MAHINERANGI WIND FARM

Shadow Flicker and Blade Glint Assessment

Tararua Wind Power Limited

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EXECUTIVE SUMMARY

Tararua Wind Power Limited ("TWP"), a fully owned subsidiary of Mercury NZ Limited, is progressing Stage 2 of the Mahinerangi Wind Farm which is to be known as "Puke Kapo Hau" ("the Project"). DNV has been commissioned by "TWP" to independently assess the expected annual shadow flicker durations in the vicinity of the Project that may occur from the Stage 2 of the Project.

Background and methodology

In New Zealand there are no specific guidelines that specify the assessment methodology for potential shadow flicker generated by wind turbines. Australia has developed guidelines and DNV has assessed the expected annual shadow flicker durations for the Project in accordance with the Victorian Planning Guidelines [1], which the Project's resource consent references. The methodology used in this study has been informed by these guidelines, the Australian Draft National Wind Farm Development Guidelines [2] (Draft National Guidelines).

The Victorian Planning Guidelines recommend a shadow flicker limit of 30 hours per year in the area immediately surrounding a dwelling.

Resource consents for the Project were granted by the Environment Court in 2009. At the time, assessments were made based on two turbine configuration possibilities both of which were realistic options, although the consent does not limit the activities in that manner. Considering progress that have been made in turbine technology since consent, it is no longer realistic to advance the second stage of the Project based on the previous configurations considered. Therefore, TPW have proposed a real-word configuration for Stage 2 of the Project that has been used in this assessment.

For the purpose of this assessment, DNV has compared the real-world configuration for Stage 2 of the Project to the proposed configuration that consists of 54 turbine locations, of which 44 will be built. The 44 turbines in Stage 2 are in addition to the 12 existing Stage 1 turbines which were commissioned in 2011.

The Stage 2 turbine configuration modelled in this assessment has a maximum rotor diameter of 136 m, a minimum ground clearance of 20 m, and a hub height of 97 m. It is understood that the final turbine configuration has not been determined. DNV considers the assessment results to be representative of the maximum shadow flicker extent and duration of the hub heights under consideration.

The locations of 24 dwellings in the vicinity of the Project have been provided by TWP. Six dwellings have been identified as having the potential to experience shadow flicker, based on their distances from the proposed turbine locations. Of those six dwellings, five have been identified as participating dwellings.

The theoretical shadow flicker durations at dwellings in the vicinity of the Project have been determined using a purely geometric analysis and the results are therefore conservative.

Outcomes of the assessment

Based on this assessment, three dwellings are expected to experience shadow flicker above a moderate level of intensity within 50 m of the dwelling. For the purposes of this assessment, shadow flicker above a moderate level of intensity is assumed to occur up to a distance of 10 rotor diameters from the wind turbines. All three dwellings are participating dwellings.

Of the three participating dwellings predicted to experience shadow flicker above a moderate level of intensity, two dwellings (dwellings 4 and 5) are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling.

The calculation of the theoretical shadow flicker duration does not take into account potential reductions due to turbine orientation, cloud cover, low wind speed, vegetation, or other shielding effects around each house.

If required, the effects of shadow flicker may be reduced through a number of mitigation measures such as installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies to shut down turbines when shadow flicker is likely to occur.

The effects of blade glint have not been quantified in this study as the Australian Draft National Guidelines do not provide any quantification methodology. The guidelines, however, recommend that the turbine blades used have a surface finish with a low reflectivity to avoid occurrences of blade glint.

An assessment was also carried out for the Project considering the combined impacts of the varied Stage 2 turbine locations and the existing Stage 1 turbines located in the south of the Project area. When considering shadow flicker above a moderate level of intensity, it was found that no dwellings were impacted from both the existing Stage 1 turbines and the varied Stage 2 turbines.

When comparing the predicted shadow flicker extents for the consented real-world configuration and to the proposed configuration, the proposed configuration results in one fewer dwelling that is expected to experience shadow flicker. Specifically, dwelling 24, which is predicted to experience shadow flicker under the consented real-world configuration, is no longer impacted for the proposed configuration. The shadow flicker conclusions for all other dwellings remain unchanged, and all dwellings that are impacted by shadow flicker for both configurations are participating dwellings. Overall, the proposed configuration leads to a reduction in shadow flicker impacts compared to the consented real-world configuration.

Blade glint is not expected to be an issue for the Project provided a non-reflective finish is applied to the wind turbine blades.

1 INTRODUCTION

Tararua Wind Power Limited ("TWP") has commissioned DNV to independently assess the expected annual shadow flicker durations in the vicinity of the Stage 2 of the Mahinerangi Wind Farm ("the Project").

Resource consents for the Project were granted by the Environment Court in 2009. The consent application was advanced on the basis that the turbines were to be selected at the detailed design stage. At the time, assessments were made based on two possibilities: a 100 x 2 MW turbine layout, or a 67 x 3 MW turbine layout, both of which were realistic options, although the consent does not limit the activities in that manner. While 2 MW turbines were realistic in 2008, given the advancement in wind technology, it is no longer realistic to advance an 82 x 2 MW turbine layout for assessment purposes. Therefore, TPW has adopted a real-world configuration for assessment purposes. This is as follows:

- Consented real-world configuration: 47 turbines, 145 m high, 9 m ground clearance, 136 m rotor diameter within a possible 78 locations
- Proposed configuration: 44 turbines, 165 m high, 20 m minimum ground clearance, 136 m rotor diameter within 54 possible locations.

For the purpose of this assessment DNV has reviewed Condition 23 of the consent which relates to shadow flicker and assessed the difference in expected shadow flicker impacts between the real-world consented turbine locations and the proposed turbine locations. DNV has compared the consented real-world configuration to the proposed configuration that consists of 54 possible turbine locations, of which 44 will be built. The modelled 54 turbines is an overestimation of 10 turbines that are proposed to be constructed by TWP.

Condition 23 of the consent requires compliance with the May 2003 Policy and Planning Guidelines for Development of Wind Energy Facilities in Victoria [3]. These guidelines have since been superseded by a new version in 2023, however the content addressing shadow flicker has not been modified. This assessment evaluates the shadow flicker durations in the vicinity of the Project in accordance with the Planning Guidelines for Development of Wind Energy Facilities (Victorian Planning Guidelines) prepared by the Victorian Government Department of Transport and Planning in September 2023 [1] and the Australian Draft National Wind Farm Development Guidelines (Draft National Guidelines) [2].

2 DESCRIPTION OF THE SITE AND PROJECT

2.1 The site

The Project is located approximately 47 km northwest of Dunedin and 20 km northeast of Lawrence.

The terrain at the Project site is relatively simple with elevations ranging from approximately 620 m to 725 m above sea level. The Project site is comprised of agricultural land with pockets of vegetation throughout. A digital elevation model of the Project terrain and surrounding terrain was derived from publicly available SRTM1 data [4], extending approximately 30 km from the Project site.

2.2 Stage 2 of the Project

2.2.1 Proposed wind farm layout

Stage 2 of the Project is proposed to consist of up to 44 wind turbines [5] in addition to 12 existing Stage 1 turbines [6] that were constructed in 2011. Although 54 potential turbine locations have been modelled for this assessment, only up to 44 turbines will be constructed within these locations ("Varied Stage 2"). A map of the Project site showing the potential turbine locations and terrain elevations considered in this assessment is shown in Figure 3. The coordinates of the potential turbine locations are given in Table 1 and the existing turbine locations are given in Table 2 [6]. Turbines may be located anywhere within the Contingency Zones. The Contingency Zones set out the specific development locations for the wind turbines, together with a +/- 100 m contingency zone to retain some flexibility regarding the precise locations of the wind turbines.

DNV has modelled the shadow flicker based on a theoretical turbine model with a rotor diameter of 136 m and hub height of 97 m.

2.2.2 Dwelling locations

The locations of 24 dwellings in the vicinity of the Project have been provided by TWP [7].

For the purposes of this assessment, six dwellings have been identified as having the potential to experience shadow flicker, based on their distances from the proposed turbine locations, and these have been considered in this assessment. Of those six dwellings, five are participating dwellings. The six dwellings considered in this assessment are shown in Figure 3 and presented in Table 3.

The remaining 18 dwellings are at locations that are considered unlikely to be impacted by shadow flicker at intensities typically considered sufficient to cause any annoyance, as discussed further in Sections 3.1 and 4.1.2, and have not been considered further in this assessment.

3 REGULATORY REQUIREMENTS

3.1 Shadow flicker

As described in Section 1, Condition 23 of the Mahinerangi Wind Farm land use consent requires that *"the extent of any shadow flicker caused by the wind turbines at any residential dwellings existing at date of consent does not exceed the duration specified in the May 2003 'Policy and Planning Guidelines for Development of Wind Energy Facilities in Victoria'"* (Victorian Planning Guidelines) [3].

Since the land use consent was awarded there have been several iterations of the Victorian Guidelines following the 2003 revision, however the content addressing shadow flicker has not been modified, and the Victorian Planning Guidelines 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 the absence of a proposed methodology in the Victorian Planning Guidelines, it is noted that the Australian 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 Australian Draft National Guidelines recommend that the shadow flicker duration at a dwelling 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 assumes that the evaluation of the maximum shadow flicker duration within 50 m of a dwelling (as recommended by the Australian Draft National Guidelines) is similar to assessing shadow flicker durations within the 'garden fenced area'. In most cases this approach is expected to be adequate, however it is acknowledged that there may be instances where the 'garden fenced area' could extend beyond 50 m from a dwelling.

The shadow flicker 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 the Australian Draft National Guidelines to assess shadow flicker durations at locations other than in the vicinity of dwellings.

The impact of shadow flicker is typically only significant up to a distance of around 10 rotor diameters from a turbine [8] or approximately 1200 m to 1700 m for modern wind turbines (which typically have rotor diameters of 120 m to 170 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, although shadow flicker may still be experienced beyond this distance. 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 term "shadow flicker above a moderate level of intensity" is used in the Australian Draft National Guidelines and in this assessment refers to shadow flicker at a level of intensity that is likely to cause annoyance for most people, although it is acknowledged that this is subjective and can vary from person to person.

The shadow flicker methodology described in the Australian Draft National Guidelines is intended to address only the shadow flicker above a moderate level of intensity, and so it is necessary to restrict the calculated shadow flicker durations to only consider shadow flicker at or above that level of intensity. The Australian Draft National Guidelines suggest a distance equivalent to 265 times the maximum blade chord as an appropriate limit, which corresponds to approximately 1000 m to 1600 m for modern wind turbines (which typically have maximum blade chord lengths of 4 m to 6 m).

3.2 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. Blade glint is not generally a problem for modern wind turbines [2].

A methodology for the quantification of blade glint impacts as well as a regulatory limit are not provided by either the Victorian Planning Guidelines or the Australian Draft National Guidelines. However, the Australian Draft National Guidelines recommends that the blades of the wind turbines have a finish with low reflectivity. Condition 18 of the Mahinerangi windfarm land use consent requires a neutral off-white or light grey, low reflectivity colour system and DNV understands that TWP is not seeking any changes to that condition.

In relation to blade glint, guidance from the Australian Draft National Guidelines states that:

> *"Blade glint can be produced when the sun's light is reflected from the surface of wind turbine blades. Blade glint has potential to annoy people.*
>
> *All major wind turbine blade 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.*
>
> *Proponents should ensure that blades from their supplier are of low reflectivity."*

4 ASSESSMENT METHODOLOGY

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:

- the direction of the property relative to the turbine
- the distance of the property from the turbine (the further the observer is from the turbine, the less pronounced the effect will be)
- the turbine height and rotor diameter
- the time of year and day (the position of the sun in the sky)
- the weather conditions (cloud cover reduces the occurrence of shadow flicker)
- the 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).

Example photographs of wind turbines and associated shadows which have the potential to cause flicker are shown in Figure 1 below.

Figure 1 Examples of wind turbine shadows

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 site area, 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, up to a specified distance limit.

In accordance with the methodology proposed in the Australian Draft National Guidelines, DNV has assessed the shadow flicker at the provided dwellings and has determined the highest shadow flicker duration within 50 m of each of these locations.

In the absence of detailed dwelling height information, shadow flicker has been calculated at the 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 could be facing a particular direction less affected by shadows cast from the turbines. The shadow flicker calculations for dwelling locations have been carried out with a temporal resolution of 1 minute. The shadow flicker map was generated using a temporal resolution of 5 minutes and a spatial resolution of 10 m 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. As noted in Section 3.1, the UK wind industry considers that 10 rotor diameters is appropriate [9, 10] while the Australian Draft National Guidelines suggest a distance limit equivalent to 265 times the maximum blade chord [2].

For the current assessment, DNV has applied a maximum shadow length of 10 times the rotor diameter (10D), corresponding to a distance limit of 1360 m for the varied Stage 2 locations, which DNV considers is more appropriate than a limit of 265 times the maximum blade chord. Beyond this distance limit, it is assumed that any shadow flicker experienced will be below a "moderate level of intensity" and unlikely to cause annoyance. However, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by shadow flicker intensities below the "moderate level of intensity" assumed by this distance limit. To account for this possibility, DNV has also calculated the shadow flicker to a distance of up to 15 times the rotor diameter (15D), or 2040 m, which should include shadow flicker below a "moderate level of intensity".

In this assessment, shadow flicker of a moderate level of intensity or above is assumed to occur up to a distance of approximately 10D from the Project. Conversely, shadow flicker below a moderate level of intensity, described as "low intensity" shadow flicker in this report, is assumed to occur beyond a distance of 10D and up to a distance of approximately 15D from the wind turbines.

DNV has reviewed the turbine Contingency Zones in relation to the shadow flicker distance limits described above and determined that the conclusions of the assessment will remain valid if the turbines are positioned anywhere within these zones.

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.
- there are no line-of-sight obstructions other than the terrain.

The settings used to execute the model can be seen in Table 4.

To illustrate typical results, an indicative shadow flicker map for a turbine located in a flat area is shown in

Figure 4. 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 months and conversely the lobes to the south result from the winter months. 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 a 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 overestimation of the 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 Impact assessment of Stage 1 and varied Stage 2

DNV notes that 12 existing Stage 1 turbines are operating in the southern part of the Project. Consequently, some dwellings near the Project may experience cumulative impacts from both the existing Stage 1 turbines and turbines at the varied Stage 2 turbine locations.

The existing Stage 1 turbine locations are shown in Table 2 and Figure 3. It is understood that the existing turbines are Vestas V90 turbines with a rotor diameter of 90 m and hub height of 80 m [11], giving a tip height of 125 m above ground level.

For the purposes of this assessment, it is assumed that the existing turbines generate shadow flicker at similar distances relative to their rotor diameter as the potential turbines (up to the 10D and 15D distance limits for shadow flicker above and below a moderate level of intensity, respectively).

The potential for nearby dwellings to experience impacts from both the existing Stage 1 turbines and turbines at the varied turbine locations in Stage 2 has therefore been assessed using distance thresholds of up to:

- 1410 m (10 times the rotor diameter of the potential turbines, plus 50 m) from all varied Stage 2 turbine locations
- 950 m (10 times the rotor diameter of the existing turbines, plus 50 m) from all existing Stage 1 turbines

when considering shadow flicker above a moderate level of intensity only. When considering potential shadow flicker impacts including shadow flicker below a moderate intensity, distance limits up to:

- 2090 m (15 times the rotor diameter of the potential turbines, plus 50 m) from all varied Stage 2 turbine locations
- 1400 m (15 times the rotor diameter of the existing turbines, plus 50 m) from the existing Stage 1 turbines

have been used.

Based on the existing turbine dimensions and the turbine dimensions proposed for the varied Stage 2 turbine locations, up to two dwellings could potentially be affected by shadow flicker from turbines in Stage 1 and Stage 2 (participating dwelling 18 and non-participating dwelling 24). The shadow flicker areas which could potentially lead to impacts from the existing Stage 1 turbines and the varied Stage 2 turbine locations are shown in Figure 6.

4.2 Blade glint

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

Condition 18 of the Mahinerangi Wind Farm land use consent requires low reflectivity turbine components and so this issue is not considered further here.

5 ASSESSMENT RESULTS

5.1 Shadow flicker

5.1.1 Predicted shadow flicker durations for varied Stage 2

Shadow flicker predictions for the varied Stage 2 turbine locations were generated at the provided dwelling locations, and the results are summarised in Table 5.

The results of the theoretical shadow flicker modelling are also shown in the form of a shadow flicker map in Figure 5. The shadow flicker values presented in this map represent the worst case between the results calculated at 2 m and 6 m above ground level for each modelled grid point.

Based on this assessment, three dwellings are expected to experience shadow flicker above a moderate level of intensity within 50 m of the dwelling. For the purposes of this assessment, shadow flicker above a moderate level of intensity is assumed to occur up to a distance of around 10 rotor diameters from the wind turbines. Of these three dwellings (dwellings 4, 5 and 18), all are participating dwellings.

Participating dwellings 4 and 5 are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling.

Beyond the 10D distance limit, it is assumed that any shadow flicker experienced will be below a moderate level of intensity and unlikely to cause annoyance. However, as discussed in Section 4.1.2, it is recognised that different people have different levels of sensitivity to shadow flicker and may therefore be affected by low intensity shadow flicker assumed by this distance limit. To inform the potential for this outcome, although not part of the methodology outlined in the Australian Draft National Guidelines, DNV has also calculated the theoretical shadow flicker impacts for the Project for an increased distance limit of 15D that is intended to include shadow flicker of low intensity. The results of this additional assessment are also included in the map presented in Figure 5.

These results indicate that two additional dwellings may have the potential to be exposed to low intensity shadow flicker. Both dwellings are participating dwellings and are noted in Table 5. DNV note that the recommended shadow flicker limits are only intended to apply to shadow flicker above a moderate level of intensity and not low intensity shadow flicker beyond the 10D distance limit.

5.1.2 Impact assessment of Stage 1 and varied Stage 2

A shadow flicker impact assessment was carried out for the existing Stage 1 turbines and the varied Stage 2 turbine locations, where two dwellings (dwellings 18 and 24) were identified as potential candidates for shadow flicker from both the existing Stage 1 turbines and varied Stage 2 turbines based on the distance thresholds outlined in Section 4.1.3.

Based on this assessment and the distance thresholds applied:

- Dwelling 18 (a participating dwelling) is predicted to experience shadow flicker above a moderate level of intensity from a varied Stage 2 turbine (turbine 54) and may experience some shadow flicker below a moderate level of intensity from an existing Stage 1 turbine (T2).
- Dwelling 24 (a non-participating dwelling) is not predicted to experience shadow flicker of any level (neither above or below a moderate level of intensity) from the varied Stage 2 turbines,

but may experience some shadow flicker below a moderate level of intensity from an existing Stage 1 turbine (T10).

Therefore, when considering shadow flicker above a moderate level of intensity, it was found that there were no dwellings impacted from both the existing Stage 1 turbines and the varied Stage 2 turbines.

5.1.3 Impact assessment of the proposed configuration

When comparing the dwellings located within the shadow flicker extents for the consented real-world configuration and the proposed configuration for Stage 2 of the Project, the proposed configuration results in one fewer dwelling that is expected to experience shadow flicker.

Specifically, non-participating dwelling 24, which is predicted to experience shadow flicker under the consented real-world configuration, is no longer impacted for the proposed configuration. The shadow flicker conclusions for all other dwellings remain unchanged, and all dwellings that are impacted by shadow flicker for both configurations are participating dwellings. Overall, therefore, the proposed configuration leads to a reduction in shadow flicker impacts compared to the consented real-world configuration.

5.1.4 Mitigation options

The effects of shadow flicker may be reduced through a number of mitigation measures, although mitigation is not expected to be required given that shadow flicker impacts above a moderate level of intensity are not expected at any non-participating dwellings.

Mitigation measures may include the installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies to shut down turbines when shadow flicker beyond acceptable levels is likely to occur.

5.2 Blade glint

As discussed in Section 4.2, blade glint is not expected to be an issue for Stage 2 of the Project provided that a non-reflective paint is applied to the wind turbine blades.

6 CONCLUSIONS

A shadow flicker assessment was carried out for dwelling locations in the vicinity of the Project.

For the purpose of this assessment, DNV has considered a layout consisting of up to 54 potential turbine locations with a turbine rotor diameter of 136 m and a hub height of 97 m. These dimensions represent the maximum turbine dimensions currently under consideration for the Project.

For the purpose of this assessment DNV have compared the consented real-world configuration for Stage 2 of the Project to the proposed configuration that consists of 54 turbine locations, of which 44 will be built. The 44 turbines in Stage 2 are in addition to the 12 existing Stage 1 turbines which were commissioned in 2011.

Based on this assessment, three dwellings are predicted to experience shadow flicker above a moderate level of intensity within 50 m of the dwelling. For the purposes of this assessment, shadow flicker above a moderate level of intensity is assumed to occur up to a distance of 10 rotor diameters from the wind turbines. Of these dwellings, all are participating dwellings.

Out of the three participating dwellings predicted to experience shadow flicker above a moderate level of intensity, two dwellings (dwellings 4 and 5) are predicted to experience theoretical shadow flicker durations above the recommended limit of 30 hours per year within 50 m of the dwelling.

An assessment was also carried out considering the combined impacts of the varied Stage 2 turbine locations and the existing Stage 1 turbines located in the south of the Project. When considering shadow flicker above a moderate level of intensity, it was found that no dwellings were impacted from both the existing Stage 1 turbines and the varied Stage 2 turbines.

When comparing the expected shadow flicker extents for the consented real-world configuration to the proposed configuration for Stage 2 of the Project, the proposed configuration results in one fewer dwelling that is expected to experience shadow flicker. Specifically, dwelling 24, which is predicted to experience shadow flicker under the consented real-world configuration, is no longer impacted for the proposed configuration. The shadow flicker conclusions for all other dwellings remain unchanged, and all dwellings that are impacted by shadow flicker for both configurations are participating dwellings. Overall, the proposed configuration leads to a reduction in shadow flicker impacts compared to the consented real-world configuration.

Blade glint is not expected to be an issue for the Project provided a non-reflective finish is applied to the wind turbine blades.

7 REFERENCES

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[3] *MWF - Clutha District Council Land Use Consent RM1409,* information provided by Mitchell Daysh to DNV, 16 June 2025.

[4] NASA JPL, “NASA Shuttle Radar Topography Mission Global 1 arc second number [Data set],” NASA EOSDIS Land Processes DAAC, 2013. [Online]. Available: https://doi.org/10.5067/MEaSUREs/SRTM/SRTMGL1.003.

[5] “Stage 2 WTG Locations – RC 2025.shp,” information provided by Mitchell Daysh to DNV, 26 May 2025.

[6] “AsBuiltLayout.shp,” information provided by Mitchell Daysh to DNV, 12 November 2024.

[7] “Housing Inventory.shp and Housing inventory LR.pdf,” information provided by Mercury to DNV, 27 February 2025.

[8] “Planning for Renewable Energy - A Companion Guide to PPS22,” Office of the Deputy Prime Minister, UK, 2004.

[9] “Planning for Renewable Energy - A Companion Guide to PPS22,” Office of the Deputy Prime Minister, UK, 2004.

[10] “Update of UK Shadow Flicker Evidence Base,” Parsons Brinckerhoff, UK, 2011.

[11] Keppel Prince, “Mahinerangi - Updated shape files,” information provided by Mitchell Daysh to DNV, 11 March 2025.

LIST OF TABLES

Table 1 Potential Stage 2 turbine locations for the Project [5]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]	Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
1	1361075	4932004	650	28	1360444	4928720	655
2	1360921	4931770	671	29	1360605	4928319	657
3	1360515	4931576	674	30	1359180	4928581	717
4	1360174	4931630	690	31	1359485	4928360	723
5	1360012	4931358	701	32	1359187	4928128	716
6	1360777	4931337	665	33	1359249	4927732	720
7	1360575	4931097	669	34	1359276	4927385	688
8	1360290	4931181	689	35	1359933	4927339	658
9	1360034	4931047	698	36	1360299	4927112	616
10	1359787	4930500	723	37	1360144	4926894	612
11	1360165	4930401	704	38	1359419	4927008	660
12	1360348	4930148	698	39	1359158	4926872	626
13	1360528	4930330	679	40	1359368	4926646	609
14	1360609	4930020	665	41	1358378	4928255	713
15	1360516	4929753	667	42	1358294	4927856	711
16	1360501	4929483	655	43	1357727	4927946	714
17	1360990	4929765	640	44	1356257	4926927	672
18	1359414	4930423	729	45	1356079	4926702	646
19	1359380	4930151	728	46	1357225	4927185	729
20	1359271	4929879	723	47	1357142	4926825	703
21	1359335	4929596	716	48	1356965	4926639	694
22	1359614	4929199	698	49	1356714	4926447	681
23	1359003	4929133	710	50	1356715	4926270	665
24	1358707	4928905	708	51	1356975	4926165	656
25	1359127	4928884	705	52	1357492	4926007	644
26	1359493	4928794	713	53	1357427	4925627	634
27	1359992	4928560	693	54	1357799	4925627	618

1. Coordinate system: NZGD2000.

Table 2 Existing Stage 1 turbine locations [6]

Turbine ID	Easting[1] [m]	Northing[1] [m]	Base elevation [m]
T1	1357062	4924759	637
T2	1357587	4925017	637
T3	1356883	4925203	618
T4	1357186	4925829	661
T5	1357621	4926301	677
T6	1357384	4926581	708
T7	1357805	4926697	701
T8	1356799	4926907	718
T9	1357656	4927123	726
T10	1356542	4927629	751
T11	1356969	4927557	740
T12	1357497	4927568	735

1. Coordinate system: NZGD2000.

Table 3 Locations of dwellings considered in this assessment [7]

Dwelling ID[3]	Easting[1] [m]	Northing[1] [m]	Dwelling status	Nearest turbine Distance [m][2]	Nearest turbine Turbine ID
4	*1361608*	*4930562*	*Participating*	*1008*	17
5	*1361844*	*4930209*	*Participating*	*963*	17
6	*1362373*	*4928600*	*Participating*	*1790*	29
7	*1362635*	*4928525*	*Participating*	*2040*	29
18	*1358797*	*4925155*	*Participating*	*1104*	54
24	1355337	4928236	Non-participating	1350	T10

1. Participating dwellings are indicated by *underlined italic text*.
2. Coordinate system: NZGD2000.
3. The shadow flicker assessment has considered dwellings up to a maximum distance of 15D + 50 m from the varied Stage 2 Project wind turbines.

Table 4 Shadow flicker model settings for theoretical shadow flicker calculation

Model setting	
Shadow distance limit (10D)	1360 m
Year of calculation	2037
Minimum elevation of the sun	3°
Time step	1 min (5 min for map)
Rotor modelled as	Sphere (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	8 points evenly spaced (every 45°) on 25 m and 50 m radius circles centred on the provided dwelling location

Table 5 Theoretical annual shadow flicker durations for the varied Stage 2 turbines

Dwelling ID	Easting[1] [m]	Northing[1] [m]	Dwelling status	Contributing turbines[2]	Theoretical annual At dwelling [hr/yr] 2 m	Theoretical annual At dwelling [hr/yr] 6 m	Theoretical annual Max within 50 m [hr/yr] 2 m	Theoretical annual Max within 50 m [hr/yr] 6 m
4	1361608	4930562	Participating	6 7 12 13 14	**109.6**	**109.1**	**110.1**	**110.0**
5	1361844	4930209	Participating	13 14 15 17	**59.9**	**60.4**	**79.7**	**80.5**
6[3]	1362373	4928600	Participating	-	0.0	0.0	0.0	0.0
7[3]	1362635	4928525	Participating	-	0.0	0.0	0.0	0.0
18	1358797	4925155	Participating	54	18.7	18.9	20.4	20.6
Recommended duration limits (hr/yr)					**30**	**30**	**30**	**30**

1. Coordinate system: NZGD2000.
2. Contributing turbines shown are for the theoretical shadow flicker calculated at 2 m above ground level.
3. Dwelling is not predicted to experience any shadow flicker above a moderate level of intensity, but may experience low-intensity shadow flicker.

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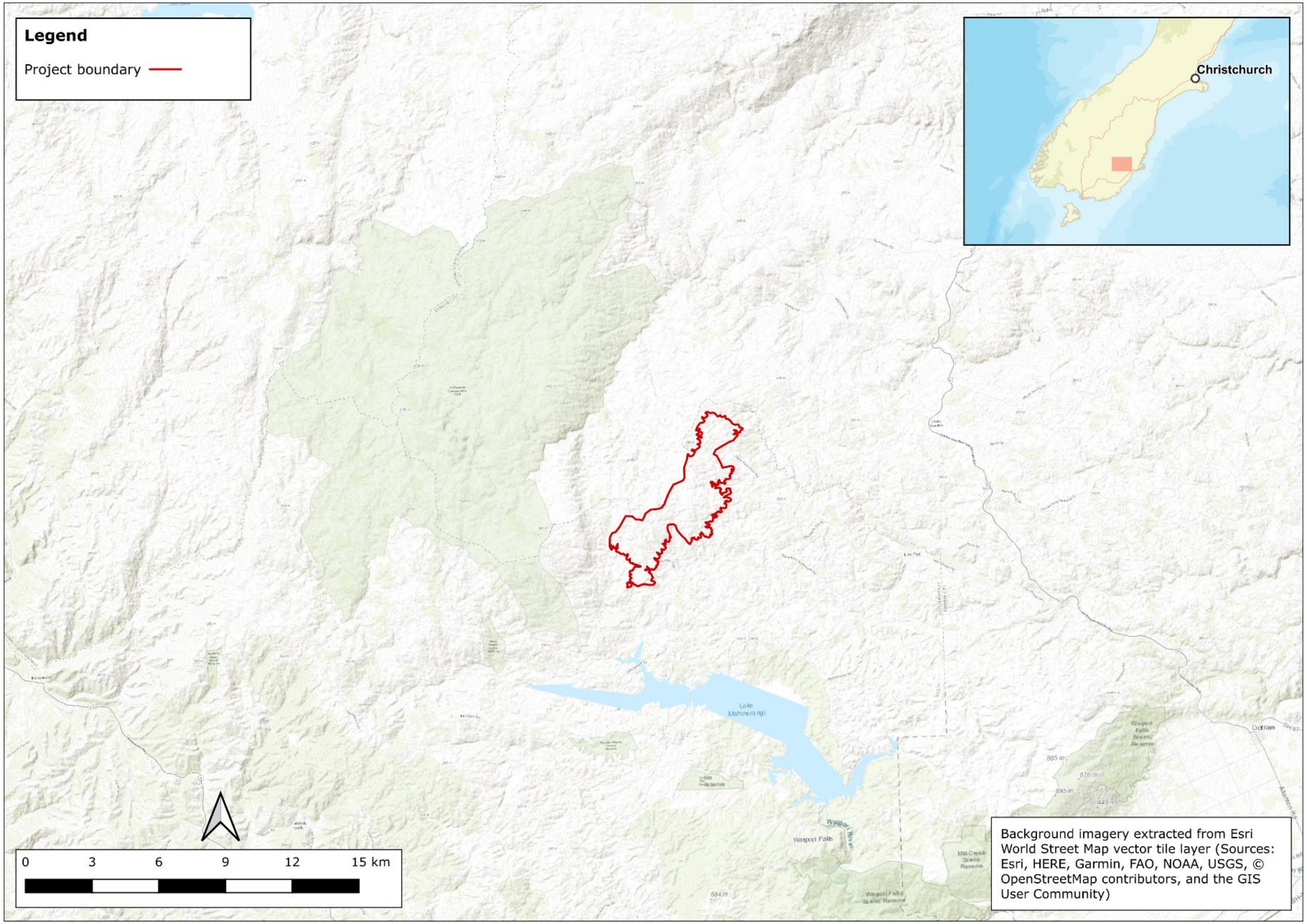

Figure 2 Location of the Project

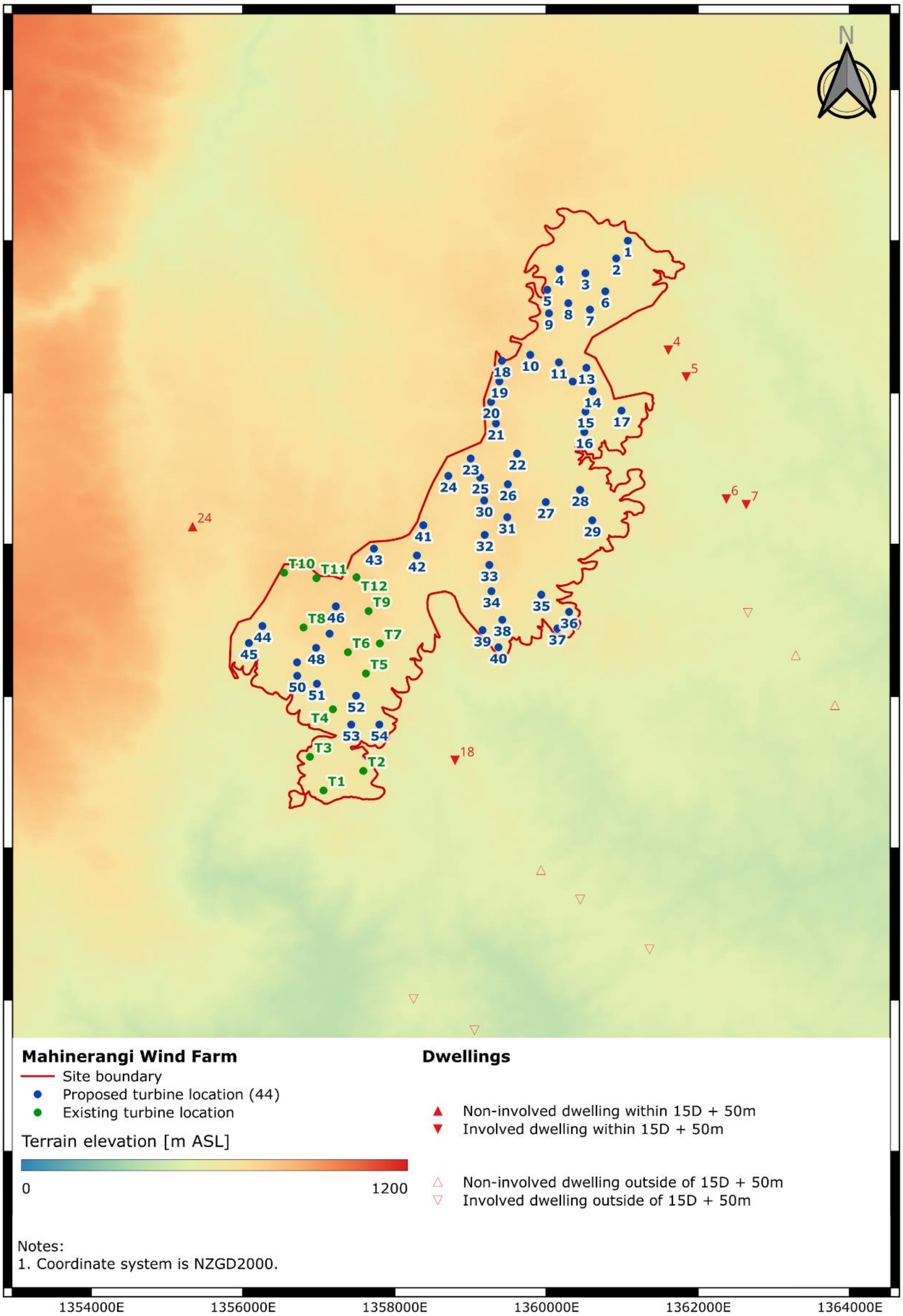

Figure 3 Map of the proposed Project, showing the Stage 1 turbine locations, the varied Stage 2 turbine locations, nearby dwellings, and terrain elevation

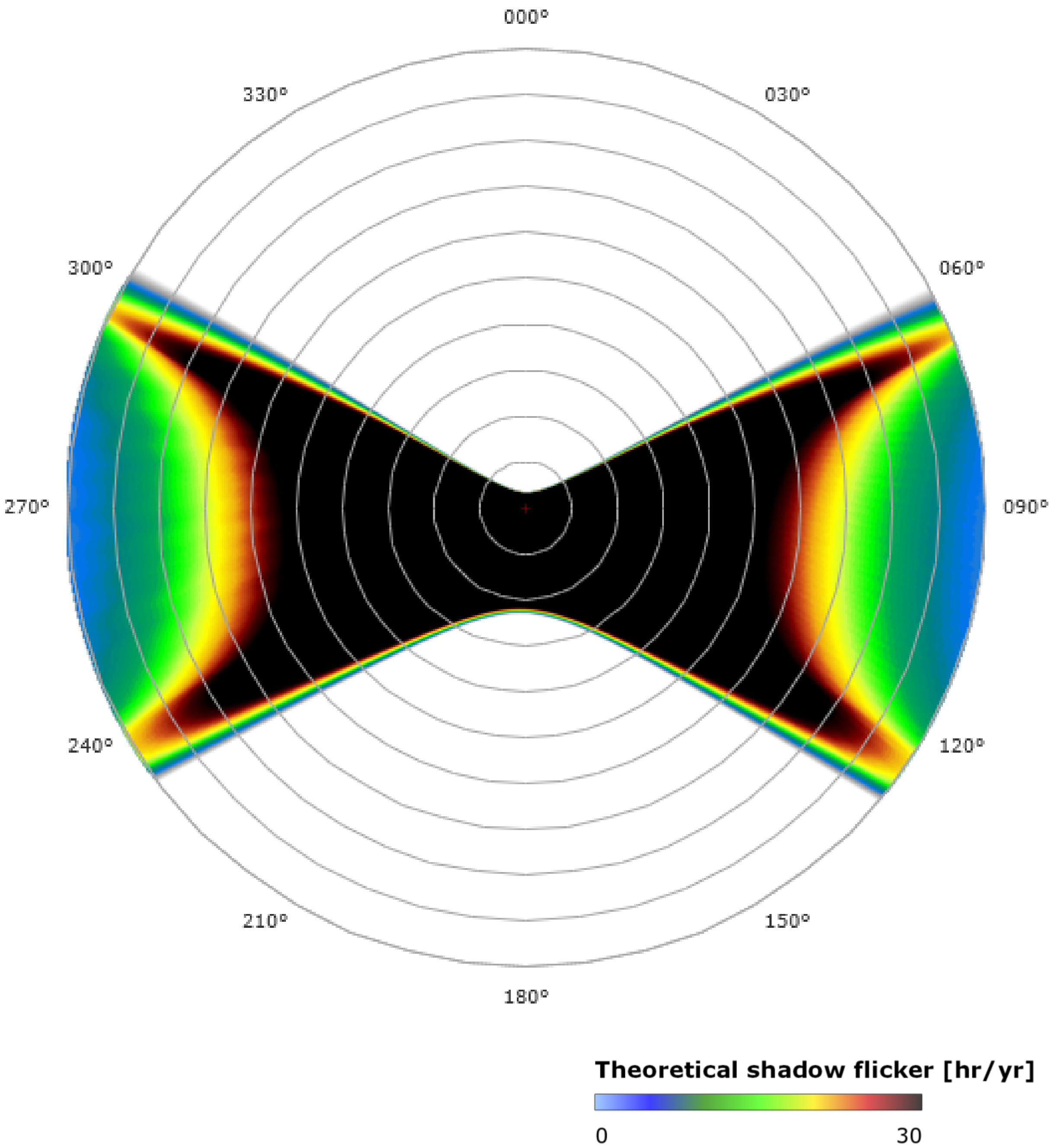

Figure 4 Indicative shadow flicker map and wind direction frequency distribution

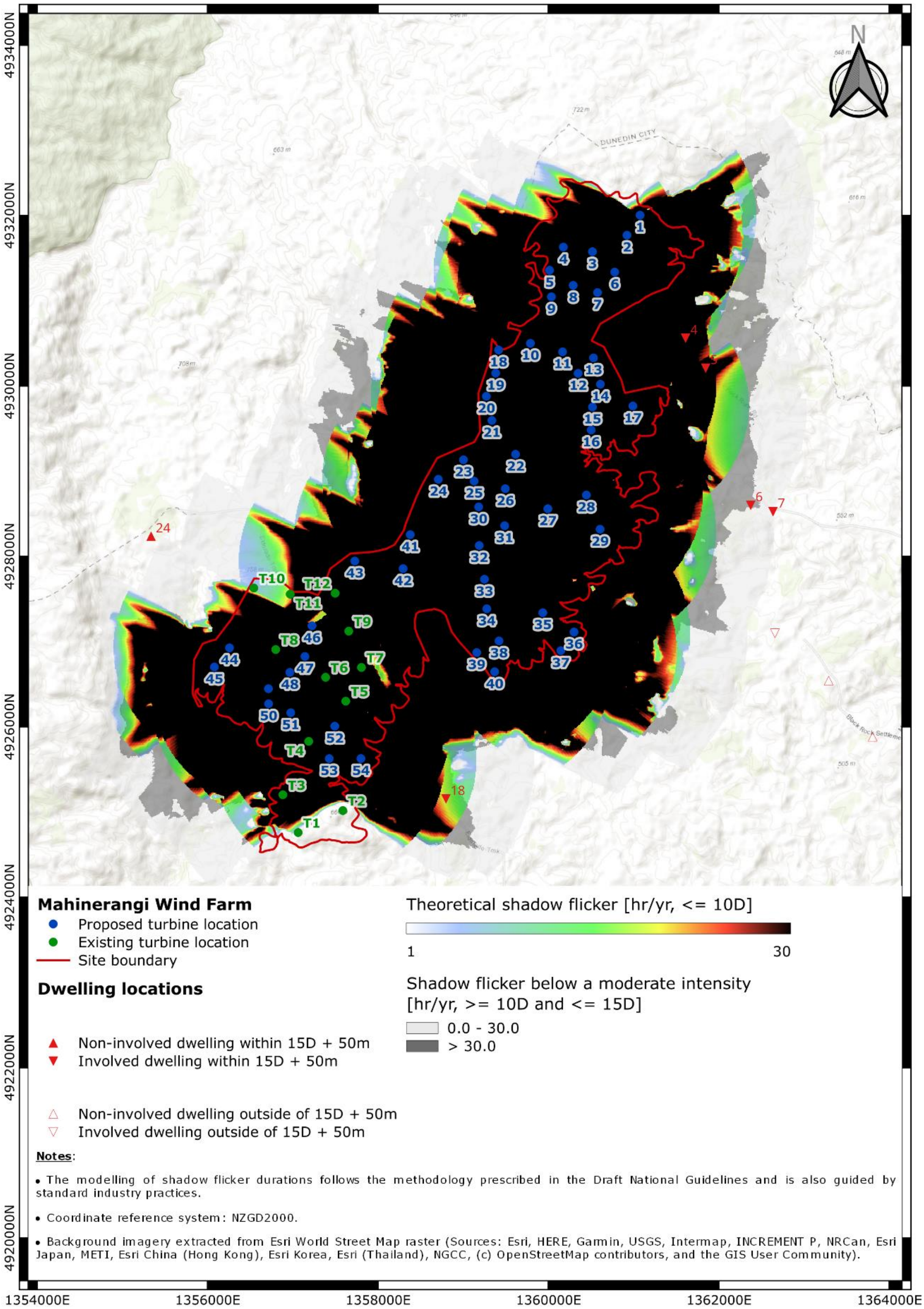

Figure 5 Theoretical annual shadow flicker duration map for the varied Stage 2 turbines

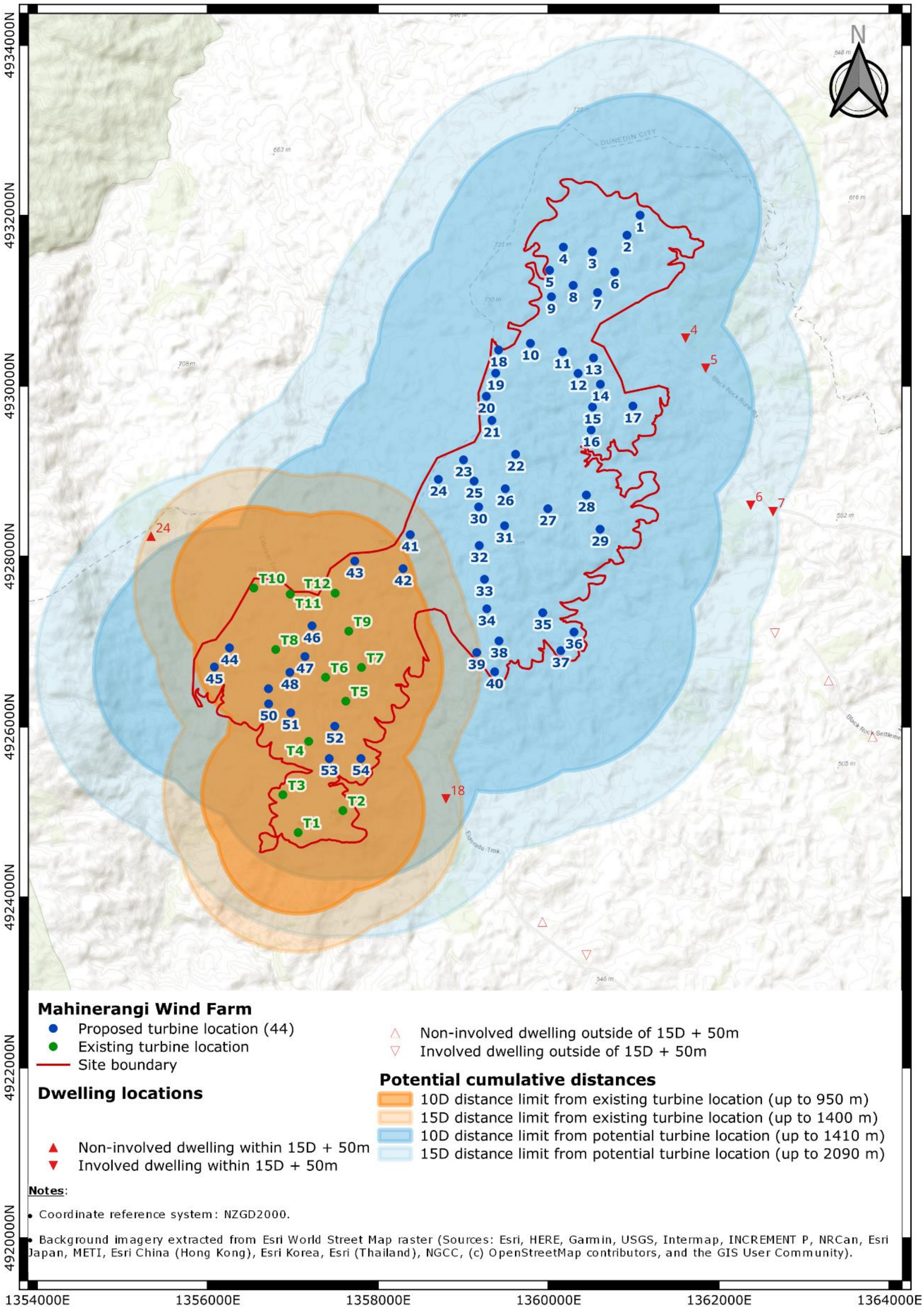

Figure 6 Potential areas for shadow flicker (impact extent of Stage 1 and varied Stage 2 turbines)