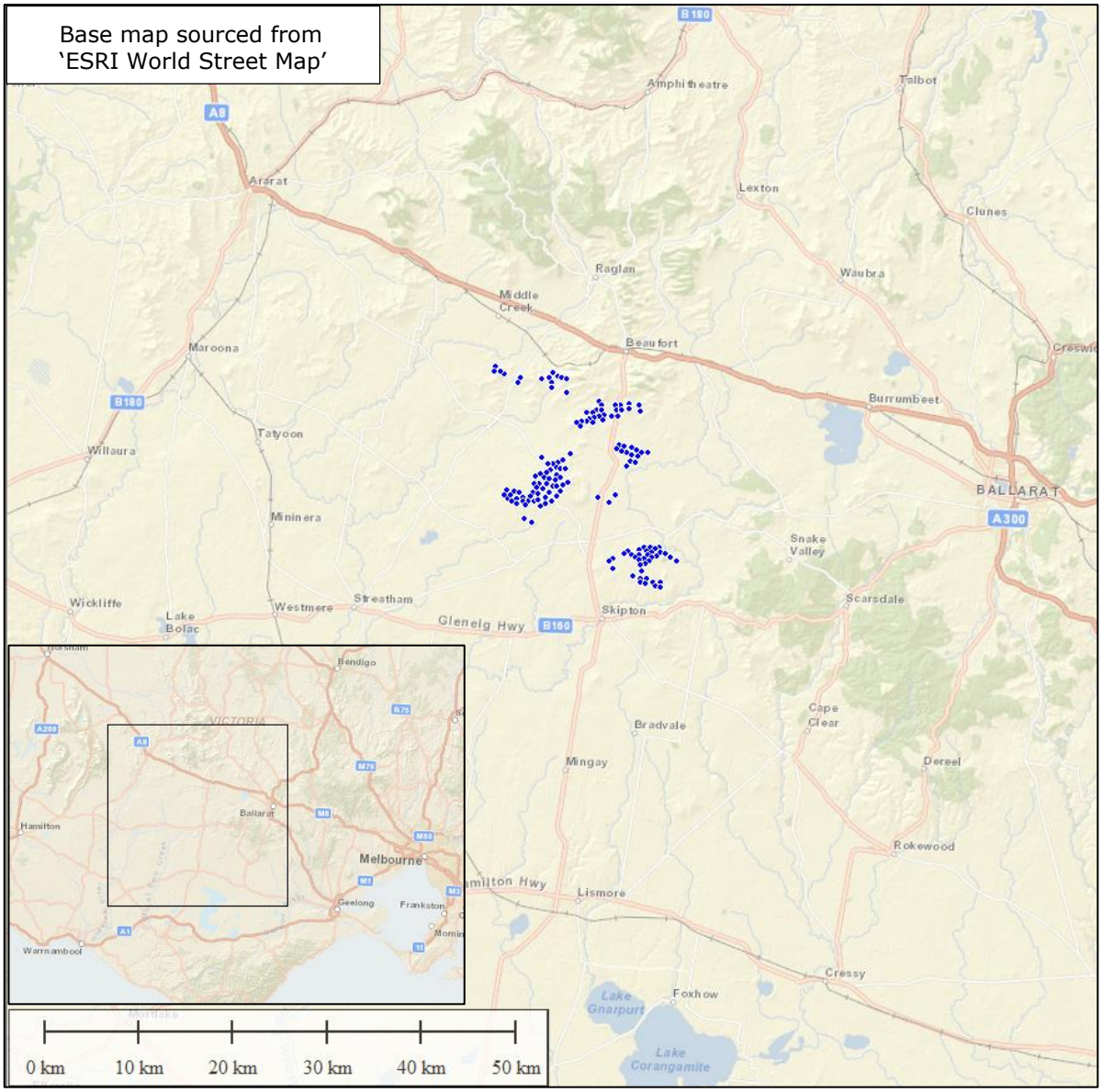


**Figure 1 Location of the proposed amended SHWF WEF**

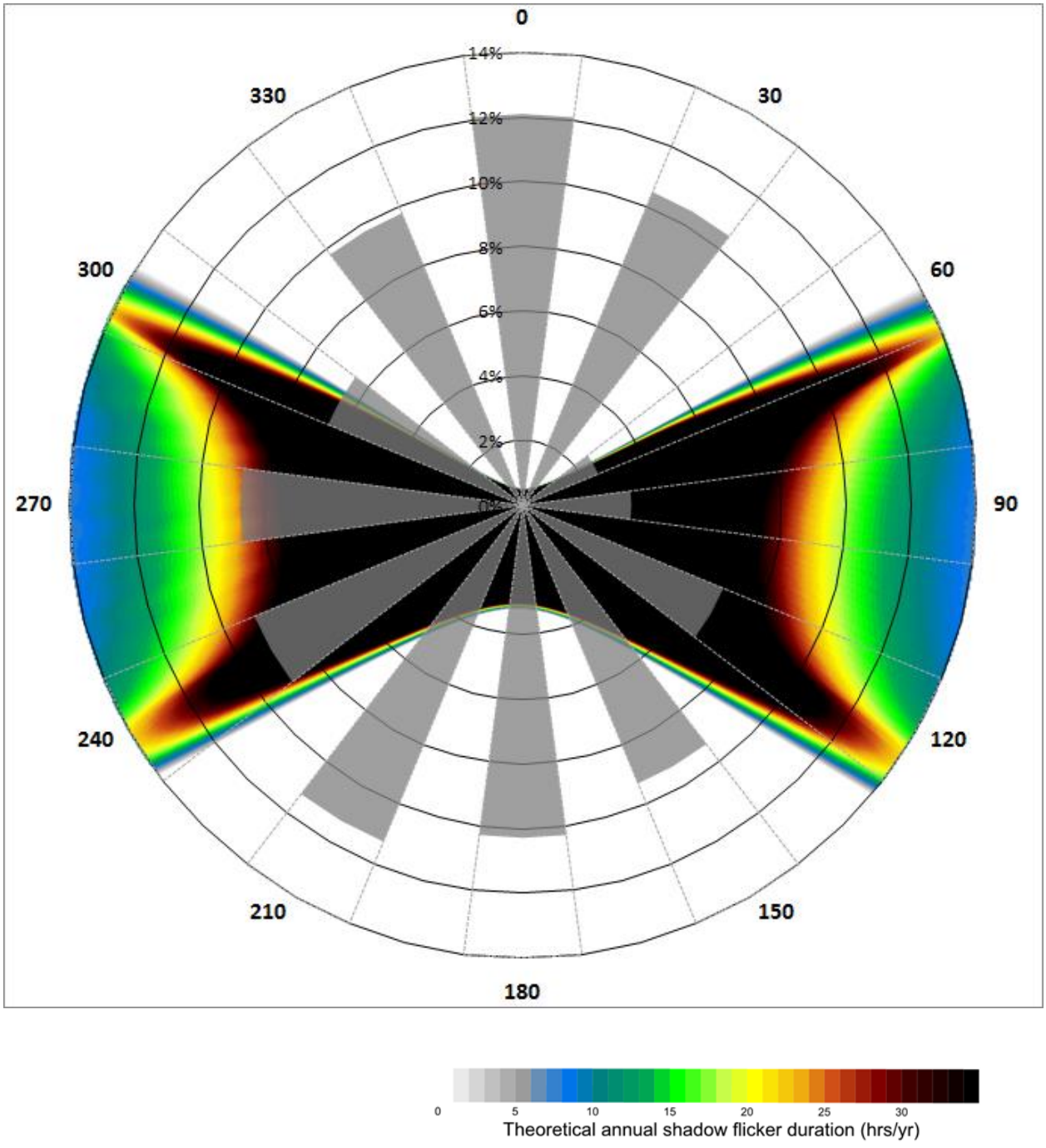


**Figure 2 Indicative shadow flicker map and wind direction frequency distribution**