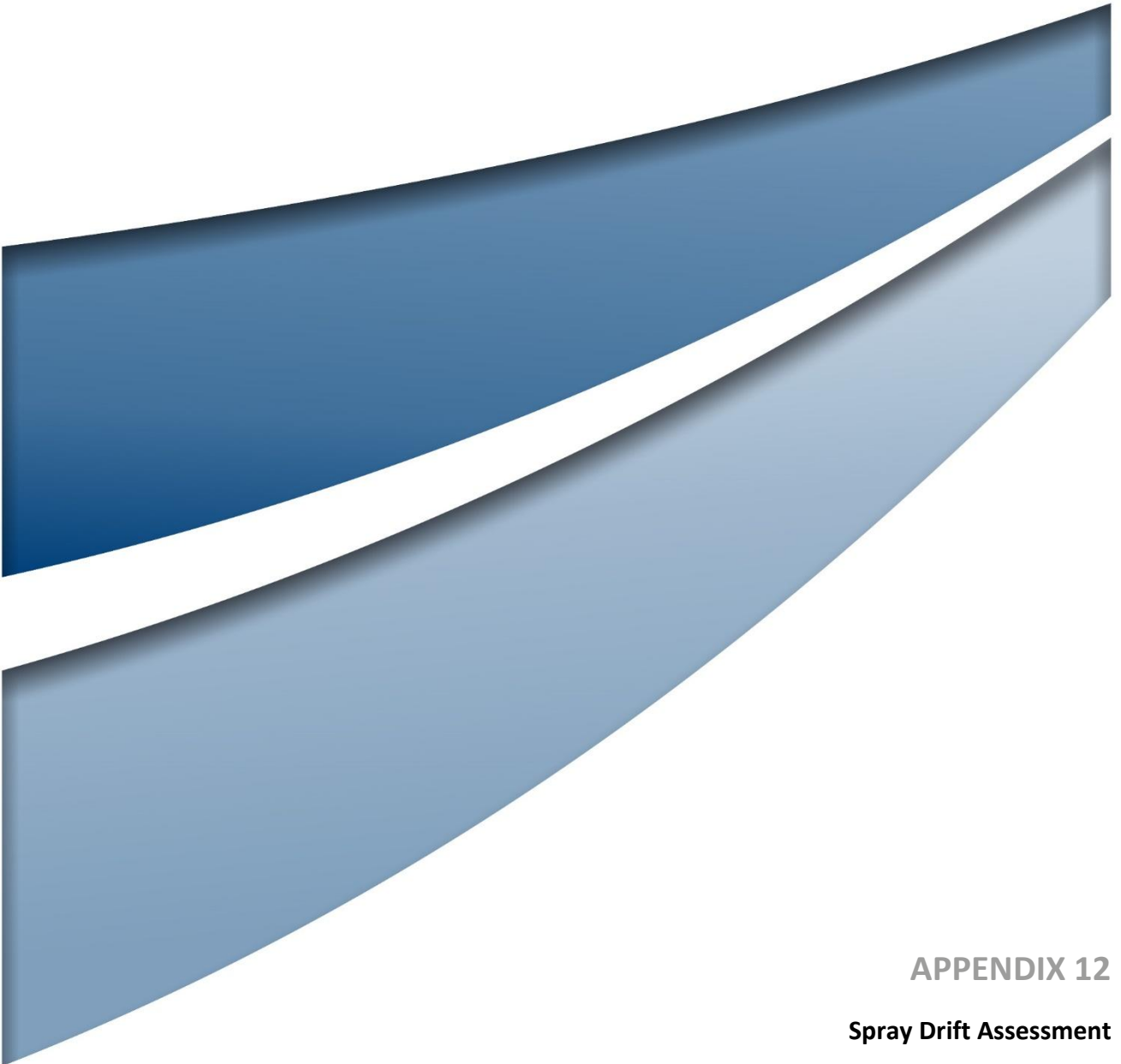




APPENDIX 12

Spray Drift Assessment



Junction Rivers Wind Project

Spray Drift Assessment

Final Report
Version E

Prepared for Windlab Developments Pty Ltd

May 2025

Project Number: 2025-3



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Executive Summary

Windlab is an Australian renewable energy company proposing to develop the Junction Rivers Wind Project (the Project) to generate renewable wind energy supply to the National Electricity Market (NEM). The Project will have a capacity of approximately 750 megawatts (MW), with the potential to power approximately 434,000 homes. The Project includes construction and operation of up to 96 wind turbine generators (WTG), up to four battery energy storage systems (BESS) or static synchronous compensators (STATcom), and associated facilities including operation and maintenance buildings, access roads, civil works, electrical infrastructure and temporary facilities for the construction phases

The Junction Rivers project site is located in the south-west of New South Wales, approximately 15 km south of Balranald, 140 km west of Hay and 20 km northeast of the NSW and Victorian border.

During public exhibition of the Environmental Impact Studies (EIS) as well as during community consultation, concerns related to spray drift related to ground base and aerial operations for agriculture in the surrounding properties to the Project were raised. As such Windlab have engaged an independent consultant to assess potential spray drift impacts from the Project.

Overview of assessment

An air dispersion modelling study has been undertaken to inform the assessment of changes in impacts of spraying from two potential areas upon surrounding areas. The air dispersion modelling study incorporated 3-dimensional (3D) meteorological data, emissions information, source characteristics, and the location of model receptors. As a conservative approach, spraying was assumed to occur whenever meteorological conditions are conducive to spraying in order to allow consideration of impacts under all possible meteorological conditions (see Figure 4.1). This frequency of spraying is highly unlikely in reality and good practice will preclude spraying when adverse wind directions result in spray drift to neighbouring properties. Furthermore, this is a highly conservative approach as conversations between the local community and Windlab indicate that chemical spraying follows the crop cycles. Ground spraying occurs no more than twice per year, and aerial spraying has not been conducted in the area for more than 20 years (Windlab, April 2025). Potential impact was evaluated by determining the change in deposition¹ of agricultural chemicals with the incorporation of the wind farm in the study area.

¹ Deposition refers to the process where particles, aerosols, and gases move from the atmosphere to the earth's surface. This is influenced by the size of the particles, so larger particles are more likely to deposit closer to the ground, while smaller particles are able to travel further. The deposition rate, expressed as mass per area over a period of time (e.g. mg/m²/day) refers to the rate at which the substances are being deposited at a location.

The scope of the modelling assessment is summarised below.

Modelled meteorological period	2020 calendar year. This is the period most representative of longer-term (climate) averages of wind speed, wind direction, temperature and rainfall.
Meteorological data	Three-dimensional prognostic meteorological data developed using the Weather Research and Forecasting (WRF) model.
Model selection	CALPUFF model suite, coupled with WRF prognostic meteorological data.
Project Emissions	Emissions for spraying have been estimated using the AGDISP model for ground and aerial spraying and volatilisation equations were sourced from the literature.
Source locations	Two key areas were defined as the location of crop spray activities, selected based on proximity to the proposed turbine locations.
Sensitive Receptors	Discrete receptor locations were nominated to represent locations 500 m, 1 km, 2 km, 3 km, 4 km and 5 km from the potential spray area.
Model Scenarios	The predicted impacts were considered for the following model scenarios: • Base case – meteorology simulated without the wind farm. • Project – meteorology simulated with the wind farm. The study has considered the incremental effects of crop spray at the two locations. Aerial spraying has the highest potential impact. As a conservative approach, the study has also considered the cumulative impact of aerial spraying occurring at the two crop spray locations occurring simultaneously.

Key findings

The operation of the wind farm will have a small effect on the atmospheric conditions relevant to the dispersion of substances from ground and aerial crop spray, as well as from the volatilisation of deposited chemicals on the ground. In particular:

- On an annual basis, the project results in a negligible reduction in wind speed close to ground level (between 0 m and 10 m) where spraying occurs.
- At 120 m aboveground, there is a marginal increase (1%) in the frequency light (<2.5 m/s) winds, as well as north-easterly winds at 120 m. However, these changes are not expected to affect dispersion on the ground.
- The wind farm has a relatively small impact on the mixing height, surface stability and vertical velocities on an annual time scale.
- Turbulence intensity increases downwind of the proposed wind farm at hub height in accordance with LiDAR measurements performed near wind farms.
- At the surface, the turbulence intensity decreases due to the decrease in vertical wind shear (from the reduction of wind speed at hub height) with a concomitant reduction in shear turbulence.

Ground spraying:

- The dispersion patterns for concentration and deposition are slightly different between the base and project cases with dispersion primarily along a west-east axis for the former and an east-southeast to west-northwest axis for the latter.
- Deposition rates are highest to the south and to the north of both spray areas.
- Maximum deposition rates decrease at discrete receptors immediately to the south, east and north of the spray areas with a small increase in deposition at receptors to the west with the project. The remaining receptors show negligible difference from the base case.

- This suggests that the presence of wind turbines may decrease deposition due to the decreased surface turbulence².

For aerial spraying:

- The dispersion pattern between the base and wind farm cases are similar, with dispersion along a southwest to northeast axis
- The dispersion patterns for concentrations are significantly different to the ground spraying and volatilisation emissions, most likely due to the increased dispersion of the chemicals due to turbulent dispersion within the aircraft wake. (*i.e.* vortices)
- For maximum hourly deposition, the patterns for the base and wind farm cases are similar and impacts are largely contained within the spray area.
- Receptors to the east of the spray Area A have the highest deposition rates and the project only has a negligible impact on deposition rates at the discrete receptors.
- Receptors to the south of Area B have the highest deposition rates followed by receptors to the west of the spray area and deposition only to the south of the spray area increases slightly with the project.
- The cumulative (Area A and B) spraying scenario shows only a negligible increase in deposition at the southern (of Area A) and at the northern (of Area B) receptors for both the base and project cases.
- Highest deposition occurs with winds less than 4 m/s blowing directly from the spray areas under moderately unstable to neutral stability conditions.

Volatilisation:

- The dispersion patterns for concentrations are slightly different between the base and wind farm cases
- For maximum hourly deposition, the patterns for the base and wind farm cases show some differences, especially to the east and northwest of the potential spraying area.
- Highest deposition rates occur at the nearest receptor to the south and the north of both the spray areas with all receptors showing a decrease in deposition rates with the project.

The dispersion modelling study suggests that generally, the operation of the wind farm has a neutral impact on deposition. While the deposition rates vary (*i.e.*, slight increase or slight decrease, depending on location), the changes are mostly negligible regardless of the spray activity type or from volatilisation. The cumulative assessment of aerial spraying occurring simultaneously in two of the most affected locations also show that potential impacts due to the operation of wind farm are minimal.

It is important to note that the results presented in this report should be treated as relative, rather than absolute. The study has applied conservative assumptions to the spraying activities and has assumed that spraying occurs for every potential hour whenever the conditions are conducive. The adoption of best practice methods during spraying will further reduce impacts.

Based on the spray drift assessment, there are no indications that crop spraying applications would need to vary when the wind farm is operational, particularly if best practice guidelines are adopted.

² The maximum occurring at a certain location, would mean that the worst-case conditions for dispersion occurred when winds are coming directly from the source. This may only have occurred for one hour during the whole year.

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1 Introduction

1.1 Background

Windlab Developments Pty Ltd (Windlab) proposes to construct and operate the Junction Rivers wind farm in the south-west of New South Wales. To support the delivery of the Response to Submissions and address concerns raised in public submissions and from the community, Windlab needs to assess the possible impact of the wakes of the turbines at the proposed wind farm on potential spray drift during surface and aerial application and due to volatilisation of chemicals deposited in the ground. The highest potential impact with and without the wind farm at multiple distances downwind are to be determined for multiple wind directions.

The specific scope of work provided by Windlab is to:

- Establish existing environment (baseline conditions) through the development of a 3D site-specific meteorological dataset to understand the range of atmospheric conditions experienced in the region for a representative meteorological year.
- Evaluate the model performance by comparing model predictions with measurement data from a local Bureau of Meteorology weather station.
- Analyse the seasonal/diurnal profiles of meteorological variables important to dispersion (i.e. wind speed/direction, stability class, mixing height [inversion layer]).
- Determine potential impacts of crop spraying activities at two key areas of crop spray activities, selected based on proximity to the proposed turbine locations.
- Assess, through modelling, impacts for receptors at 500 m, 1 km, 2 km, 3 km, 4 km and 5 km distance from the two spray areas to identify worst-case conditions that lead to highest concentrations of tracer substances at a receptor.
- The following specific scenarios are to be assessed:
- Determine potential incremental impacts due to the following specific scenarios at the two crop spraying locations
 - Study A – crop spraying impacts:
 - Scenario A1: baseline surface crop spray (no turbines).
 - Scenario A2: surface crop spray (with turbines)
 - Scenario A3: baseline aerial crop spray (no turbines).
 - Scenario A4: aerial crop spray (with turbines)
 - Study B – volatilisation impacts:
 - Scenario B1: no turbines
 - Scenario B2: with turbines
- Determine potential cumulative impacts from simultaneous aerial spraying at the two crop spraying locations. Aerial spraying has the greatest potential impact, and this scenario is representative of the worst case conditions.

1.2 Project Description

The Junction Rivers Wind Project is located approximately 15 km south of Balranald, 140 km west of Hay and 20 km northeast of the NSW and Victorian border within the southern section of the Murray-Darling Basin. The project is proposed to generate up to 750MW, with up to 96 turbines (maximum tip height of 300 m) and potentially a Battery Energy Storage System of 200MW/800MWh.

Two areas (A and B), nominated by Windlab for potential spraying, were selected on the basis of likely being the most impacted by turbine wake effects post wind farm construction (Figure 1.1).

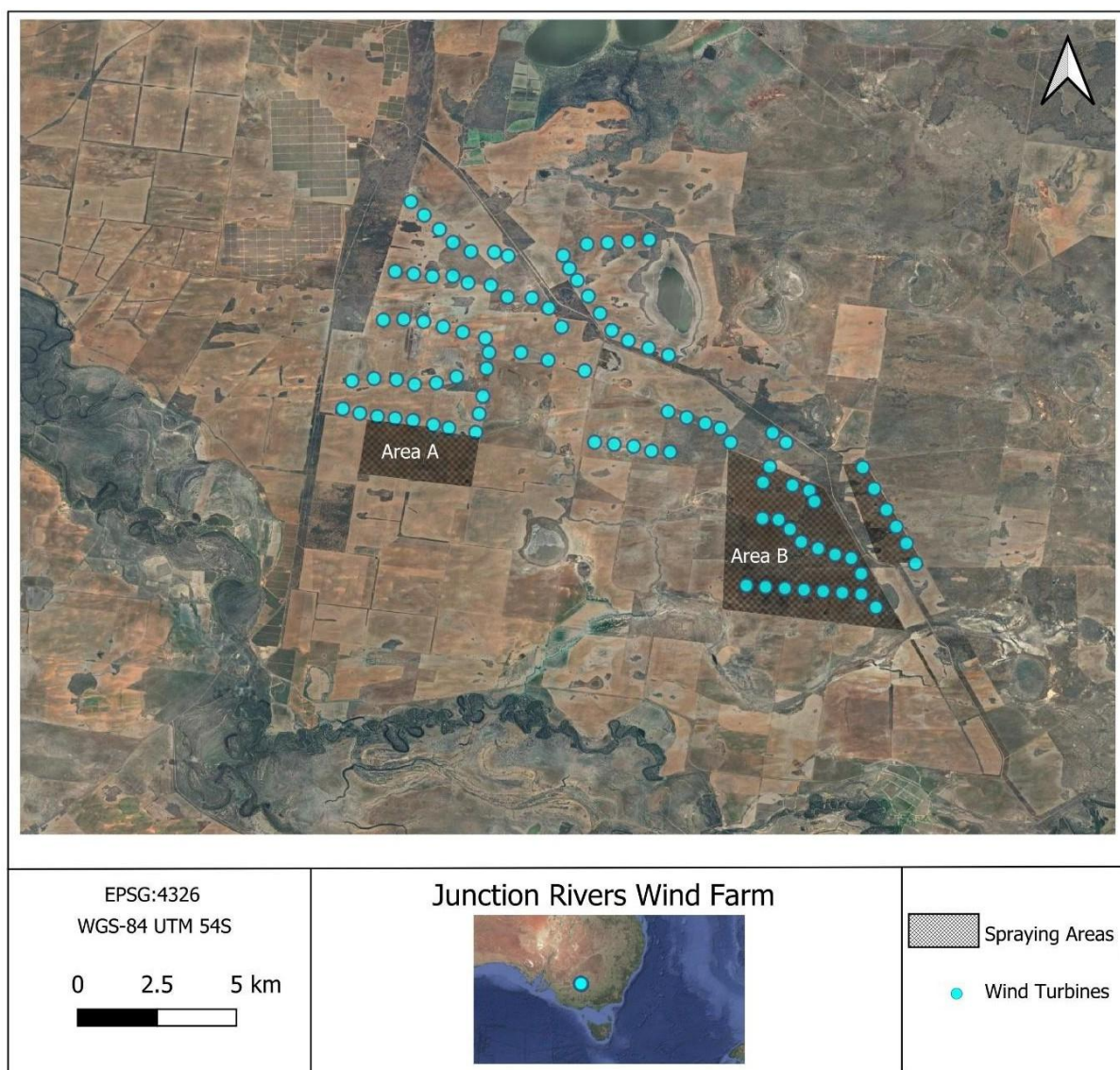


Figure 1.1: Project location and setting

1.3 Study Approach

The spray drift study incorporates meteorological data, emissions information, source characteristics, and the location of model receptors (as defined in Section 3.3.2). The emphasis of the emission estimation and modelling is on determining any relative changes in impact from agricultural spraying before (base case) and after completion of the project.

The key aspects and underlying basis of the modelling approach used in this assessment are outlined below.

- *Modelled meteorological period:*

The modelled meteorological period of this assessment was the 2020 calendar year. A review of 10 years (2010 – 2023) of historical surface observations obtained from the Bureau of Meteorology (BoM) for the Swanhill weather station concluded this period as most representative against longer term climatic averages and was selected on this basis.

- *Modelling approach*

The meteorological modelling has been conducted using the Weather Research and Forecasting (WRF) Version 4.0) model, a mesoscale numerical weather prediction model. The WRF model was used to develop a three-dimensional (3D) meteorological field across the model area. The WRF model performs with a high degree of accuracy, as verified against observational surface data available for the Bureau of Meteorology (BoM) automated weather station (AWS) at Swanhill.

The CALifornia Puff Model (CALPUFF Version 7) dispersion model has been used to predict the spray drift dispersion and deposition across the model domain and at identified sensitive receptor locations. As an advanced non-steady-state meteorological and air quality modelling system, it can be used to simulate near-field impacts in complex flow or dispersion situations, and longer-range transport of substances.

- *Emissions information:*

Emissions from ground and aerial spraying was developed using the AGricultural DISPersal (AGDISP Version 9.0) model while volatilisation of chemicals deposited in the ground after spray events was estimated from the literature (e.g. Ghosh and Crist (2022)).

1.4 Structure of Report

This report describes the methods and findings of an assessment of the potential impacts to the terrestrial environment arising from spraying operations in the vicinity of the proposed wind farm. The assessment includes:

- Project description in Section 1.2.
- Characterisation of site meteorology and terrain in Section 2.
- Outline of the modelling methodology in Section 3.
- Emissions estimations are considered in Section 4.
- Predicted meteorological and spraying impacts are presented in Section 5.
- Conclusions of the assessment are presented in Section 6.

The appendices contain detailed technical information.

1.5 Assumptions

This study is subject to a number of assumptions:

- As spraying practices are varied, with different application methods, equipment, agricultural chemical type and quantity of chemical sprayed, a number of assumptions have been made regarding:
 - Spraying duration and frequency.
 - Aircraft type(s) and properties for aerial spraying.
 - Properties of surface sprayer
 - Quantity of agricultural chemical dispensed.
 - Boom dimensions for both aerial and ground spraying
 - Initial spray droplet size distribution.
- Information on the above was largely sourced from AGDISP default settings for both ground and aerial spraying.
- Emissions were modelled for every hour of the year when spraying is possible (see Section 4.1 for full details) in order to allow consideration of impacts under all possible meteorological conditions. This frequency of spraying is highly unlikely in reality and good practice will preclude spraying when adverse wind directions result in spray drift to neighbouring properties.
- As the purpose of the study is to determine the relative changes attributed to the project on potential spray drift rather than the quantitative impacts from spraying, the assumptions applied are deemed to be valid.

1.6 Acronyms and Glossary

Acronym	Description
AGDISP	AGricultural DISPersal
BoM	Bureau of Meteorology
°C	Degrees Celsius (temperature)
CALPUFF	California Puff
Concentration	Amount of material (substance) per unit volume of air
Deposition	Process whereby particles, aerosols, and gases move from the atmosphere to the earth's surface
Contours	Lines joining places with equal concentration or deposition
DJF	December-February
GLC	Ground Level Concentration
g/m ² /hour	Grams per square metre per hour
g/s	grams per second
h/yr	Hours per year
JJA	June-August
km	kilometre
MAM	March-May
m	metre
mm	millimetre

Acronym	Description
NSW	New South Wales
TI	turbulence intensity
SON	September-November
$\mu\text{g}/\text{m}^3$	micro grams (one millionth of a gram) per cubic metre
USEPA	United States Environment Protection Agency
WRF	Weather Research and Forecast

2 Site Characteristics

2.1 Climate and Meteorology

The nearest climate station with a similar geographic setting to the proposed wind farm is Balranald, located approximately 25 km to the north-northeast. Balranald has a cold semi-arid climate (Köppen: BSk) with warm to hot summers and cool winters. Annual rainfall is low, with slightly higher amounts during winter and spring.

A summary of the long-term meteorological conditions as measured at Balranald AWS is presented in the following sections.

2.1.1 Temperature

The long-term temperature statistics from the Bureau of Meteorology (BoM) station at Balranald are presented in Figure 2.1. From this figure it is apparent that summer is characterised by warm days and cool nights. During December and January, temperatures in excess of 45 °C sometimes occur. Winters are cool, with daytime maximums averaging 15 °C although nights are cold, occasionally dropping as low as -5 °C.

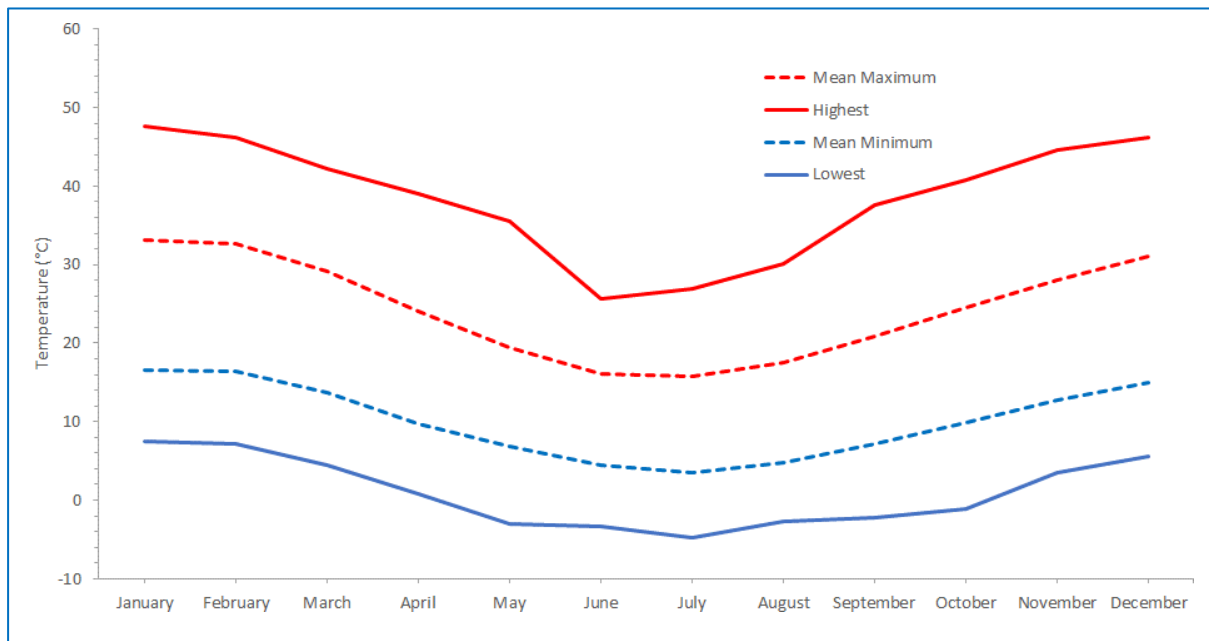


Figure 2.1: Long term temperature statistics, Balranald (1907-2023) (source: Bureau of Meteorology)

2.1.2 Rainfall

The long-term rainfall data measured at the BoM station at Balranald are presented in Figure 2.2.

Rainfall is very sparse, with an average annual rainfall of 147 mm and occurs infrequently, with less than 50 days in the year receiving 1 mm or more of rain (long term average). Rainfall is evenly distributed throughout the year although there is a minimum in late summer and autumn, and a maximum in winter and spring (Figure 2.2). Rainfall is mainly due to frontal activity (cold fronts), but occasional afternoon thunderstorms may occur during summer. Rainfall variability is high, as evident in the figure, where the maximum monthly rainfall is significantly greater than the average rainfall.

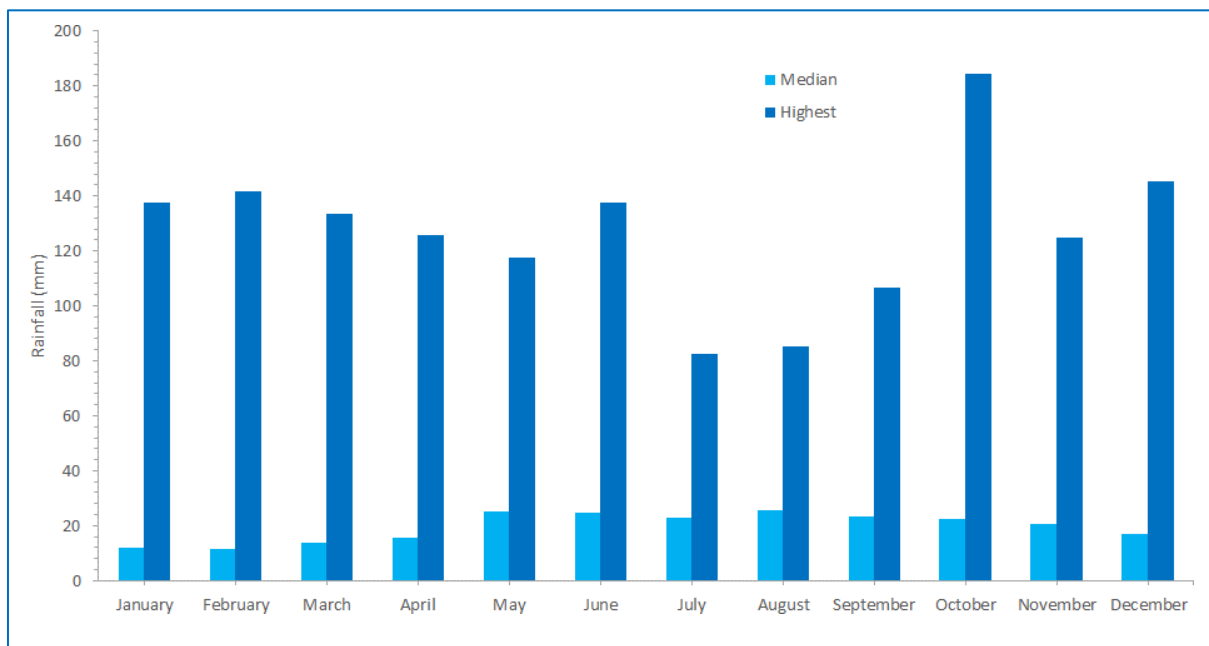


Figure 2.2: Long term rainfall statistics, Balranald (1879-2023) (source: Bureau of Meteorology)

2.1.3 Wind speed/direction

The annual wind rose, derived from the Swanhill³ measurement data from 2012 to 2022, is presented in Figure 2.3 while the seasonal wind roses are presented in Figure 2.4. Wind roses show the frequency of occurrence of winds by direction and strength. The bars correspond to the 16 compass points – N, NNE, NE, etc. The bar at the top of each wind rose diagram represents winds blowing from the north (i.e. northerly winds), and so on. The length of the bar represents the frequency of occurrence of winds from that direction, and the widths of the bar sections correspond to wind speed categories, the narrowest representing the lightest winds

The major features evident from these wind roses are as follows:

- The predominance of south-easterly to south westerly winds is evident, occurring more often during spring and summer than at other times of the year.
- During autumn and winter south-westerly to north westerly winds occur more often, with a high frequency of northerly winds.
- Light winds are more predominant from the south to south-west, occurring more often during autumn and winter.
- Strong winds are predominantly from the south-west to north-west and occur in any season.

³ Swanhill is located approximately 55 km south of the project site and is used for this analysis in the absence of wind measurement data at Balranald.

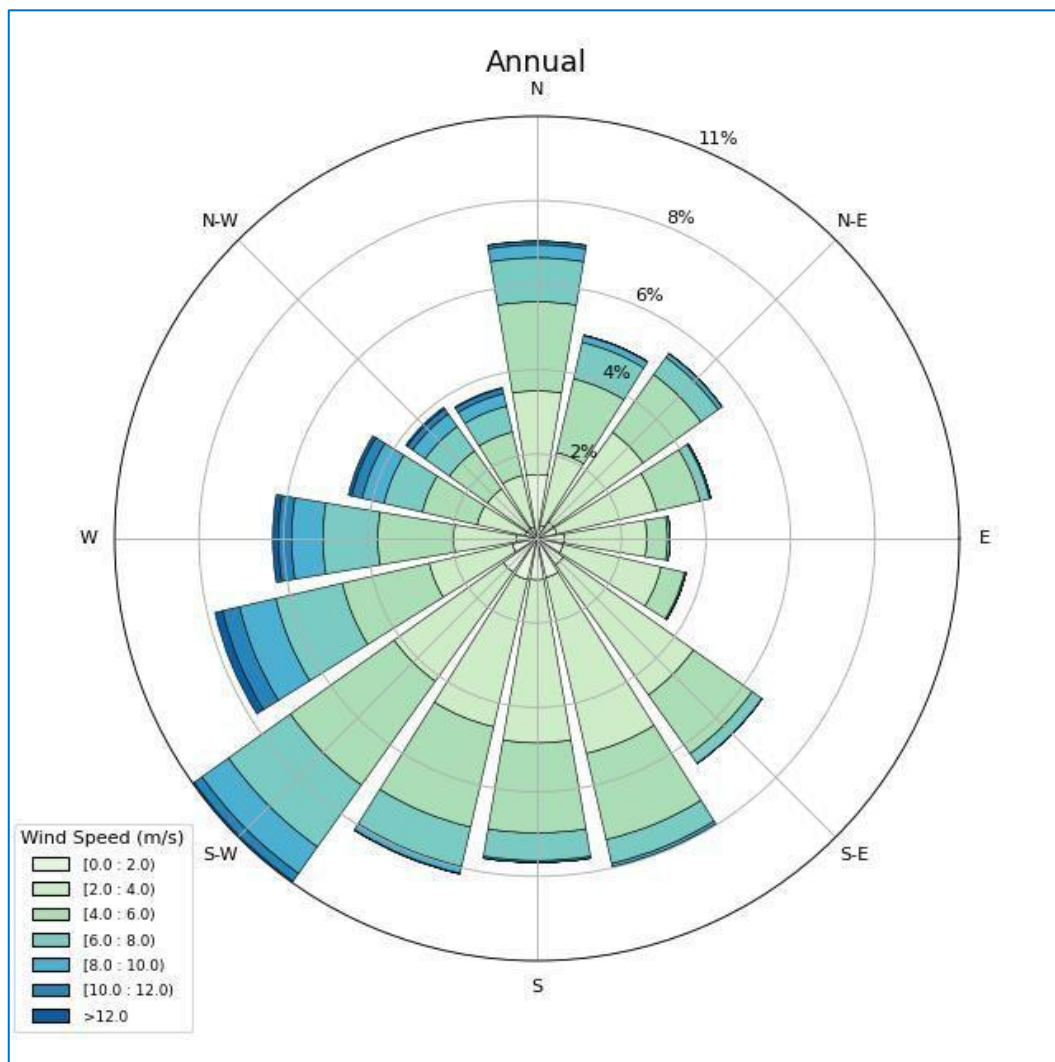


Figure 2.3: Annual wind rose (BoM Swanhill 2012-2022)

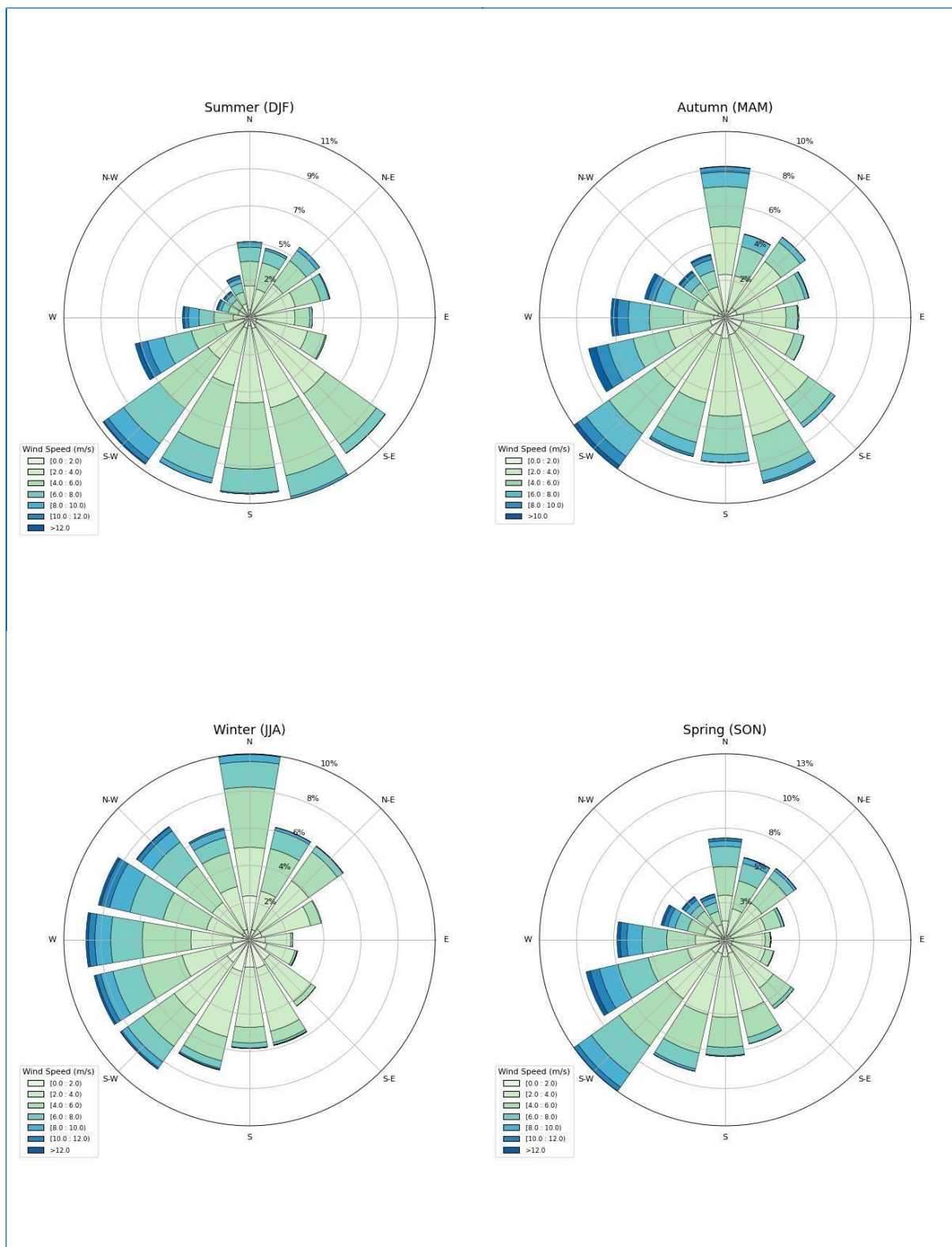


Figure 2.4: Seasonal wind roses (BoM Swanhill 2012-2022)

2.2 Geophysical Environment

The environment in the vicinity of the proposed wind farm is characterised by relatively flat topography with an average height of 66 m with scattered sand hills up to 82 m (Australian Height Datum). Land cover consists of cropland and grazing, interspersed with areas of natural woodland (Figure 2.5). The Limondale and Sunraysia solar farms covering an area of approximately 2,100 ha is located approximately 1.7 km to the northwest of the proposed wind farm.

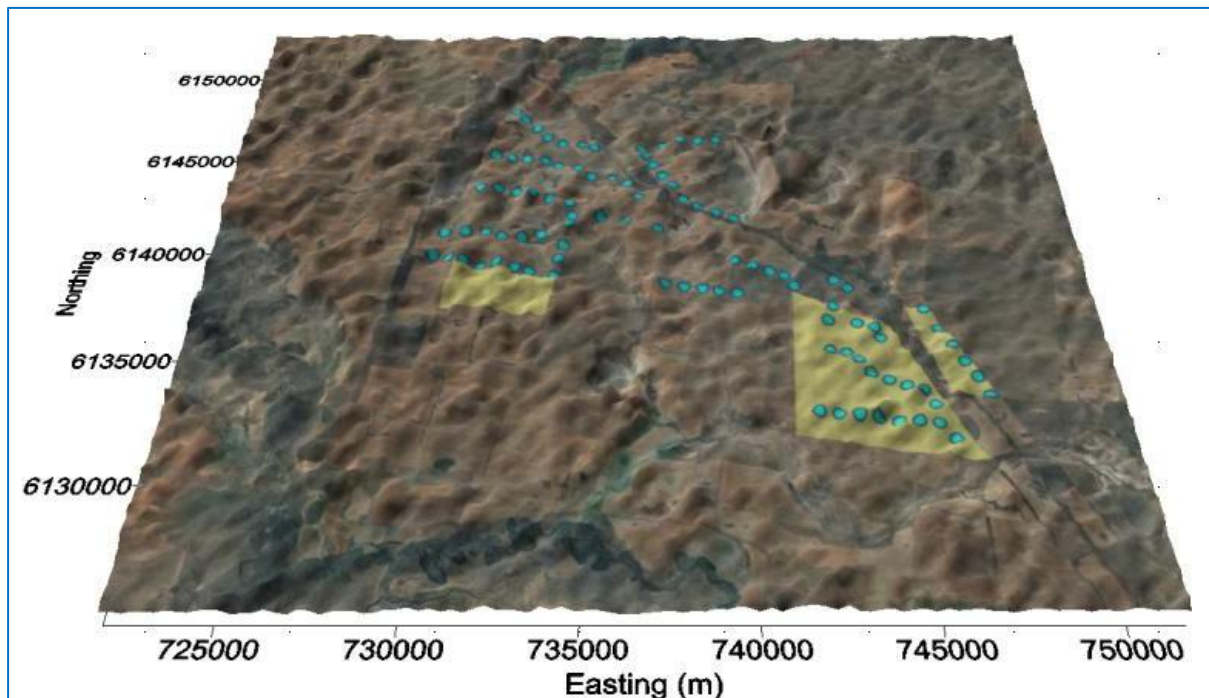


Figure 2.5: Three-dimensional terrain elevation showing location of wind turbines and potential spray areas

3 Modelling Methodology

3.1 Overview

For this assessment, spray dispersion and deposition modelling has been conducted using the CALPUFF dispersion model with meteorological data produced from the WRF prognostic model. The WRF meteorological model has been used to develop the required 3-dimensional meteorological inputs, and the CALPUFF model has been used to predict concentration and deposition at ground-level across the model domain and at nominated discrete receptor locations. Meteorological measurements from the BoM Swanhill AWS have been used to assess the accuracy of the meteorological inputs generated by WRF for the modelling.

An overview of the air quality modelling approach is shown in Figure 3.1.

Further details of model settings and input parameters are provided in the subsections following.

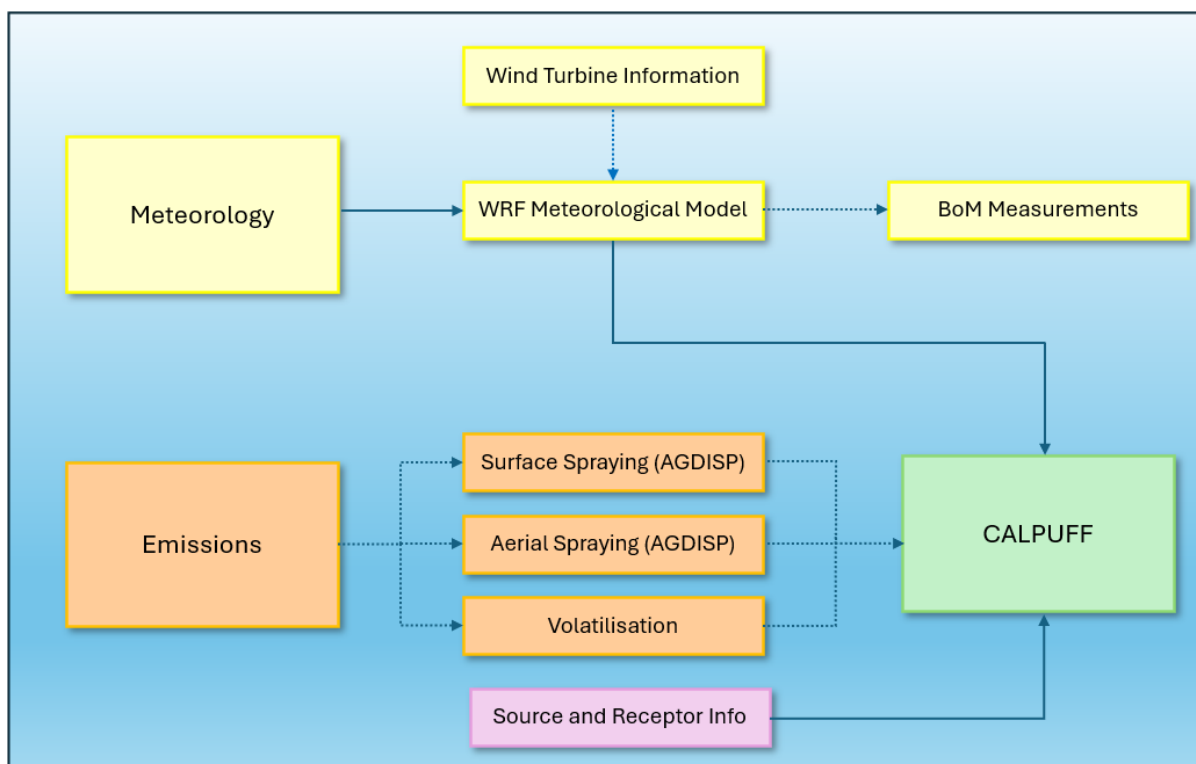


Figure 3.1: Air quality assessment – study approach

3.2 Meteorology

3.2.1 Selection of representative year

Generally, a minimum of one year of meteorological data is accepted by regulators for dispersion modelling in Australia. The data must, however, adequately represent worst-case meteorological conditions and the data should be assessed in terms of representativeness against climatic averages. In other words, the meteorology for selected years must be deemed representative of the “normal” range of conditions in the area.

To determine the year of meteorological data to use for the dispersion modelling, 11-years of historical surface observations from the BoM weather station at Swanhill (2012 to 2022 inclusive) were reviewed. The 2020

calendar year was selected for modelling based on visual and statistical tests for representativity against long-term average conditions. The results of the statistical analysis performed to support selection of the representative year is presented in Appendix A.

3.2.2 Meteorological Models

3.2.2.1 The Weather Research and Forecast (WRF) model

In the absence of adequate meteorological data to produce an accurate 3-dimensional representation of the dispersion meteorology over the area, the Weather Research and Forecast (WRF V4.1) model (<https://www.mmm.ucar.edu/models/wrf>) was used to generate hourly 3-dimensional data for the region. WRF is the next-generation mesoscale numerical weather prediction system primarily designed to serve both operational forecasting and atmospheric research. WRF features multiple dynamical cores, a 3-dimensional data assimilation system and a software architecture allowing for computational parallelism. In addition, WRF has the capability of modelling the effects of wind turbines on the regional wind and turbulence through a wind turbine drag parameterisation scheme. Hourly meteorological data for the full 2020 year was generated with- and without the wind farm in order to determine the effects of the proposed windfarm on the local meteorology.

Further information on WRF, including technical discussion of the WRF validation against Swanhill measurements is provided in Appendix A

3.3 CALPUFF

CALPUFF is the dispersion module of the CALMET/CALPUFF suite of models. It is a multi-layer, multi species, non-steady-state puff dispersion model that can simulate the effects of time-varying and space-varying meteorological conditions on pollutant transport, transformation and removal. The model contains algorithms for near-source effects such as building downwash, partial plume penetration, sub-grid scale interactions as well as longer range effects such as pollutant removal, chemical transformation, vertical wind shear and coastal interaction effects. The model employs dispersion equations based on a Gaussian distribution of substances across released puffs and considers the complex arrangement of emissions from point, area, volume and line sources (Scire et al., 2011).

It is listed by the United States Environmental Protection Agency (USEPA) as an alternative regulatory dispersion model for assessing certain near-field applications involving complex meteorological conditions and long-range transport of substances (US EPA, 2024). The CALPUFF model is used extensively throughout Australia for regulatory assessments of mining projects.

The CALPUFF model was set to calculate concentration and deposition on a set grid (gridded receptors). The model domain was defined as 32 km in the east–west and 29 km in the north-south direction at a spacing of 200 m x 200 m.

3.3.1 Particle Sizing | Gravitational Settling

CALPUFF was set up to model depletion of the spray drift concentration through gravitational settling and dry deposition of substances at the surface. To simulate gravitational settling of airborne particles, information on the particle size distribution (PSD) is required as input to the model. A final droplet diameter distribution is estimated using the AGDISP model (See Appendix B).

3.3.2 Discrete Receptors

The modelling assessment considers the impacts at discrete receptor locations surrounding both potential spraying areas. These have been selected at 500 m, 1 km, 2 km, 3 km, 4 km and 5 km distances from the potential spray area as per the Windlab scope of work. The discrete receptor locations are listed in Table 1 and shown in Figure 3.2.

Table 1: Summary of discrete receptor locations

Direction	Distance (m)	Area 1			Area 2		
		Receptor No.	Easting (m)	Northing (m)	Receptor No.	Easting (m)	Northing (m)
East	500	E1	729490	6138100	E7	741000	6134684
	1000	E2	728990	6138100	E8	740500	6134684
	2000	E3	727990	6138100	E9	739500	6134684
	3000	E4	726990	6138100	E10	738500	6134684
	4000	E5	725990	6138100	E11	737500	6134684
	5000	E6	724990	6138100	E12	736500	6134684
South	500	S1	731510	6136090	S7	743980	6130390
	1000	S2	731510	6135590	S8	743980	6129890
	2000	S3	731510	6134590	S9	743980	6128890
	3000	S4	731510	6133590	S10	743980	6127890
	4000	S5	731510	6132590	S11	743980	6126890
	5000	S6	731510	6131590	S12	743980	6125890
West	500	W1	734270	6138100	W7	747480	6134684
	1000	W2	734770	6138100	W8	747980	6134684
	2000	W3	735770	6138100	W9	748980	6134684
	3000	W4	736770	6138100	W10	749980	6134684
	4000	W5	737770	6138100	W11	750980	6134684
	5000	W6	738770	6138100	W12	751980	6134684
North	500	N1	731510	6139215	N7	743980	6136765
	1000	N2	731510	6139715	N8	743980	6137265
	2000	N3	731510	6140715	N9	743980	6138265
	3000	N4	731510	6141715	N10	743980	6139265
	4000	N5	731510	6142715	N11	743980	6140265
	5000	N6	731510	6143715	N12	743980	6141265

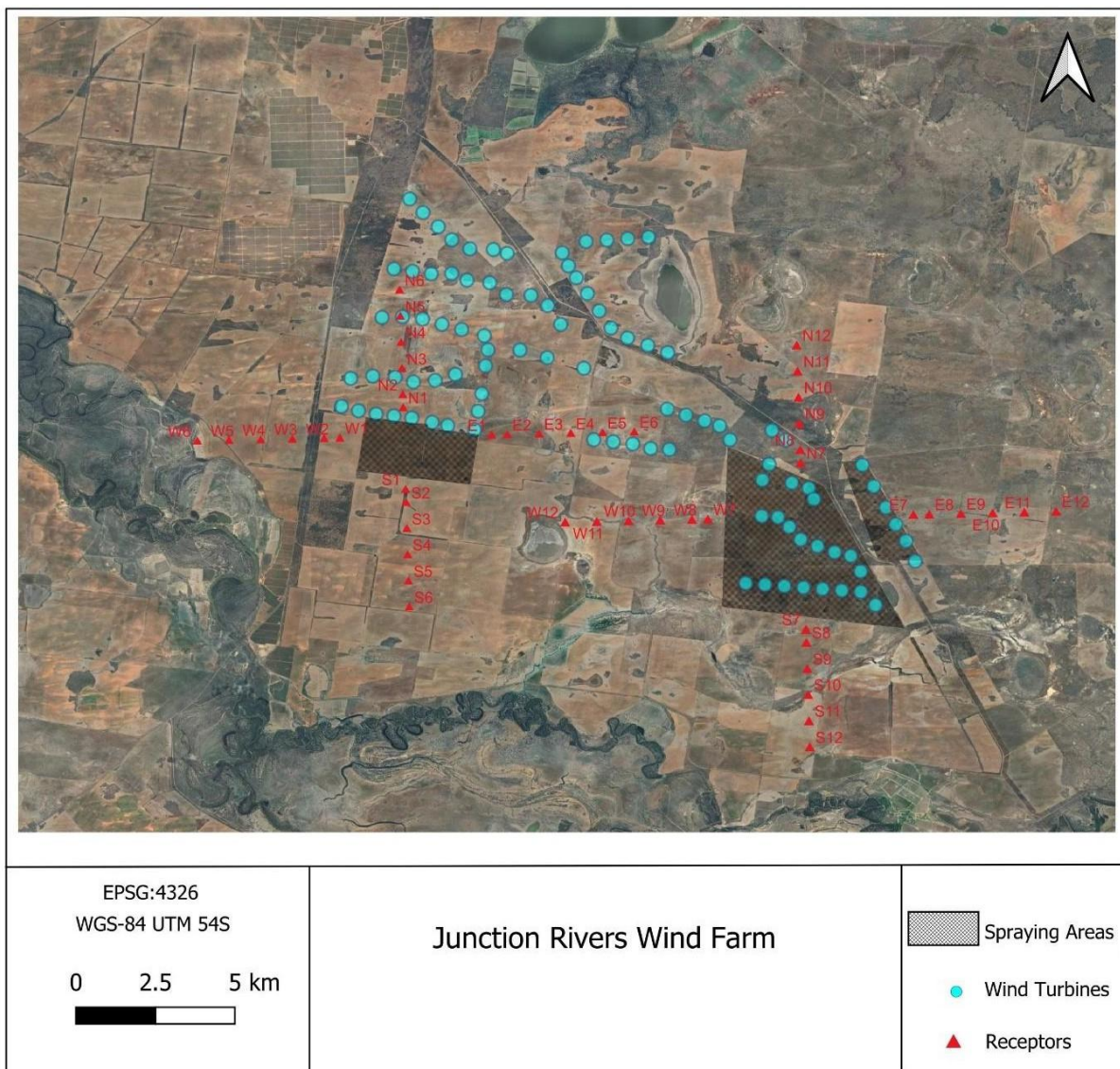


Figure 3.2: Sensitive receptor locations

3.4 Model Uncertainty

Atmospheric dispersion models represent a simplification of the many complex processes involved in approximating ground-level concentrations of substances. The model uncertainty is therefore composed of uncertainties associated with model chemistry and physics, data, and stochastic uncertainties. There are also inherent uncertainties in the behaviour of the random turbulence of the atmosphere.

As with any modelling assessment of this nature, there are areas of uncertainty in this spray drift assessment. To ensure that potential air quality impacts are not underestimated, conservative assumptions have been applied as appropriate, to provide over-predictions rather than under-predictions of ground-level concentrations.

Factors contributing to the general uncertainty in model results include:

- the turbulent (random) nature of dispersion in the turbulent atmosphere

- inaccuracies in the mathematical description of the physical and chemical processes that occur in the atmosphere (i.e. uncertainties in the numerical solutions)
- stochastic uncertainties, as models predict 'ensemble mean' concentrations (i.e. they predict the mean concentrations that would result from a large set of observations under the specific conditions being modelled)
- data uncertainty or variability, particularly in emission information and meteorological data inputs.

3.5 Conservatism of Assessment

This assessment has been performed with an emphasis on conservatism. Specifically:

- Emission sources (i.e., spraying events) were modelled as occurring every time suitable meteorological criteria for spraying occurred in order to capture impacts under most meteorological conditions (Section 4.1). Consequently, modelling assumed spraying for 1,160 hours a year. In reality, single pesticide products were used on most crops intermittently and no more than seven times a year, with the most intensively treated crops sprayed between 10 and 20 times a year (van Drooge et. al., 2001).
- The modelled concentration and deposition results were presented as maximum hourly values that can occur over a full calendar year. This means that these values represent the highest single potential impacts that can occur and is also compounded by the conservative emissions approach outlined in the bullet point above.
- The contour plots showing dust deposition show the maximum experienced at any point during the year. These may occur at different times.

4 Emission and Source Information

4.1 Introduction

This section outlines the emission estimation process used to develop the emission inventory for the Project. It includes the emissions generated from ground spraying, aerial spraying and volatilisation from sprayed surfaces.

Spraying activities and hence emissions for modelling have been restricted to daytime hours and during suitable meteorological conditions as per the *NSW Aerial Spraying Guidelines* (NSW DPE, 2022) and *A guide to using agricultural chemicals in Victoria: ground-based spray applications* (Agriculture Victoria, 2018). Suitable weather conditions for spraying are:

- wind direction – especially when wind is blowing away from susceptible areas. This criterion was not applied to allow for assessment of impacts with all wind directions
- thermal inversion absent. Stability classes 1-4 (unstable to neutral conditions) were taken to reflect a lack of inversion (NSW EPA, 2014)
- wind speed between 4 and 15 km/hr
- lack of extremely low or high temperatures ($>15^{\circ}\text{C}$ and $<28^{\circ}\text{C}$)
- Delta T (ΔT)⁴ between 2 and 8. ΔT is an important indicator of acceptable spraying conditions and gives an indication of evaporation rate and droplet lifetime.

Figure 4.1 shows the frequency of suitable spraying conditions by time of day and month, based on the WRF - generated meteorology for the wind farm. As expected, optimal spraying conditions are between 6 am and 10 am while the cooler months have more suitable conditions throughout the day.

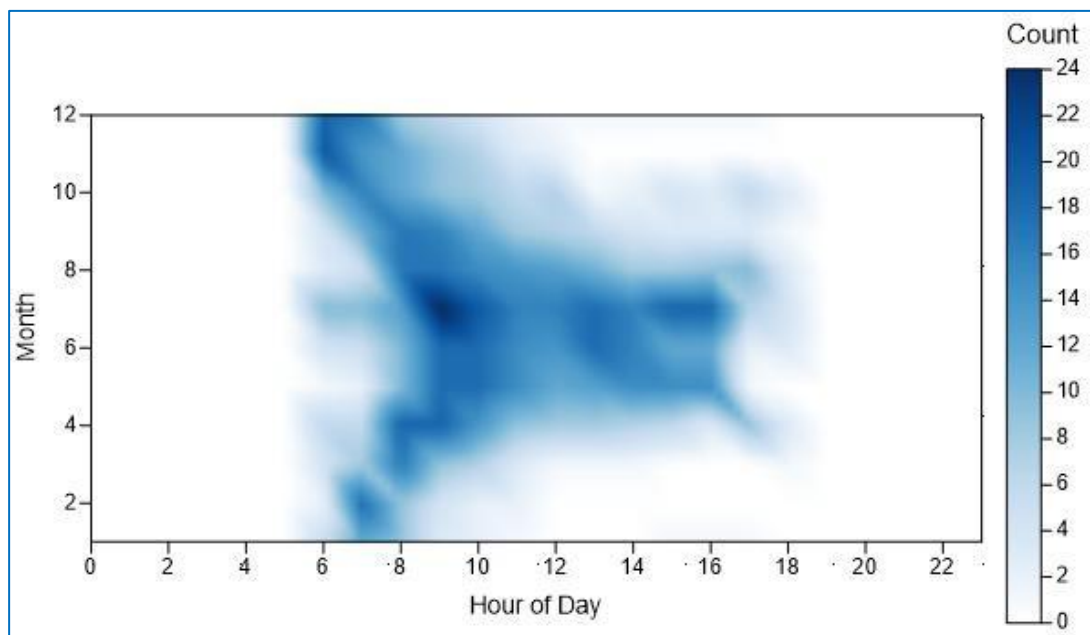


Figure 4.1: Seasonal and temporal frequency of spraying activity based on suitable meteorological conditions

⁴ ΔT is the difference between the dry and wet bulb temperature

As a conservative approach, spraying activity is assumed to occur whenever meteorological conditions are conducive for spraying in order to allow consideration of impacts under all possible meteorological conditions. This frequency of spraying is highly unlikely in reality and good practice will preclude spraying when adverse wind directions result in spray drift to neighbouring properties. Furthermore, conversations between the local community and Windlab have indicated that chemical spraying follows the crop cycles. Ground spraying occurs no more than twice per year, and aerial spraying has not been conducted in the area for more than 20 years (Windlab, April 2025).

4.2 Ground Spraying

Ground-based spraying of agricultural chemical products is the most common method of application. There are a number of agriculture sprayers designed for spraying applications, including boom sprayers (example in Figure 4.2). A boom sprayer typically applies spray downward from a ground-based horizontal boom, which is mounted to a vehicle and used to produce a spray swath significantly wider than the vehicle itself.



Figure 4.2: Indicative ground spraying (Photo by Mark Stebnicki)

Ground spraying emissions during suitable meteorological conditions (see Section 4.1) were estimated using the AGDISP spray model. This model is used for estimating downwind deposition of spray drift from aerial and ground boom applications and is used by the U.S. Department of Agriculture Forest Service to evaluate and manage spray applications and forms the basis of a regulatory tool used by the U.S. Environmental Protection Agency (EPA). Further information on this model is provided in Appendix B.

Appendix B. also provides a technical discussion on the methodology used to estimate ground spraying emissions for this study. A maximum emission rate of 6.46×10^{-6} g/m²/s was thus calculated. The sources were configured in the CALPUFF dispersion model as multiple area sources, with each area source representing a single swathe of the sprayer (Figure 4.3). The width and length of each source was approximately 100 m and 3,400 m respectively. An emission rate of 6.46×10^{-6} g/m²/s was randomly assigned to one of the individual areas shown in the figure during suitable meteorological conditions but never repeating the same area for consecutive time

steps. Each source is only expected to emit for an hour, given that the sprayer (speed of 5.5 km/hr) will traverse the length of the spray sector in slightly less than an hour. Both spray areas were modelled in an identical fashion.

A description of the model set up is provided in Appendix C.

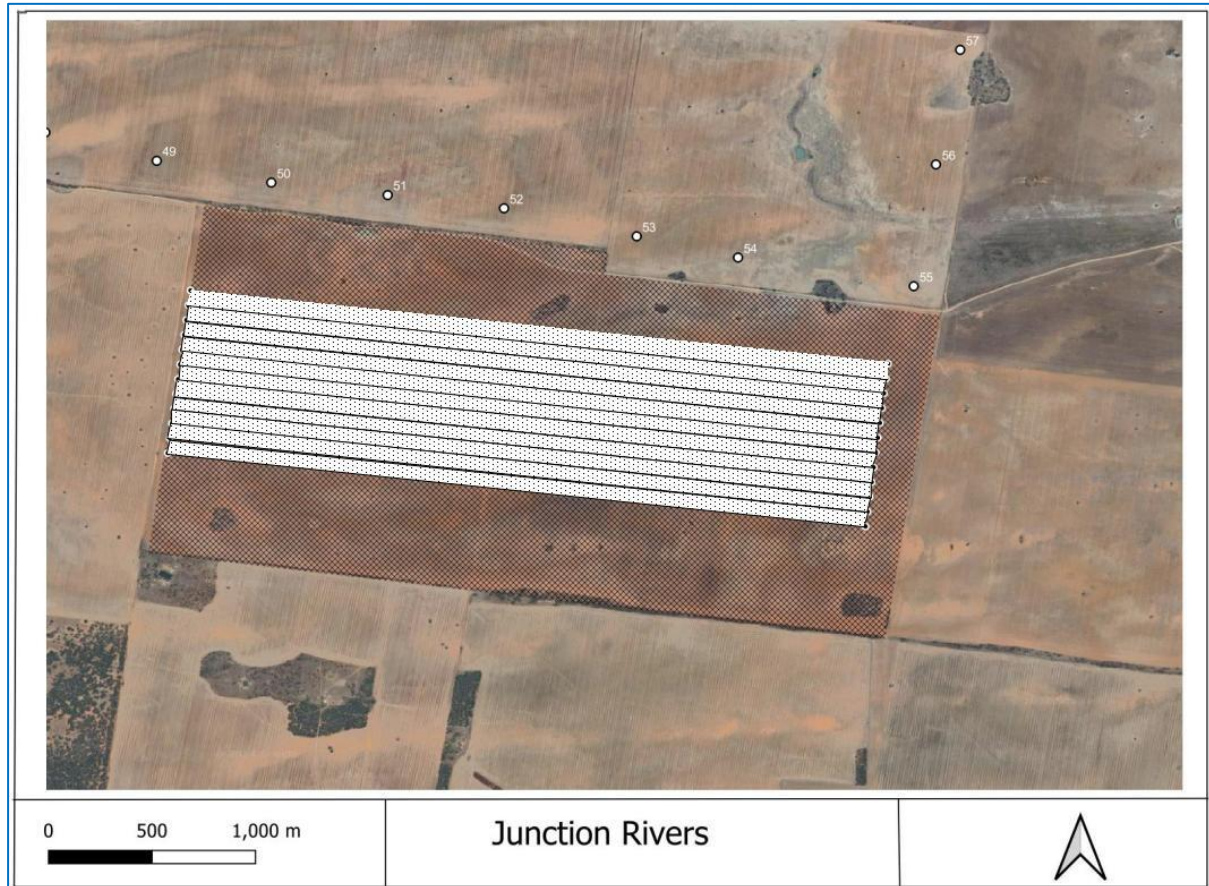


Figure 4.3: Example of area source configuration for the CALPUFF dispersion model

4.3 Aerial Spraying

Aerial application of agricultural chemical products (crop dusting) involves using specialised, purpose-built aircraft (example in Figure 4.4). The use of aircraft as a means of application of agricultural chemical products has developed due to the greater speed, better timing, and efficiency of application offered by an airborne platform. Aircraft are able to apply agricultural products rapidly over large areas within optimum application windows.

The CALPUFF dispersion model has been adapted to accommodate emissions produced during aerial spraying activities. The emissions input to the CALPUFF model are produced by the model AGDISP which predicts the motion of spray material released from aircraft, including evaporation and turbulent dispersion within the aircraft wake (Exponent, 2019). The aerial spraying will occur during suitable meteorological conditions and over a similar area to the ground spraying over both potential spraying areas. A technical discussion on the methodology used to model aerial spraying emissions in CALPUFF is provided in Appendix B and a description of the model set up is provided in Appendix C.



Figure 4.4: Indicative aerial spraying (Photo by Eric Brehm)

4.4 Volatilisation

Volatilisation of crop spraying refers to the process where a fraction of a sprayed agricultural chemical product evaporates from the treated area, transforming into a gas and potentially drifting away into the atmosphere, which can lead to off-target contamination. The rate of volatilisation is dependent on temperature and humidity, with high temperatures increasing the rate of volatilisation of the chemical and increase the rate of evaporation of the liquid that forms the spray droplets. Low humidity will also increase the rate of evaporation of droplets.

A technical discussion on the calculation of volatilisation rates used in the dispersion model is provided in Appendix B. The sources were configured in the CALPUFF dispersion model as multiple area sources, identical to those used for ground spraying (Figure 4.3). For the purposes of dispersion modelling, the emissions of volatilised chemical product (taken as carbofuran) are assumed to be related to ground spraying, with volatilisation at the same locations (source areas A and B) commencing immediately after ground spraying (See Section 4.2).

A description of the model set up for this emission source is provided in Appendix C.

4.5 Summary of Estimated Emissions

A summary of the estimated emission statistics is shown in Table 2.

Table 2: Estimate of pesticide emissions.

Source Type	Emissions		
	Maximum	Average	Standard Deviation
Ground Spraying ¹	-	6.46x10 ⁻⁶	-
Aerial Spraying ²	4.57x10 ⁻⁴	5.63x10 ⁻⁵	1.07x10 ⁻⁴
Volatilisation ¹	1.3x10 ⁻⁵	9.6x10 ⁻⁷	1.4x10 ⁻⁶

¹Emission rate in g/m²/s

²Emission rate in g/m

Ground spraying emissions are assumed to be constant while aerial and volatilisation emissions vary with time or location/height. It is important to reiterate that the focus of the study is to assess the relative impacts of the proposed wind farm on spraying operations at an adjacent property rather than a quantitative assessment of impacts.

5 Modelled Impacts

This section presents the results of the modelling in terms of predicted meteorology and ground-level concentration and deposition without the wind farm (base) and with the proposed wind farm.

Contours of the modelled maximum hourly ground-level concentration and deposition predicted across the model domain are also presented, overlain on an aerial of the project site and surrounds. The modelled changes in deposition are presented as shaded contour plots and graphically displayed for maximum, 2nd highest and 3rd highest values at the discrete receptors shown in Figure 3.1. It is important to note that the concentration and deposition contours should be viewed in the context of patterns rather than absolute values given the uncertainties and limitations in this study, as outlined in Section 1.5.

5.1 Meteorology

Selected meteorological variables were extracted from the meteorological model for a point corresponding to the potential spraying area (see Figure 4.3). In summary, the changes in meteorological conditions due to the proposed wind farm operations are:

- That there are minimal changes in wind conditions at 10m, and are not expected to significantly affect dispersion conditions
- That at 120 m, there is a marginal increase in the frequency light winds, as well as north-easterly winds. However, at this height, the changes are not expected to affect dispersion on the ground.
- That the decrease in mixing heights during the day is not expected to significantly affect dispersion conditions, as there is generally good dispersion during the day.
- That there are no appreciable changes to atmospheric stability.
- That vertical velocity shows a slight increase in the frequency of up- and downdrafts at both the 10 m and 120 m heights with the wind turbines.

5.1.1 Wind

The general features of the 10 m and 120 m winds with and without the proposed wind farm are illustrated in the annual and seasonal wind rose diagrams for the 12-month period from January 2020 – December 2020⁵ are shown in Figure 5.1. Seasonal wind roses are presented in Appendix A.

The wind roses show the frequency of occurrence of winds by direction and strength. The bars correspond to the 16 compass points – N, NNE, NE, etc. The bar at the top of each wind rose diagram represents winds blowing from the north (i.e. northerly winds), and so on. The length of the bar represents the frequency of occurrence of winds from that direction, and the widths of the bar sections correspond to wind speed categories, the narrowest representing the lightest winds.

The major features of the wind rose are as follows:

⁵ The selected representative meteorological year (as determined previously).

- At 10 m, the base and project wind rose patterns are comparable although there is a slight increase in frequency of north-easterly and south-easterly to south-westerly winds with the project.
- At 120 m, the base and project rose patterns are also comparable, but there is a slight increase in the frequency of north-easterly winds with the project.
- Frequency of lighter winds increase at both 10 m and 120 m with the project.

The frequency histograms⁶ for wind speed for the base case and the project at 10 m and 120 m are shown in Figure 5.2 (seasonal and hourly statistics of wind speeds are shown in Appendix A). At 10 m, there is a slight increase in the frequency of light winds and a decrease in frequency of stronger winds with the project. This is an expected outcome.

The most significant change to wind occurs at higher elevations (i.e. 120 m), which is less significant for this study.

The impacts of the potential wind farm on the local meteorology are examined in more detail for two case studies, one at 11 am on 2 October under northerly wind conditions and the other one at 5 pm on 7 October. To better illustrate the impact of the proposed wind farm, selected meteorological parameters for the wind farm are subtracted from the base case parameters. Figure 5.3 shows the difference in 10 m wind speed between the base and wind farm cases. The figure shows reduced wind speeds over and extending in a plume of up to 10 km downwind of the wind farm in both cases.

5.1.2 Mixing Height

The average hourly variation of mixing height⁷ is summarised in Figure 5.4⁸ (seasonal statistics are shown in Appendix A) with the diurnal cycle evident. At night, mixing height is relatively low (average of 200 m) and after sunrise it typically increases to between 1,200 m and 2,200 m in response to convective mixing generated by solar heating of the Earth's surface. A rapid reduction in mixing height commences around sunset when convective mixing ceases, and a mechanical mixing regime is re-established. There is only minimal difference between the base and wind farm mixing heights.

The frequency histograms for mixing height for the base case and wind farm is shown in Figure 5.5. The figure shows that there is a relatively small increase in the frequency of mixing heights (i.e., inversion layers) below 250 m and a decrease between 250 m and 500 m with the project. This is also seen by the slight increase in the frequency of stable (i.e. non-turbulent) conditions, especially at night (see Appendix A).

⁶ A frequency histogram shows the number of events between several set values occurring in a year

⁷ Mixing height is the depth of the atmospheric surface layer beneath an elevated temperature inversion (where temperature increases with height as opposed to decreases with height) and is a function of the amount of turbulence in the lower levels in the atmosphere. Vertical mixing is limited by the mixing height, as the air above this layer tends to be stable, with restricted vertical motion. In terms of dispersion, contaminants released below the inversion (i.e. mixing height) will have restricted vertical dispersion.

⁸ The blue bars depict the 10th and 90th percentile values while the diamond shape shows the average conditions. The whiskers indicate minimum and maximum values of the data, and the line within the blue bar indicates the median.

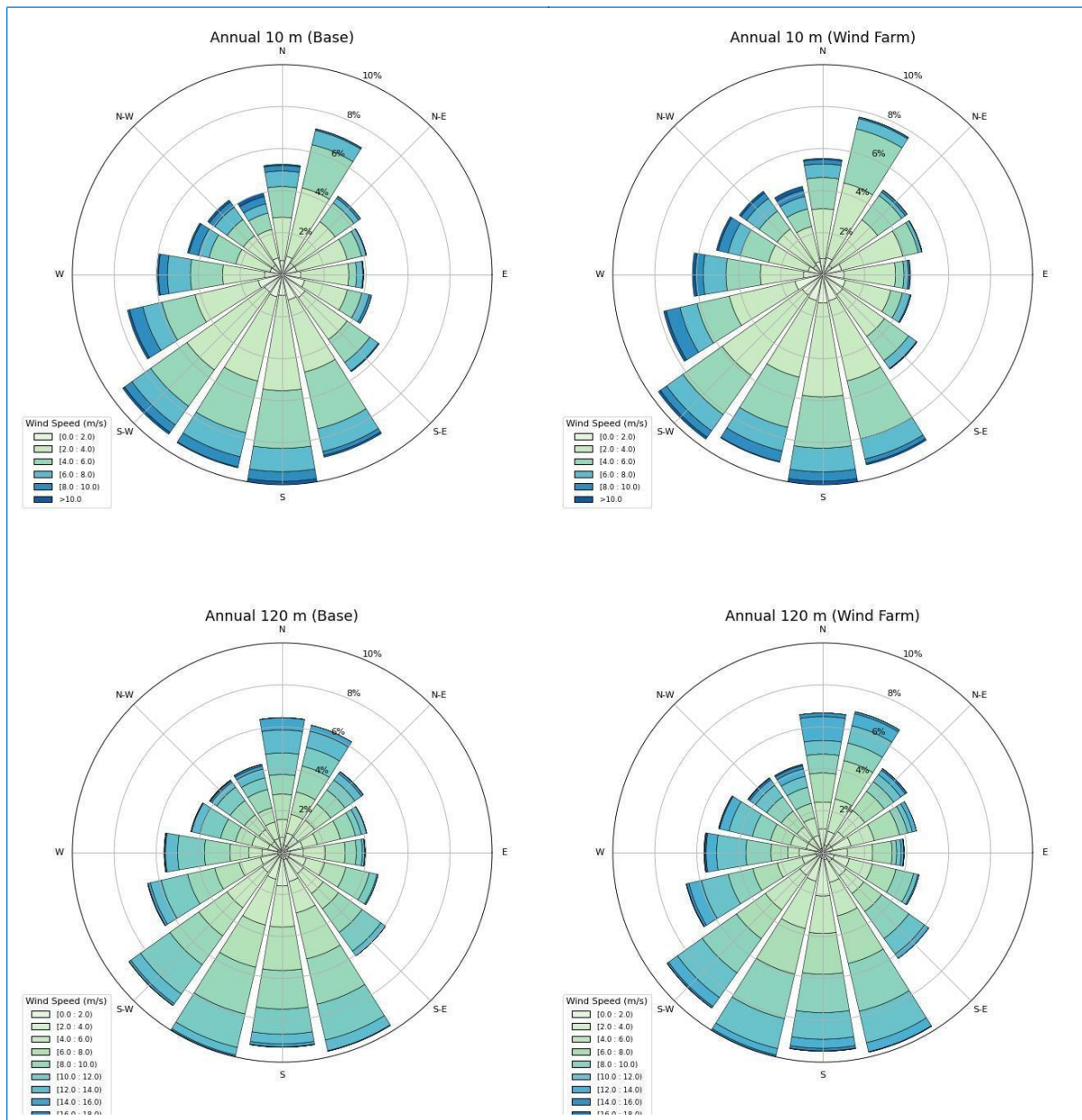


Figure 5.1: Annual wind roses generated from WRF for the spray area at 10 m (top) and 120 m (bottom). Figures on the left represent base case and figures on the right the wind farm

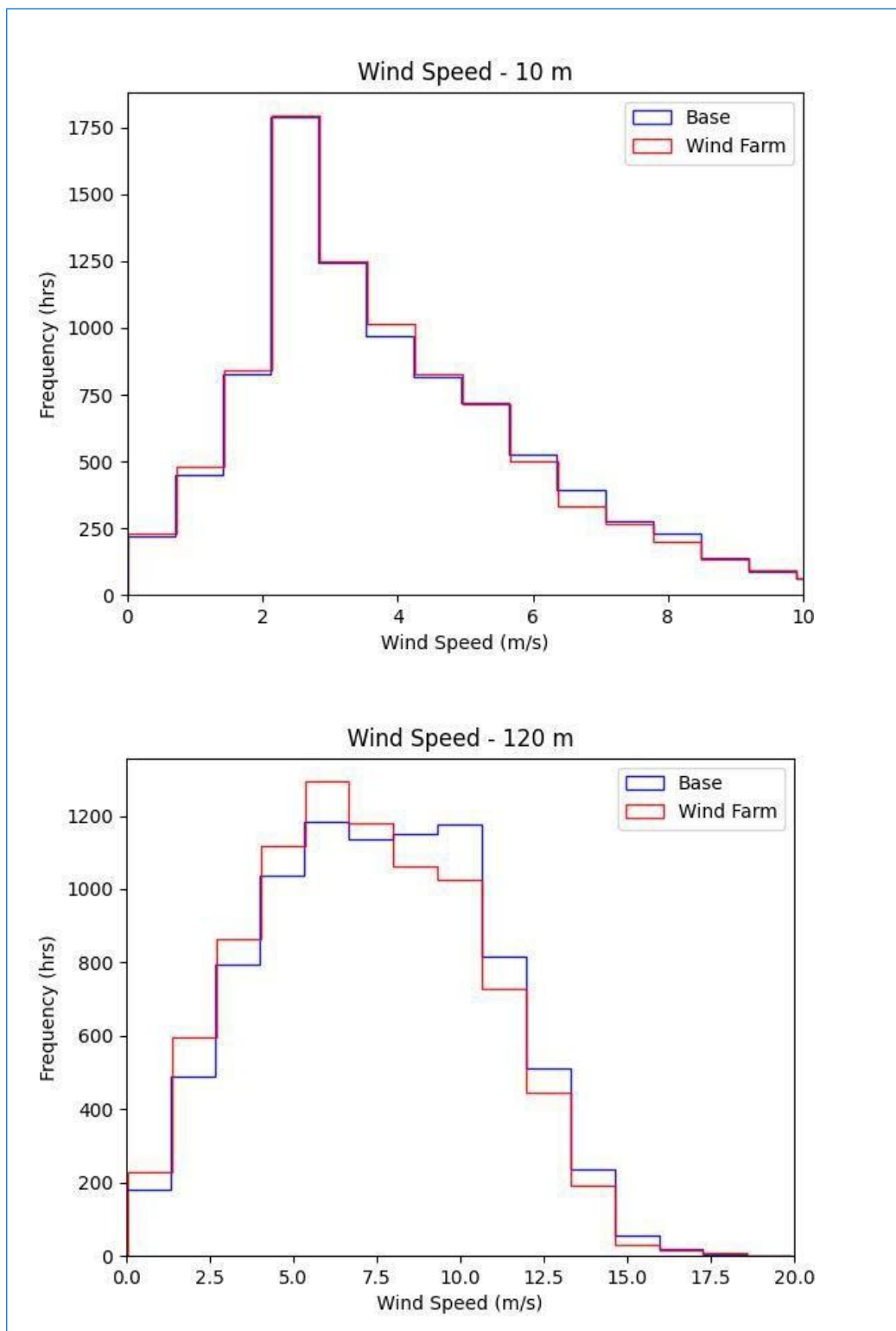


Figure 5.2: Difference in frequencies of wind speeds for the base and wind farm cases at 10 m (top) and 120 m (bottom)

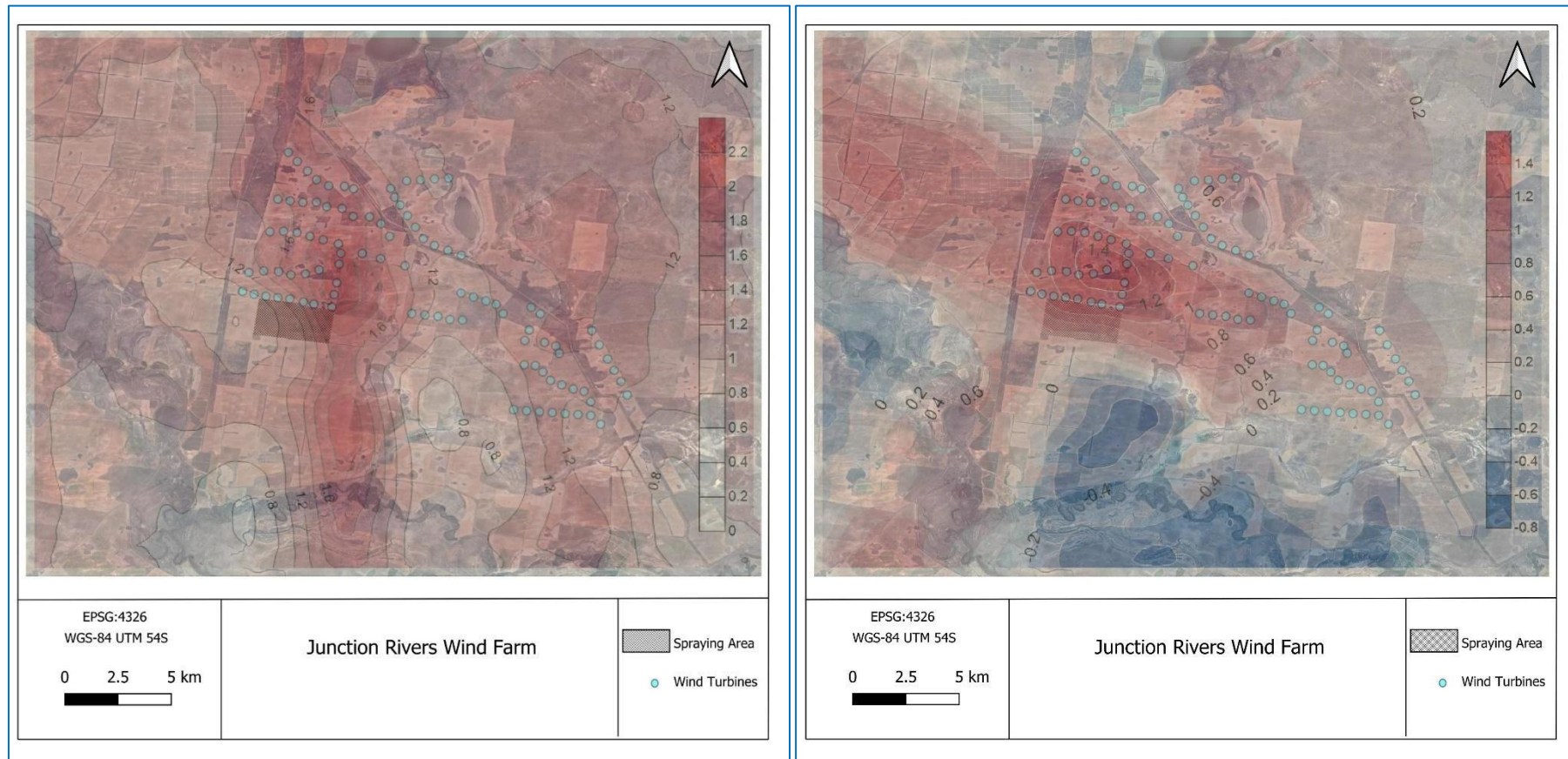


Figure 5.3: Contours of difference (base minus wind farm) in wind speed at 10 m for northerly wind at 11 am on 2 October (left) and easterly wind at 5 pm on 7 October (right). Units in m/s

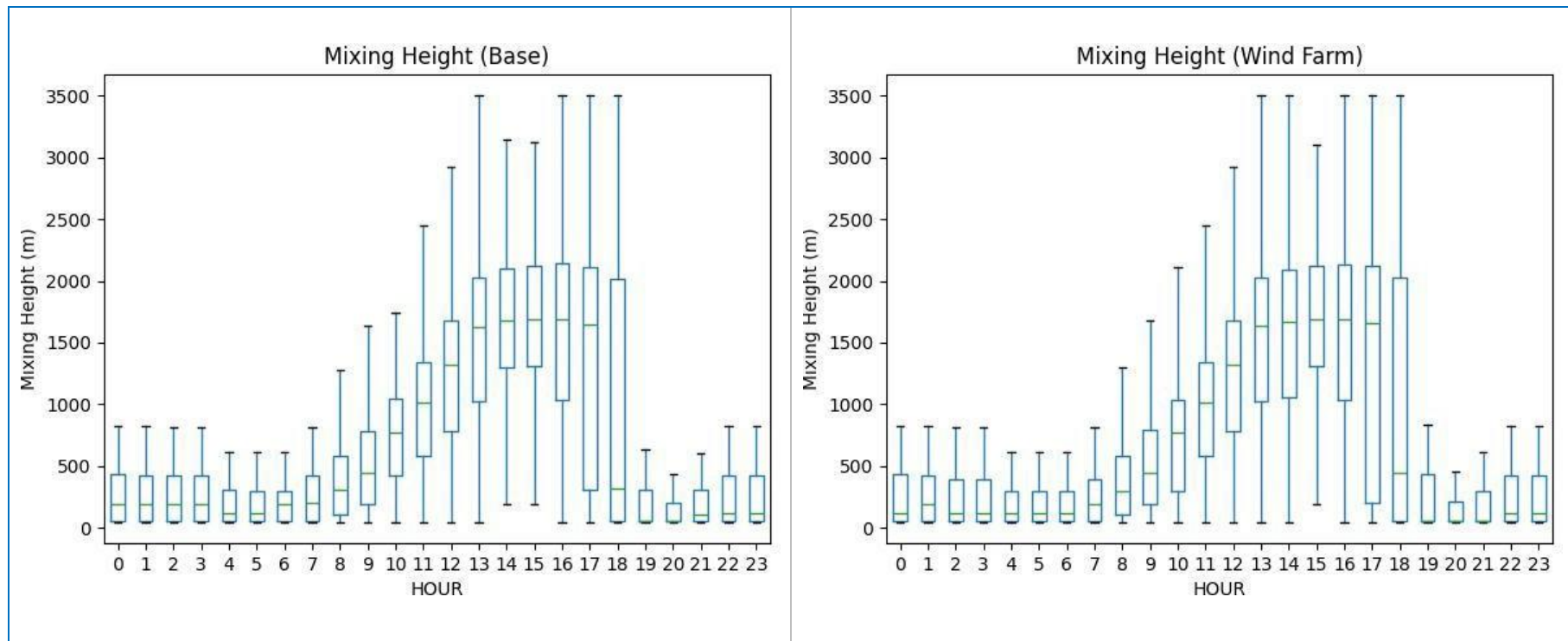


Figure 5.4: Simulated annual statistics. of hourly mixing heights for extracted point Base case (left) and the project (bottom)

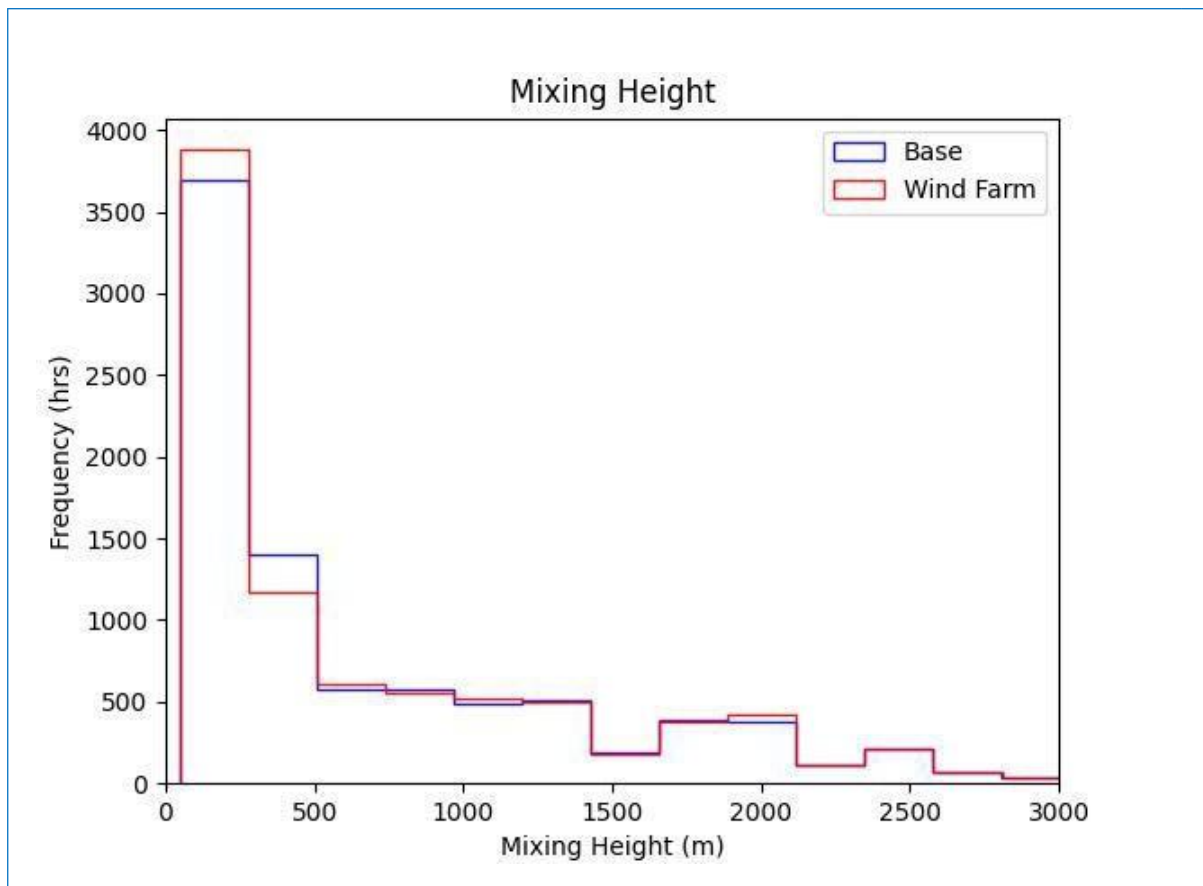


Figure 5.5: Difference in frequencies of mixing height for the base and wind farm cases

5.1.3 Vertical Velocity

The comparison of the frequencies of vertical velocity at 10 m and 120 m (base and wind farm cases) for the extracted location coinciding with the potential spraying area is shown in Figure 5.6 (additional statistics of vertical velocity is provided in Appendix A.3: At both 10 m and 120 m, vertical velocity magnitudes (upward and downward) increase with the inclusion of wind turbines in the modelling as is seen by the wider frequency bands.

The difference in 10 m vertical velocity (base minus project) on 11 am on 2 October and 5 pm on 7 October is shown in Figure 5.7 and the difference at 120 m at 11 am on 2 October is shown in Figure 5.8. The 10m heights show an increase in upward motion (positive values) in the immediate vicinity of the turbines, extending for a short distance downwind. A similar pattern is seen at 120 m. It is important to note that the effect of the wind farm on the vertical velocity is an order of magnitude lower at 10 m than at 120 m, as expected.

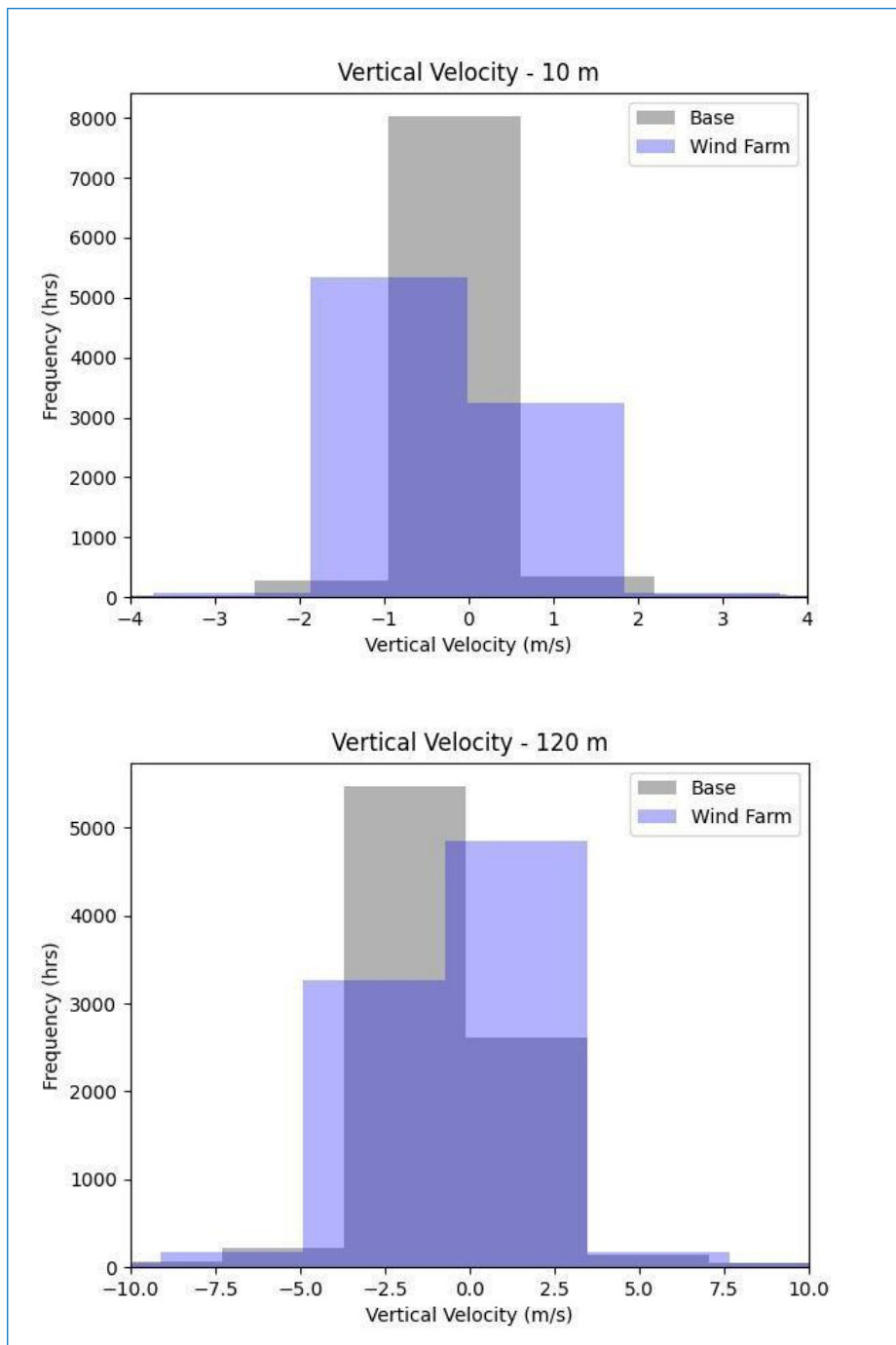


Figure 5.6: Difference in frequencies of vertical velocity for the base and wind farm cases at 10 m (top) and 120 m (bottom)

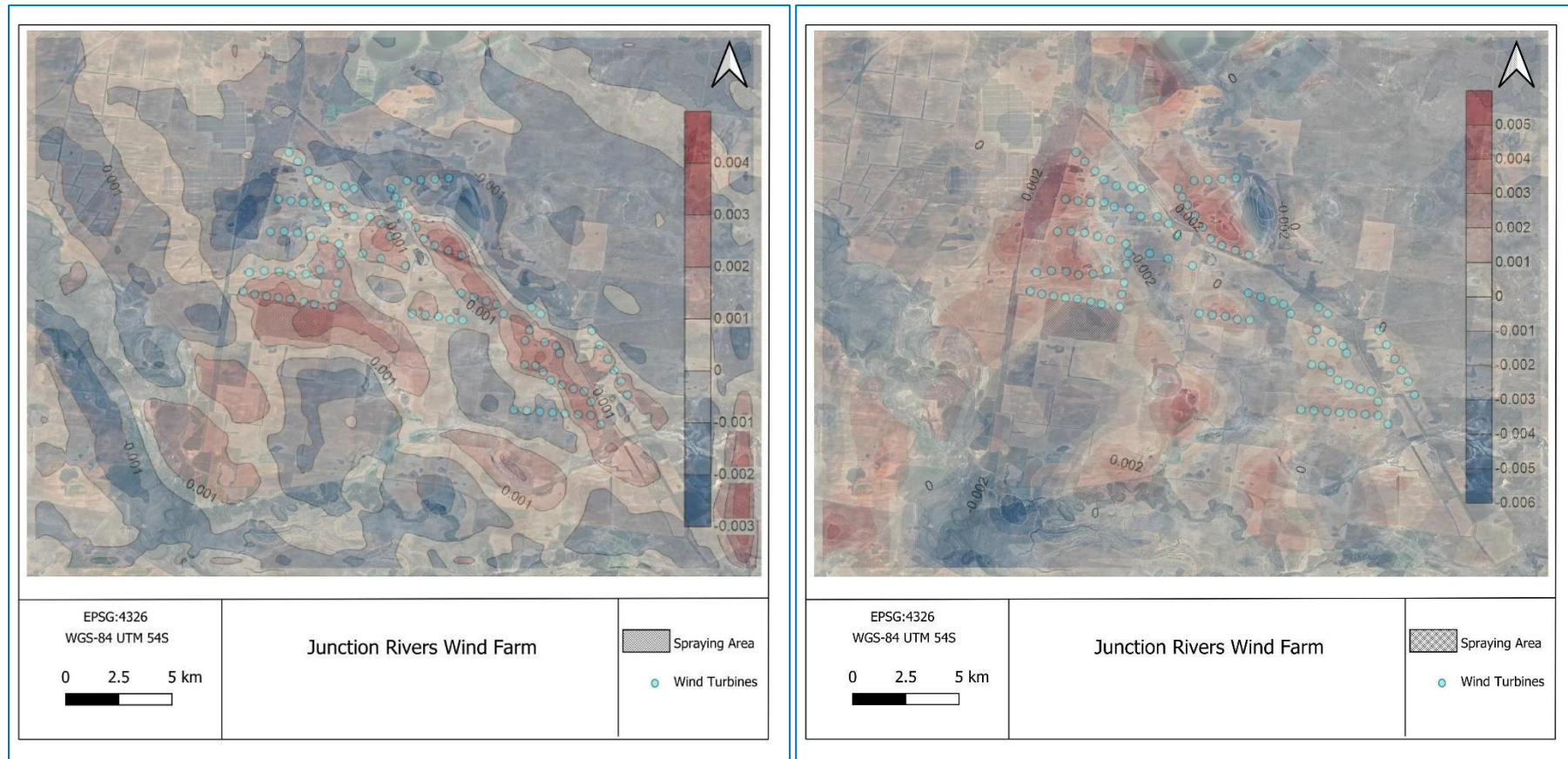


Figure 5.7: Contours of difference (base minus wind farm) in vertical velocity at 10m for northerly wind at 11 am on 2 October (left) and easterly wind at 5 pm on 7 October (right). Units in m/s

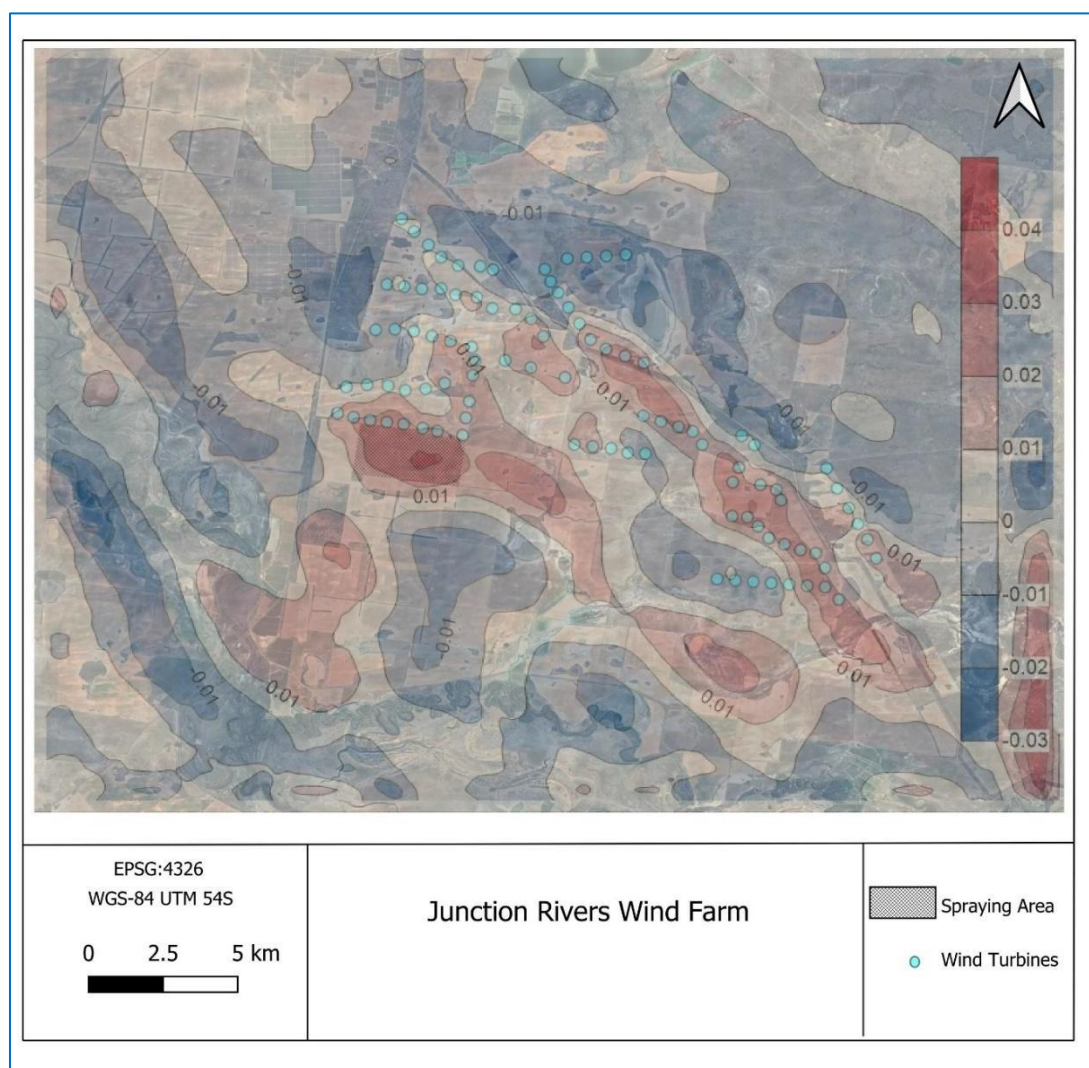


Figure 5.8: Contours of difference (base minus wind farm) in vertical velocity at 120 m for northerly wind.
Units in m/s

5.1.4 Atmospheric Stability

Turbulence is an irregular motion of the air resulting from eddies and vertical currents. Turbulence is generated by both thermal and mechanical effects:

- Thermal turbulence occurs when the surface is being heated, in turn transferring heat to the air above by convection.
- Mechanical turbulence is caused by the effects of wind moving over obstacles on the earth's surface.

Turbulence controls how effectively a plume is diffused into the surrounding air and hence diluted. With stronger turbulence, the rate of plume diffusion increases. Weak turbulence limits diffusion and contributes to high plume concentrations downwind of a source. Similarly, deposition is a function of turbulence, with more turbulent conditions inducing a stronger flux⁹ (Sievering, 1987; Dai *et al*, 2001; Grönholm *et al*, 2007). This suggests that the presence of wind turbines may in fact decrease deposition due to decreased surface turbulence.

Plume models generally use indicators of atmospheric stability (i.e. turbulence) in conjunction with other meteorological data to estimate the dispersion conditions in the atmosphere. Stability can be described across a spectrum ranging from highly unstable conditions with enhanced plume diffusion through neutral to highly stable conditions with reduced plume diffusion. The comparative results of stability with and without the project are discussed in Appendix A.3:

Figure 5.9 and Figure 5.10 show the difference in turbulence intensity¹⁰ (TI) between the base and the project scenarios. The TI difference at 10 m shows a slight decrease in TI at the surface with the inclusion of the wind farm for both the northerly wind case (11 am on 2 October) and easterly wind case (5 pm on 7 October). This decrease in turbulence intensity at the surface is most likely due to decreased vertical wind shear¹¹ (and hence shear-driven turbulence) between the surface and the turbine hub height. This is consistent with previous studies that have shown turbulence is generally lower where the wind shear is smaller (e.g. Barlas *et al*, 2016; Tai *et al*, 2023).

By contrast, at 120 m, the inclusion of the project increases TI in a downwind plume from the turbines at 120 m (Figure 5.7).

⁹ The rate of particle transport onto a surface.

¹⁰ Turbulence intensity is often referred to as turbulence level and is defined as the ratio of the standard deviation of wind speed fluctuations to the mean wind speed.

¹¹ Vertical wind shear is the change of wind speed with height.

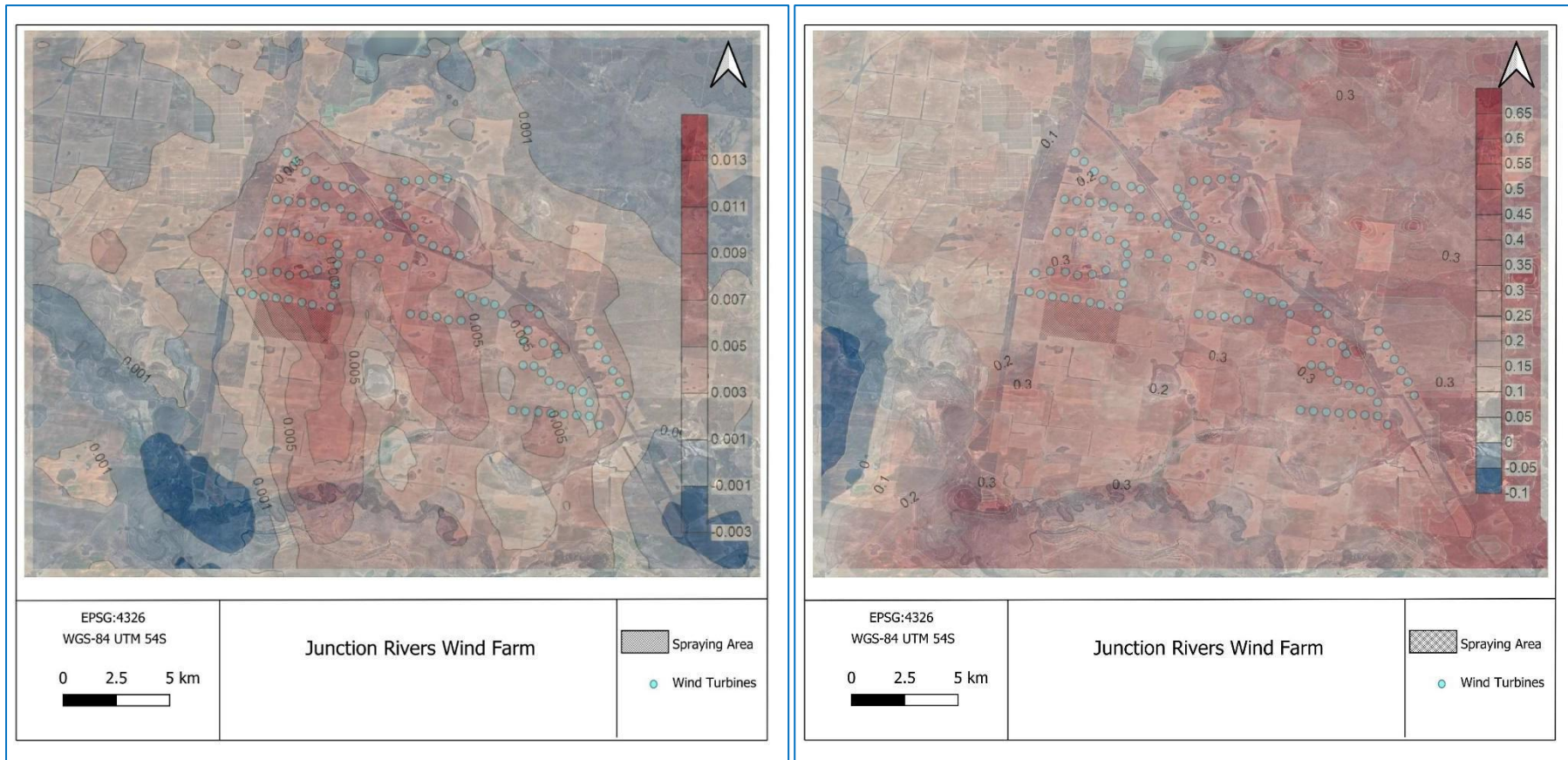


Figure 5.9: Contours of difference (base minus wind farm) in turbulence intensity at 10 m for northerly wind at 11 am on 2 October (left) and easterly wind at 5 pm on 7 October (right). Units in percentage

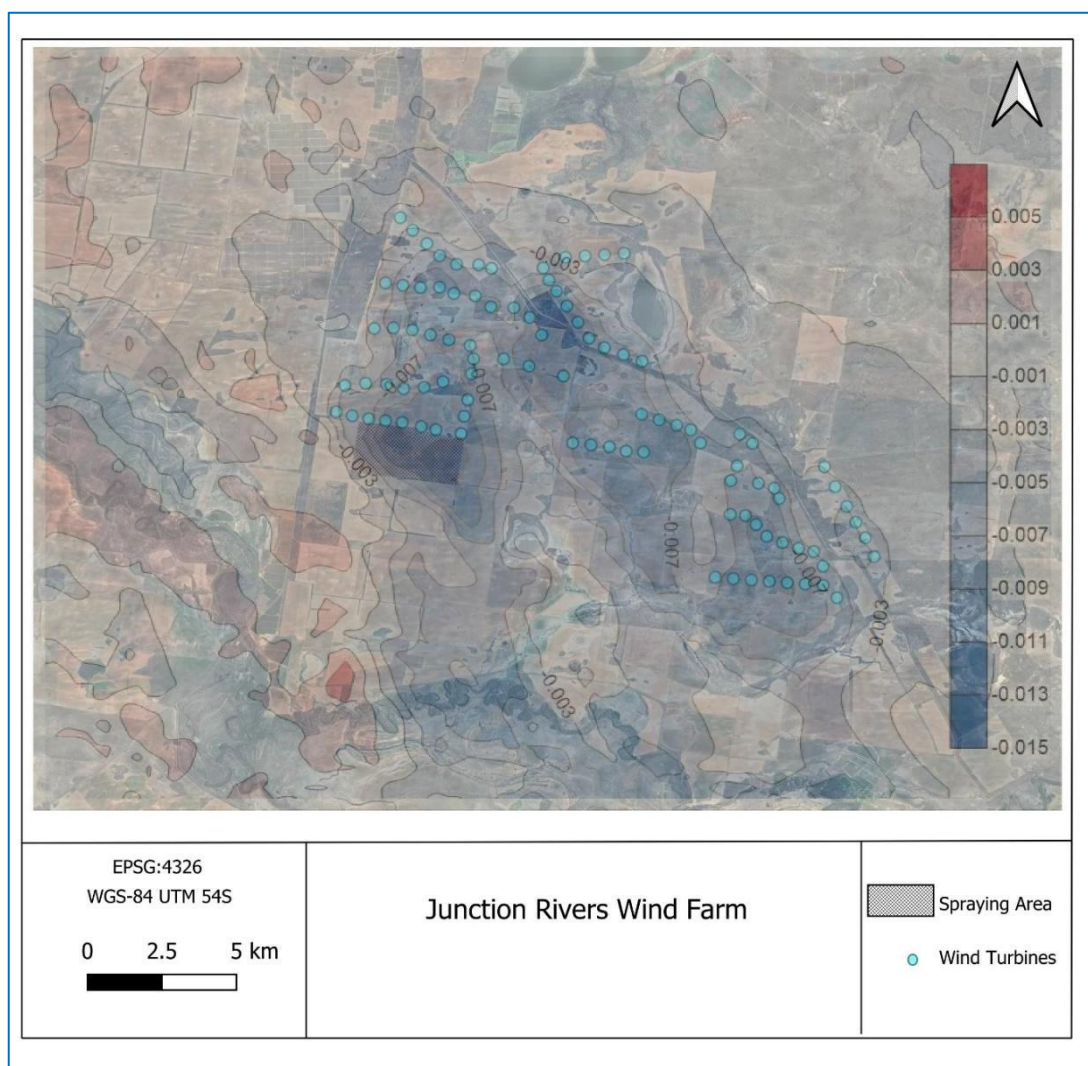


Figure 5.10: Contours of difference (base minus wind farm) in turbulence intensity at 120 m for northerly wind at 11 am on 2 October. Units in percentage

5.2 Spray Drift and Volatilisation

The results of the modelling are presented as contour plots of maximum concentration and deposition¹² and at discrete receptors for ground and aerial spraying and volatilisation of spray material over two selected areas, namely Area A and Area B (Figure 1.1).

5.2.1 Ground Spraying

5.2.1.1 Area A

The qualitative concentration and deposition contours attributed to ground spraying operations at Area A show:

- the dispersion patterns for concentrations are slightly different between the base and project cases (Figure 5.11) with dispersion primarily along a west-east axis for the former and an east-southeast to west-northwest axis for the latter
- for maximum hourly deposition, the patterns for the base and wind farm cases are similar (Figure 5.12)

The deposition rates at the discrete receptors 500 m, 2,000 m, 3,000 m, 4,000 m and 5,000 m to the north, east, south and west of the potential spray area are shown as box and whisker¹³ plots in

Figure 5.13 and show:

- deposition rates are highest within 1 km to the south (S1 and S2) and 500 m to the north (N1) of the spray area
- maximum deposition rates decrease at discrete receptors S1 and S2, E1, E2 and N1 with the project. This suggests that the presence of wind turbines may decrease deposition due to the decreased surface turbulence
- A small increase in deposition is however seen at receptors W1 and W2 with the project.

¹² Note that the plots showing concentration and deposition cover the entire year and show the maximum experienced at any point during the year. These may occur at different times.

¹³ In the box and whisker plot the box shows the first quartile to the third quartile of the data. The whiskers show data lying within 1.5x the inter-quartile range (the difference between the 75th and 25th percentiles of the data) from the box. Points are beyond the end of the whiskers.

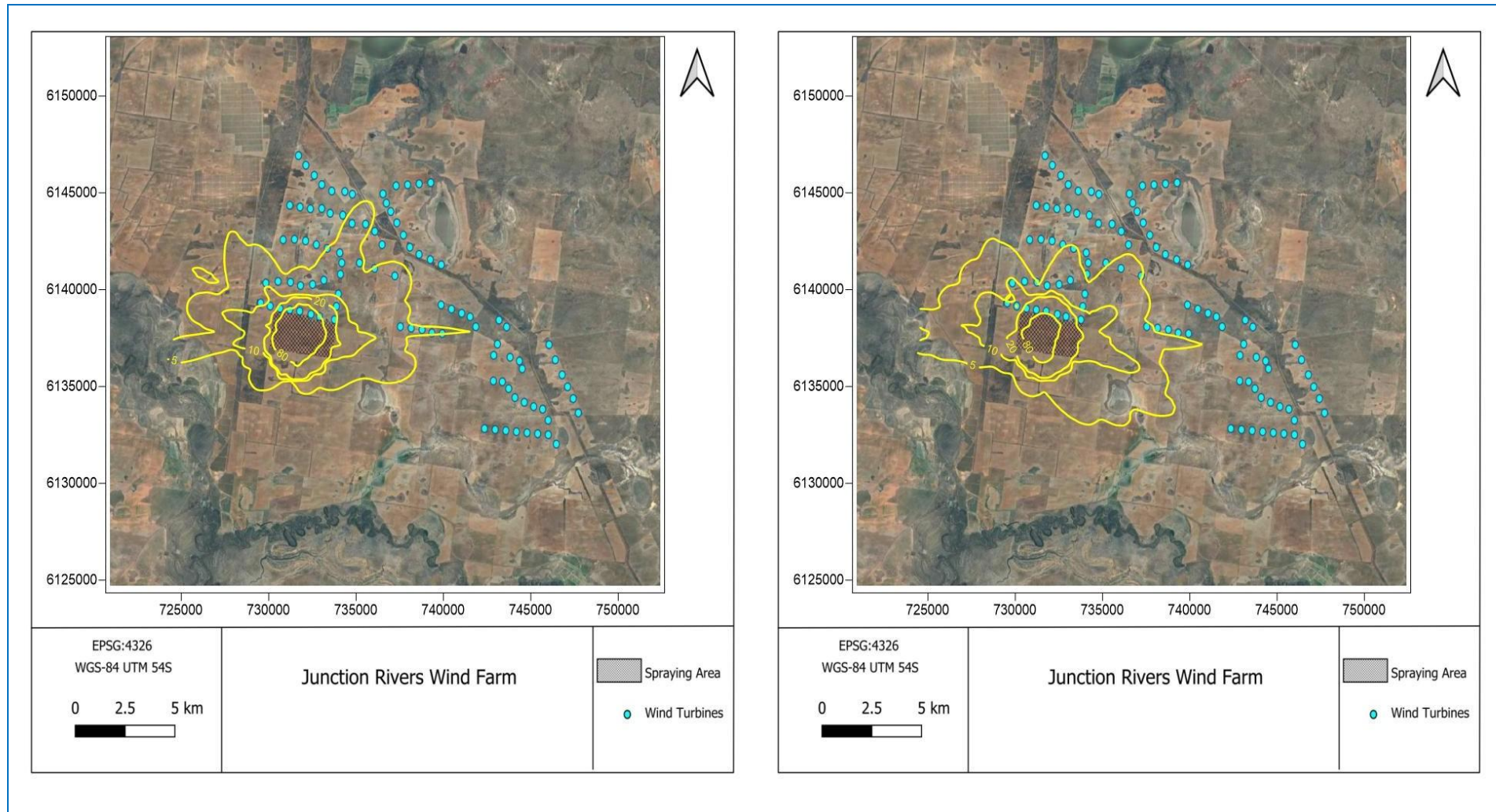


Figure 5.11: Predicted maximum 1-hour ground spraying (Area A) concentration contour ($\mu\text{g}/\text{m}^3$) – Base (left) and Project (right). Units in $\mu\text{g}/\text{m}^3$

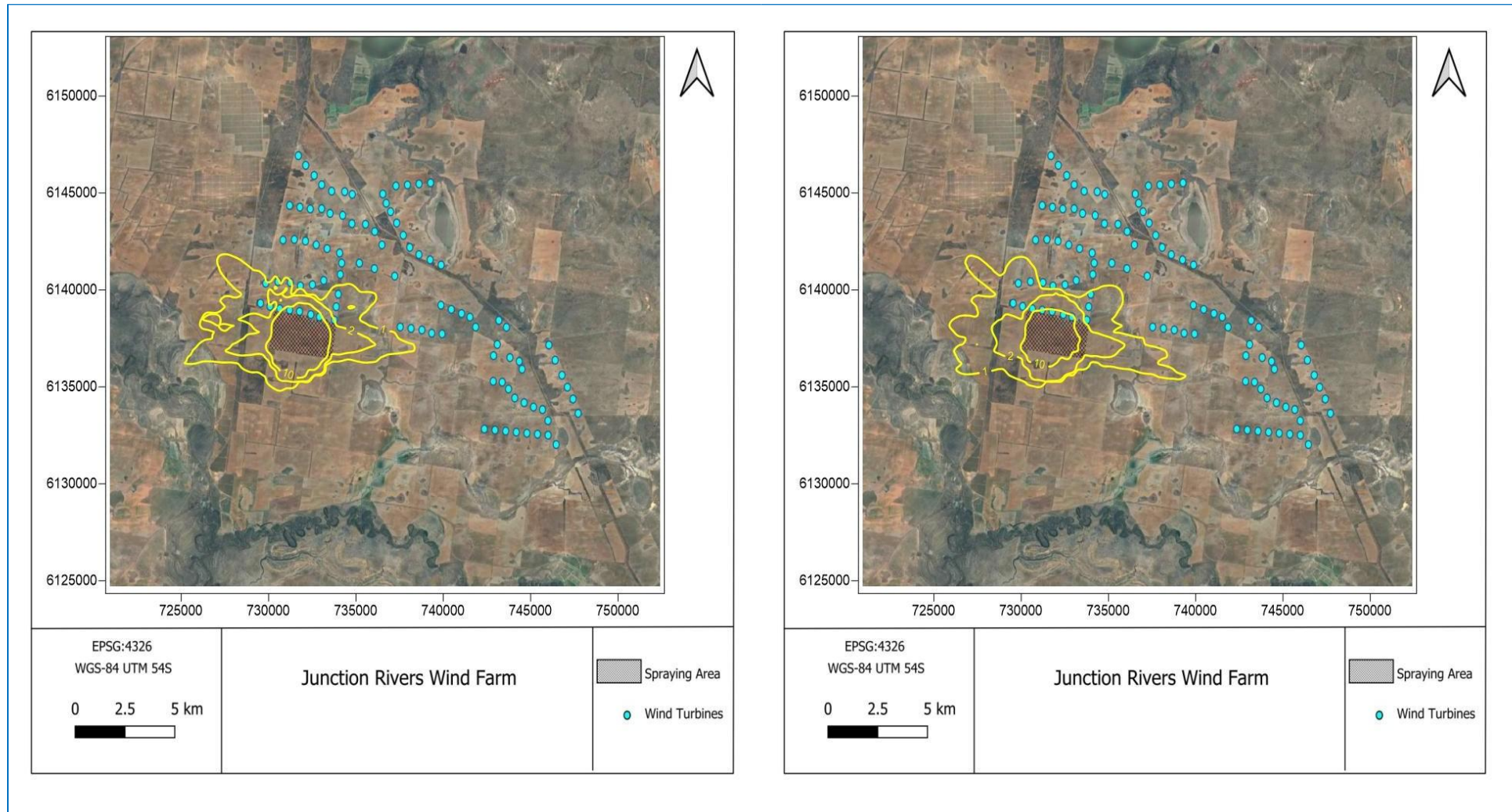


Figure 5.12: Predicted maximum 1-hour ground spraying (Area A) deposition contour (mg/m^2) – Base (left) and Project (right). Units in $\text{mg}/\text{m}^2/\text{hour}$

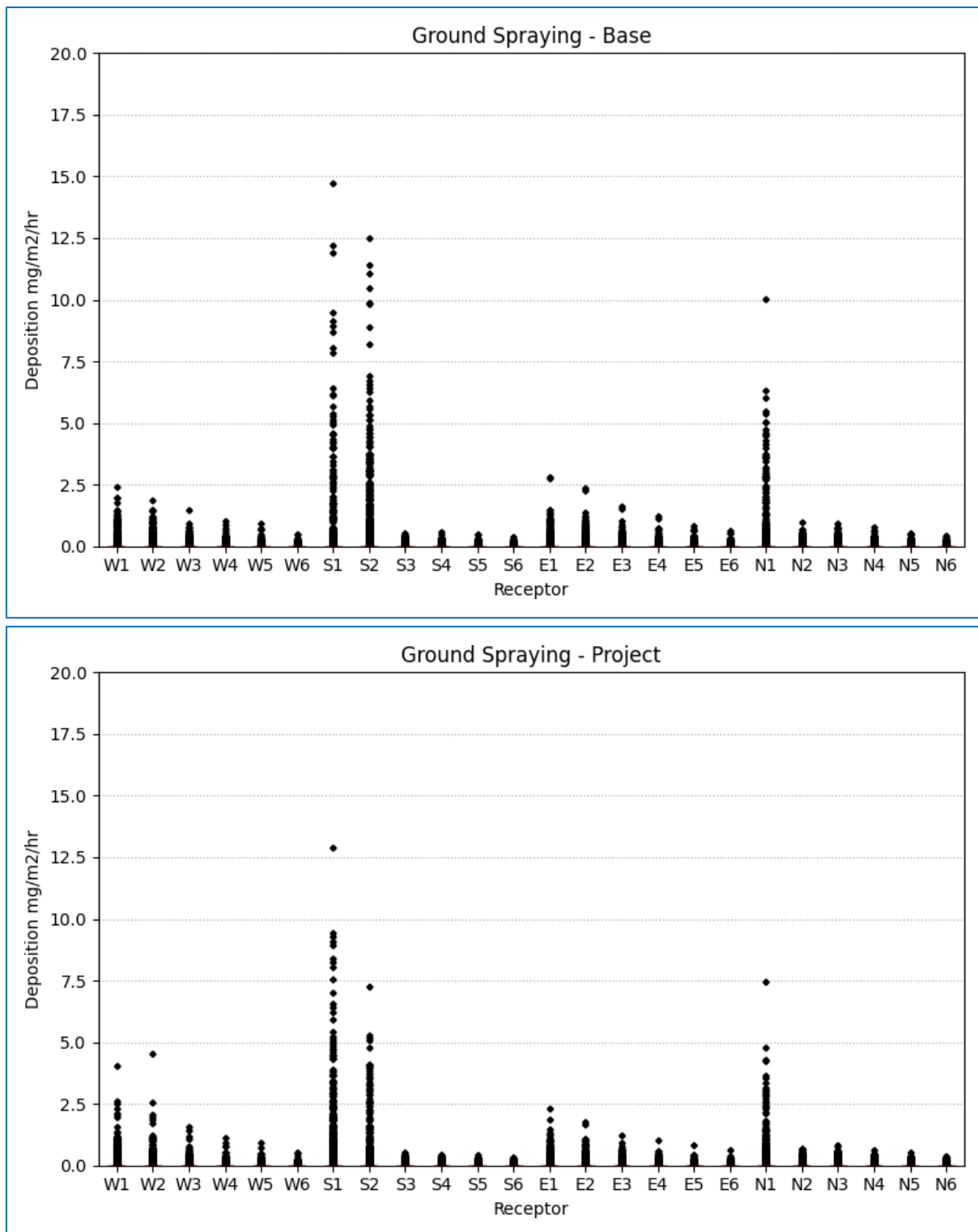


Figure 5.13: Statistics¹⁴ of hourly deposition rates at the discrete receptors for the base (top) and project (bottom) at the 24 adjacent receptors¹⁵

¹⁴ As described by the box and whisker plot.

¹⁵ The prefixes in the x-axis label show if receptor is located to the east (E), north (N), south (S) or west (W)

5.2.1.2 Area B

The concentration and deposition contours attributed to ground spraying operations at Area B show:

- the dispersion patterns for concentrations are slightly different between the base and project cases (Figure 5.14) with a slightly larger footprint especially to the southwest with the project
- for maximum hourly deposition, the patterns for the base and project cases are largely similar although the dispersion footprint is reduced to the west with the project (Figure 5.15)

The deposition rates at the discrete receptors 500 m, 2,000 m, 3,000 m, 4,000 m and 5,000 m to the north, east, south and west of the potential spray area are shown as box and whisker¹⁶ plots in Figure 5.16:

- deposition rates are highest within 500 m to the south (S7) and 2 km to the north (N7 – N9) of the spray area
- while maximum deposition rates decrease at discrete receptors S1 with the project, the remaining discrete receptor deposition rates are largely unchanged from the base case.

¹⁶ In the box and whisker plot the box shows the first quartile to the third quartile of the data. The whiskers show data lying within 1.5x the inter-quartile range (the difference between the 75th and 25th percentiles of the data) from the box. Points are beyond the end of the whiskers.

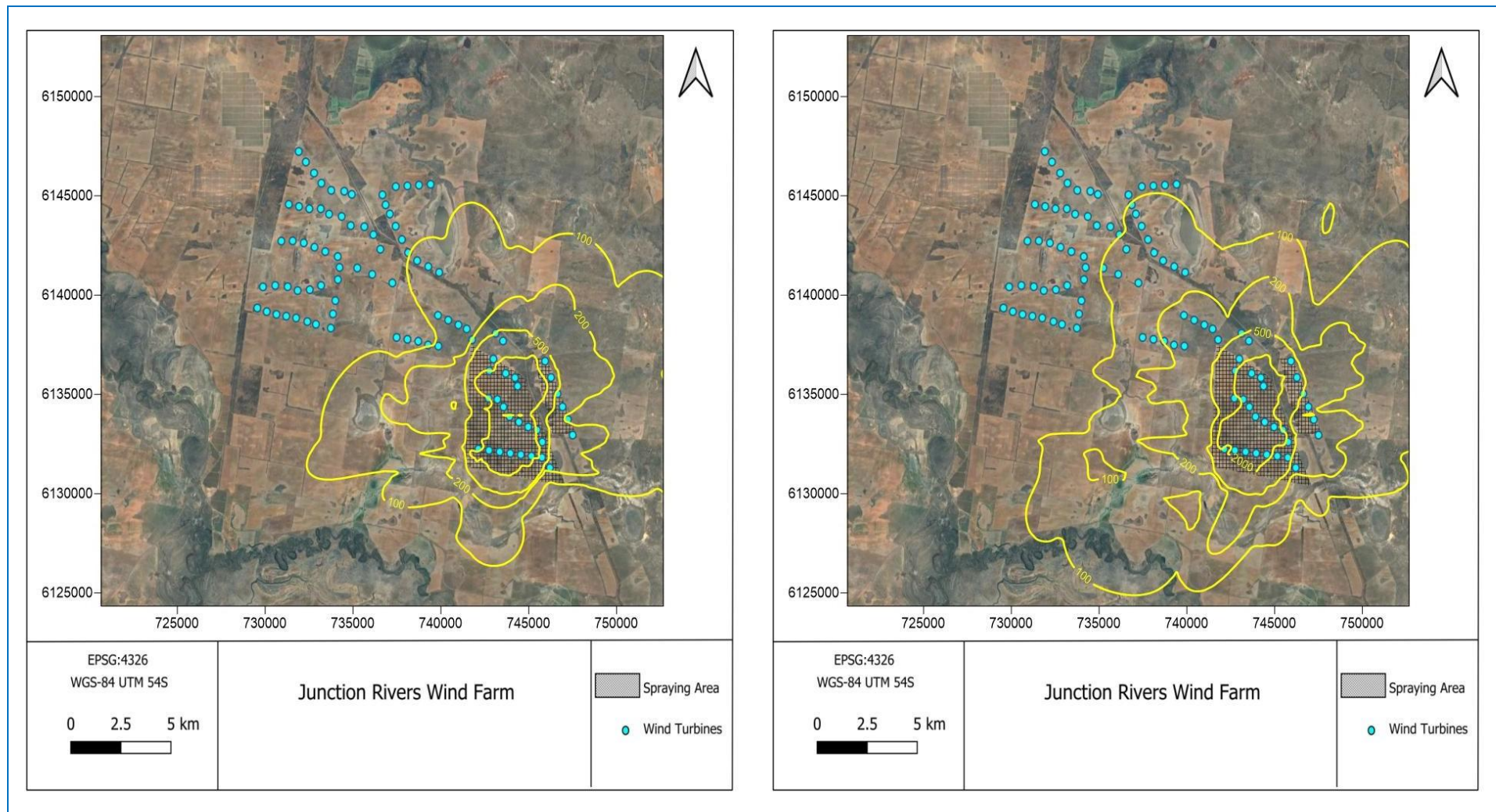


Figure 5.14: Predicted maximum 1-hour ground spraying (Area B) concentration contour ($\mu\text{g}/\text{m}^3$)– Base (left) and Project (right). Units in $\mu\text{g}/\text{m}^3$

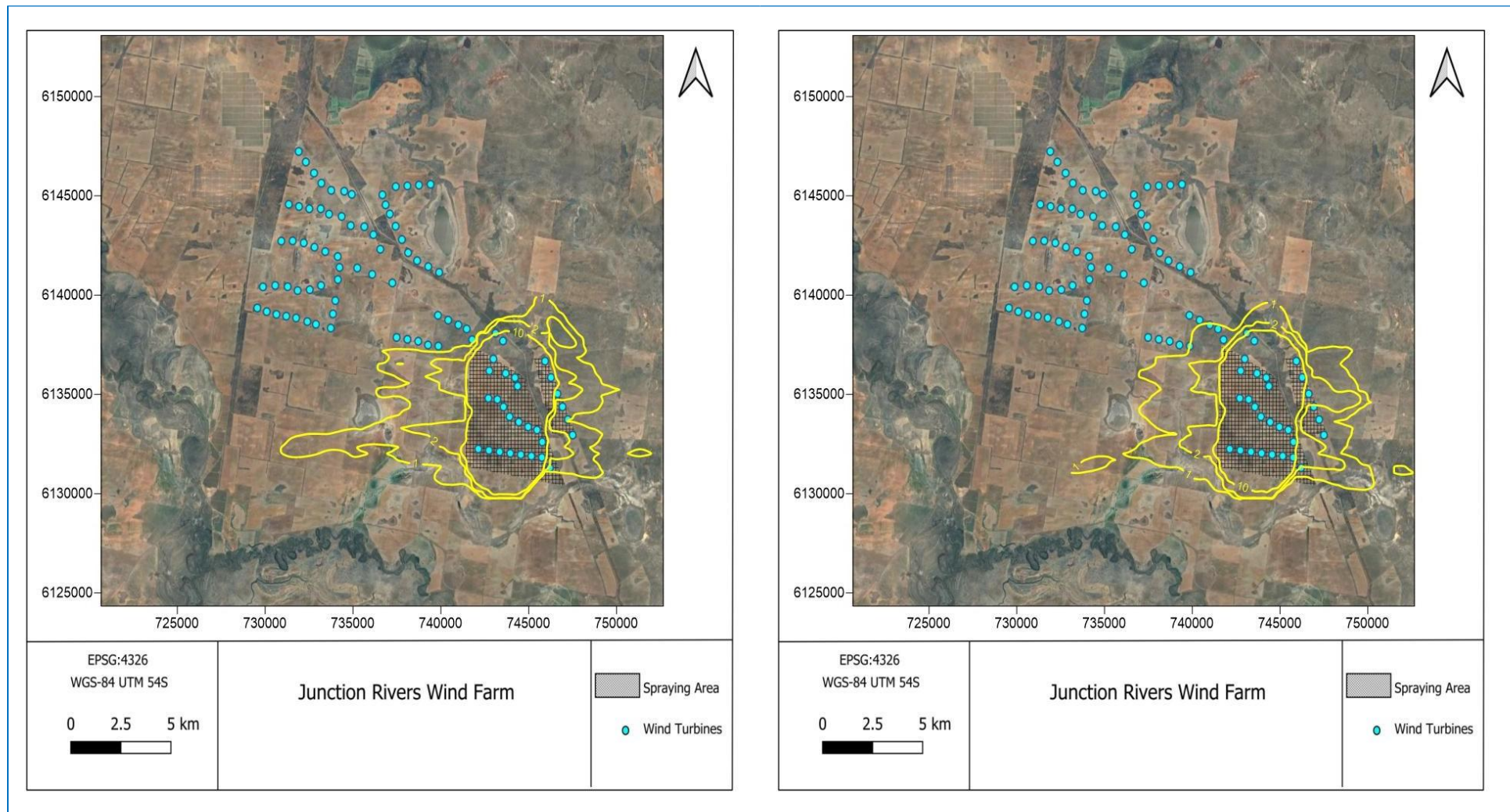


Figure 5.15: Predicted maximum 1-hour ground spraying (Area B) deposition contour (mg/m^2)– Base (left) and Project (right). Units in $\text{mg}/\text{m}^2/\text{hour}$

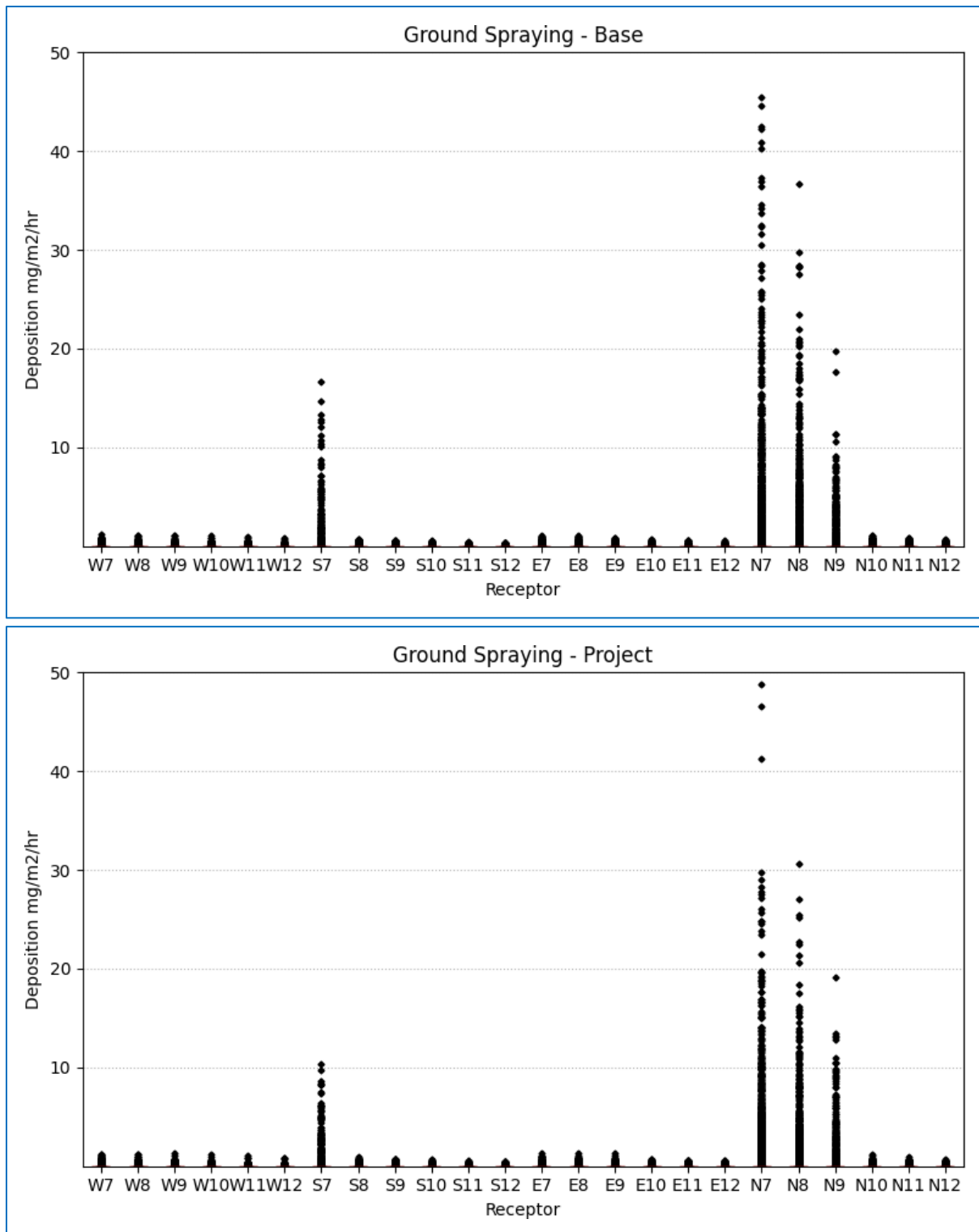


Figure 5.16: Statistics¹⁷ of hourly deposition rates at the discrete receptors for the base (top) and project (bottom) at the 24 adjacent receptors¹⁸

¹⁷ As described by the box and whisker plot.

¹⁸ The prefixes in the x-axis label show if receptor is located to the east (E), north (N), south (S) or west (W)

5.2.2 Aerial Spraying

5.2.2.1 Area A

The qualitative concentration and deposition contours attributed to aerial spraying operations at Area A show:

- the dispersion pattern between the base and wind farm cases are similar, with dispersion along a southwest to northeast axis (Figure 5.17)
- the dispersion patterns for concentrations are significantly different to the ground spraying and volatilisation emissions, most likely due to the increased dispersion of the chemicals due to turbulent dispersion within the aircraft wake. (*i.e.* vortices)
- for maximum hourly deposition (Figure 5.18), the patterns for the base and wind farm cases are similar in pattern and spatial extent.

The statistics of hourly deposition rates at the discrete receptors 500m, 1,000m, 2,000 m, 3,000 m, 4,000 m and 5,000 m to the north, east, south and west of the potential spray area for the base case and project are shown as box and whisker¹⁹ plots in Figure 5.19:

- that receptors to the east of the spray area (E1-E4) have the highest deposition rates
- the project only has a negligible impact on deposition rates at the discrete receptors.

¹⁹ In the box and whisker plot the box shows the first quartile to the third quartile of the data. The whiskers show data lying within 1.5x the inter-quartile range (the difference between the 75th and 25th percentiles of the data) from the box. Points are beyond the end of the whiskers.

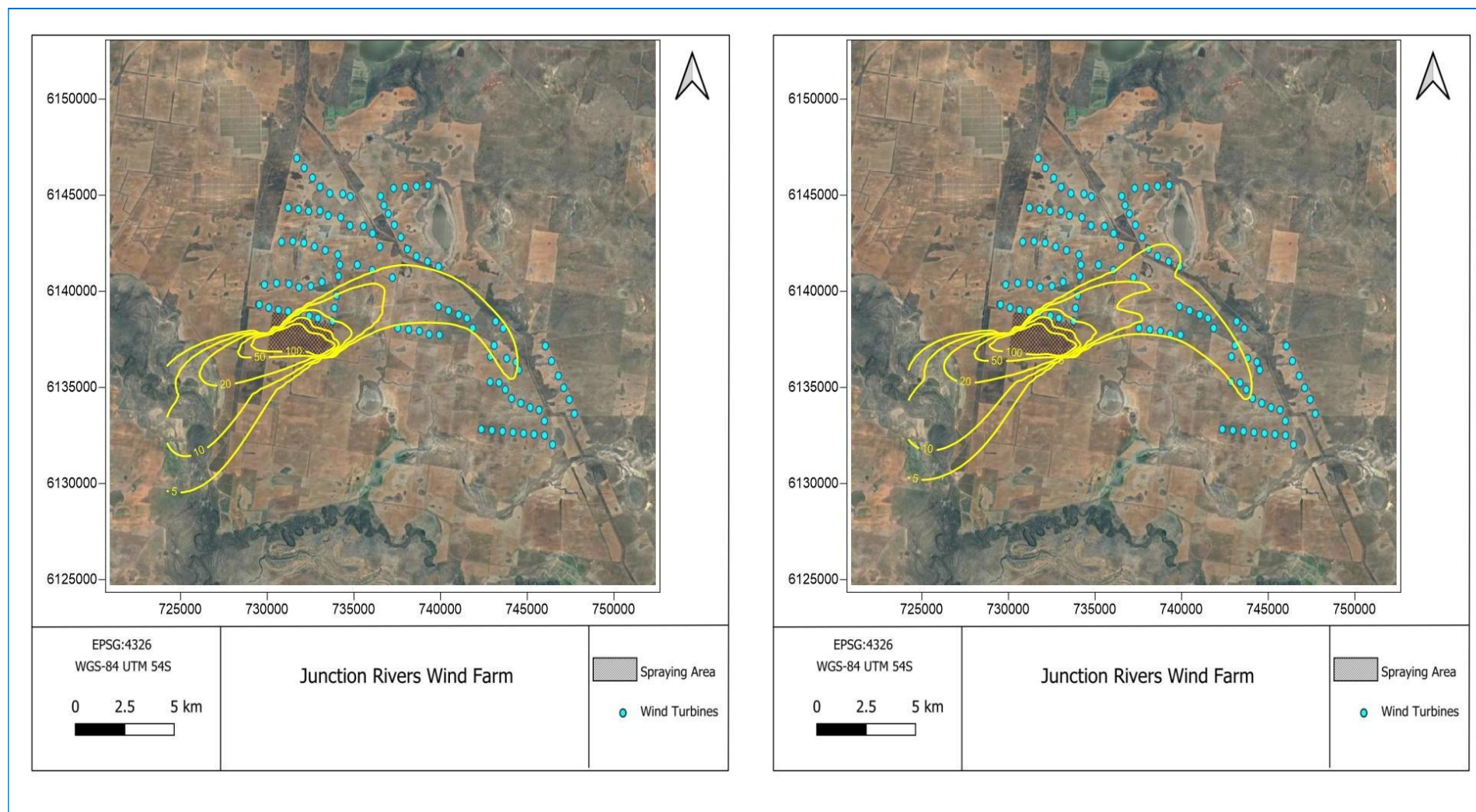


Figure 5.17: Predicted maximum 1-hour aerial spraying (Area A) concentration contour ($\mu\text{g}/\text{m}^3$) – Base (left) and Project (right). Units in $\mu\text{g}/\text{m}^3$

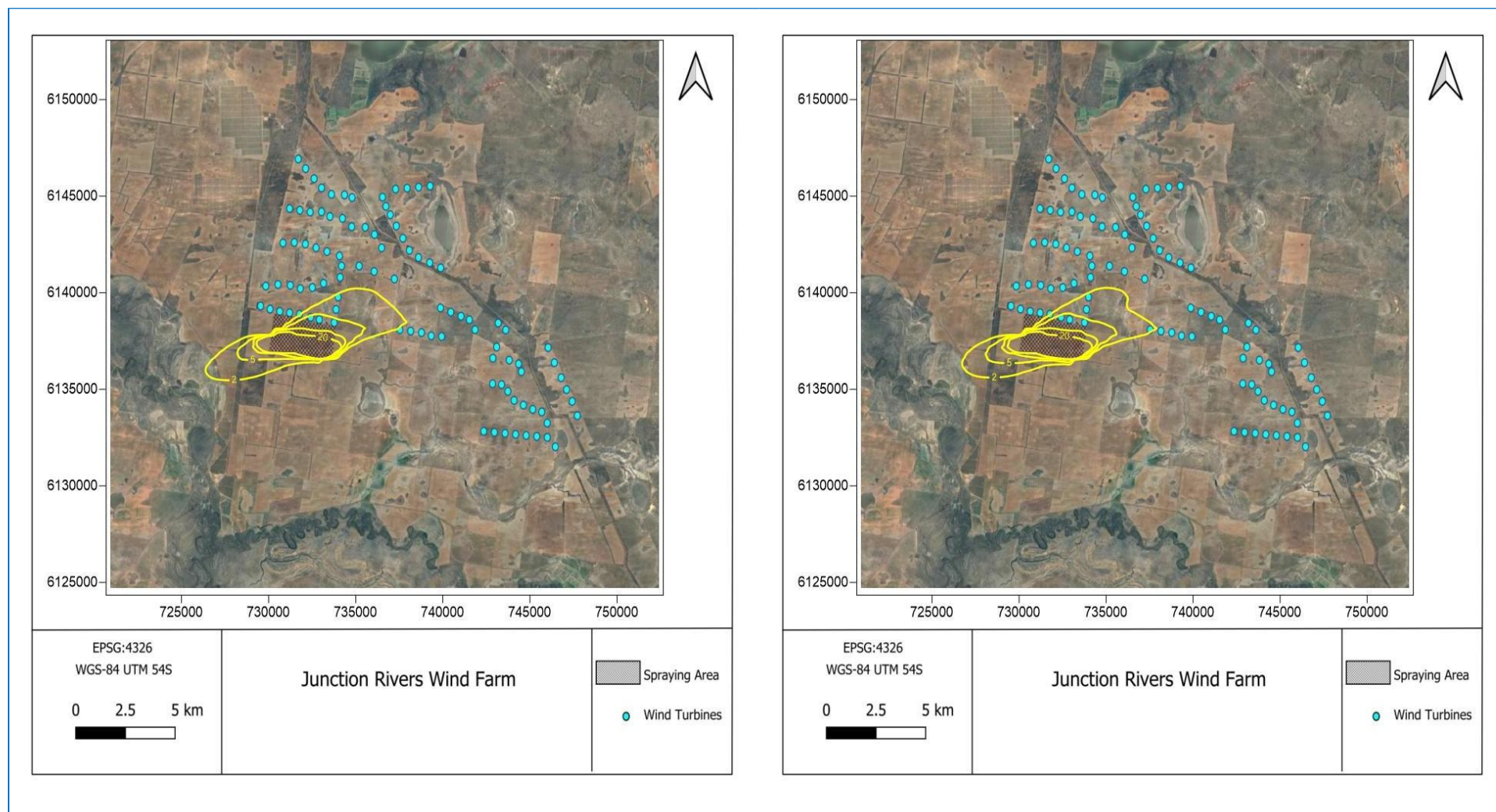


Figure 5.18: Predicted maximum 1-hour aerial spraying (Area A) deposition contour (mg/m^2) – Base (left) and Project (right). Units in $\text{mg}/\text{m}^2/\text{hour}$

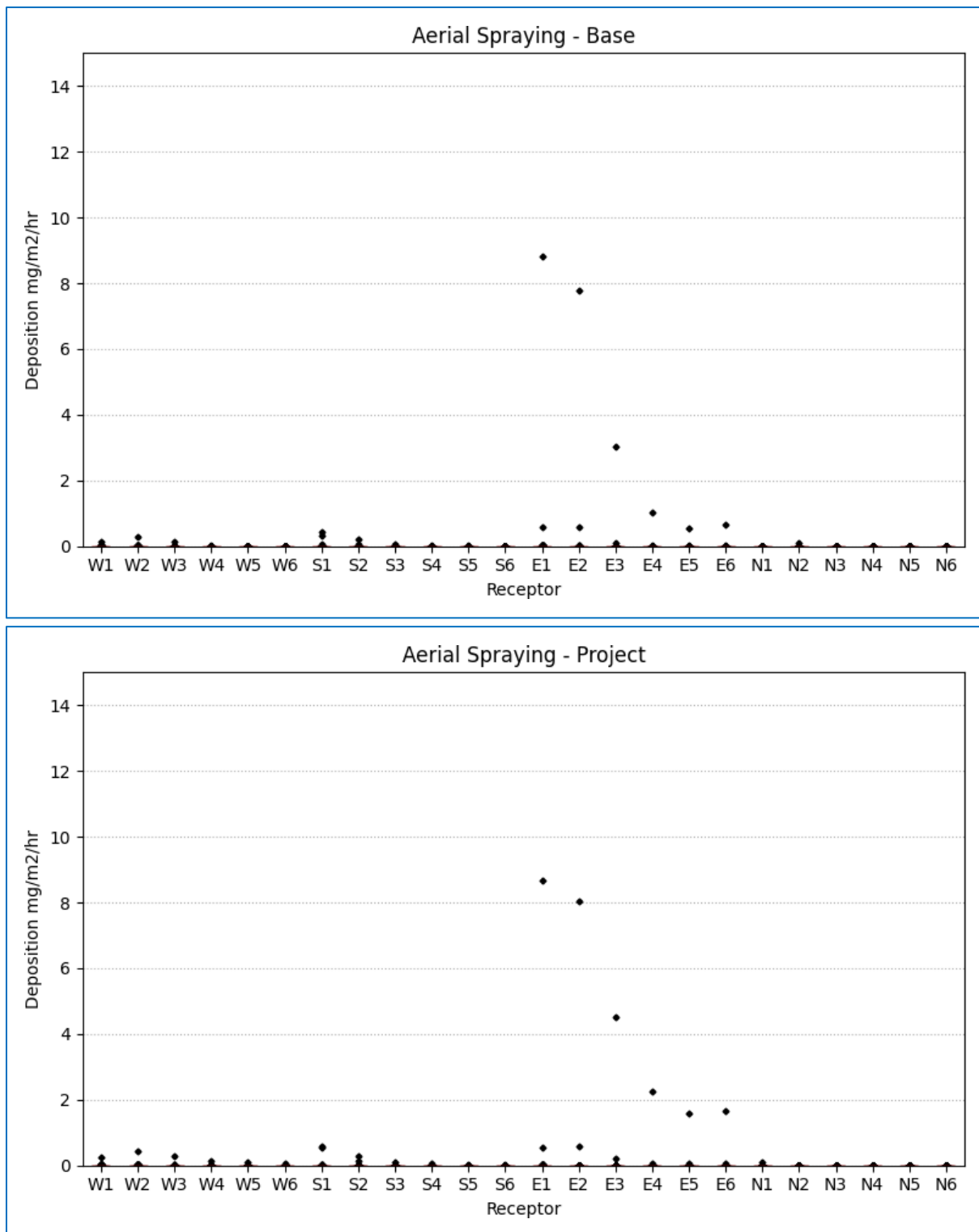


Figure 5.19: Statistics²⁰ of hourly deposition rates at the discrete receptors for the base (top) and project (bottom) at the 24 adjacent receptors.

²⁰ As described by the box and whisker plot.

5.2.2.2 Area B

The concentration and deposition contours attributed to aerial spraying operations at Area B show:

- the dispersion pattern between the base and wind farm cases are similar, with dispersion along a south/southwest to northeast axis (Figure 5.20)
- the dispersion patterns for concentrations are significantly different to the ground spraying emissions, most likely due to the turbulent dispersion within the aircraft wake
- maximum hourly deposition (Figure 5.21), the patterns for the base and wind farm cases are similar in both pattern and spatial extent.

The statistics of hourly deposition rates at the discrete receptors 500m, 1,000m, 2,000 m, 3,000 m, 4,000 m and 5,000 m to the north, east, south and west of the potential spray area for the base case and project (Figure 5.22) show:

- that receptors to the south (S7 - S11) have the highest deposition rates followed by receptors to the west of the spray area (W7-W9)
- deposition within 1 km to the south of the spray area increases slightly with the project while there is minimal impact at the remaining receptors.

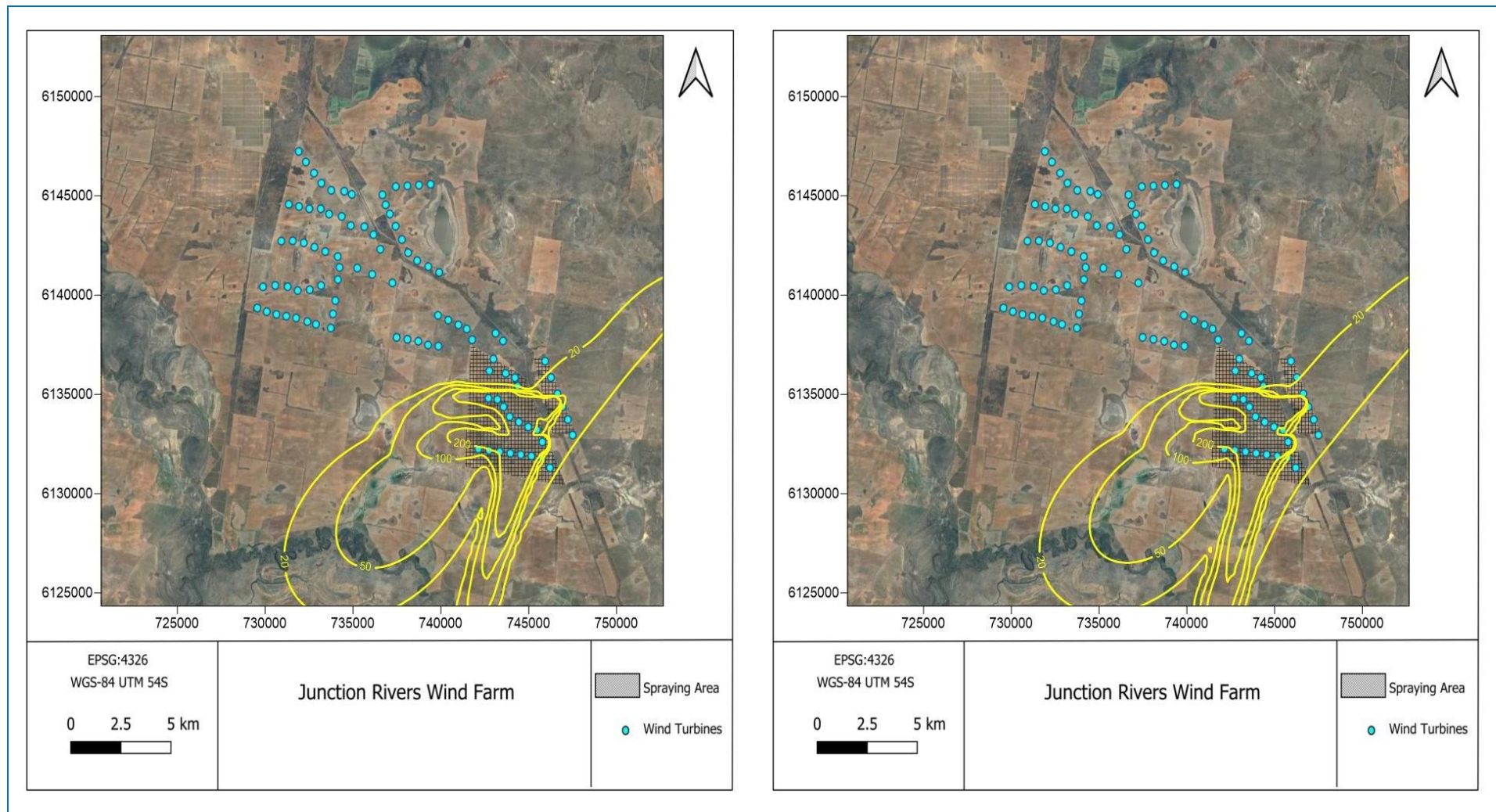


Figure 5.20: Predicted maximum 1-hour aerial spraying (Area B) concentration contour ($\mu\text{g}/\text{m}^3$)– Base (left) and Project (right). Units in $\mu\text{g}/\text{m}^3$

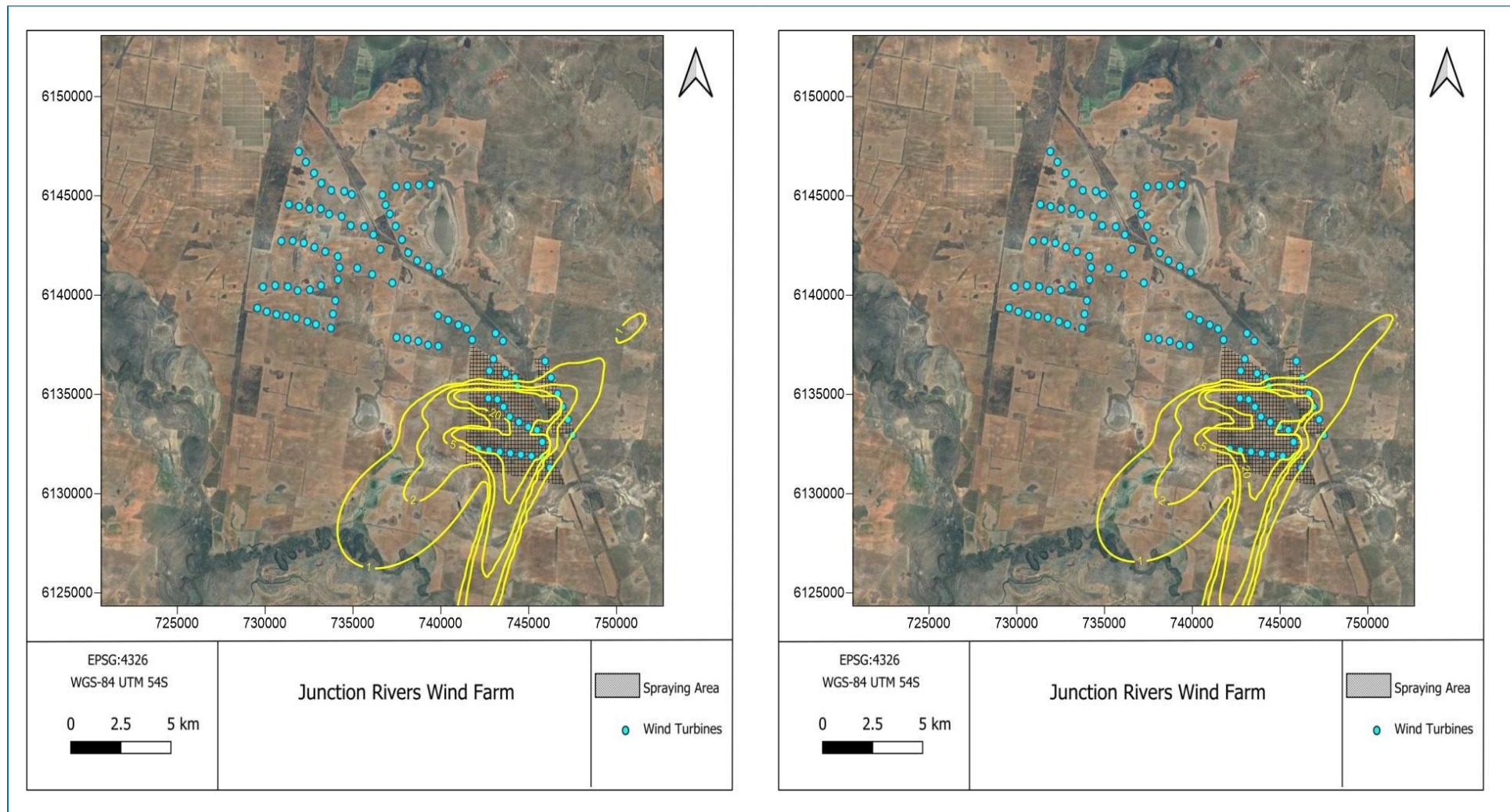


Figure 5.21: Predicted maximum 1-hour aerial spraying (Area B) deposition contour (mg/m²) – Base (left) and Project (right). Units in mg/m²/hour

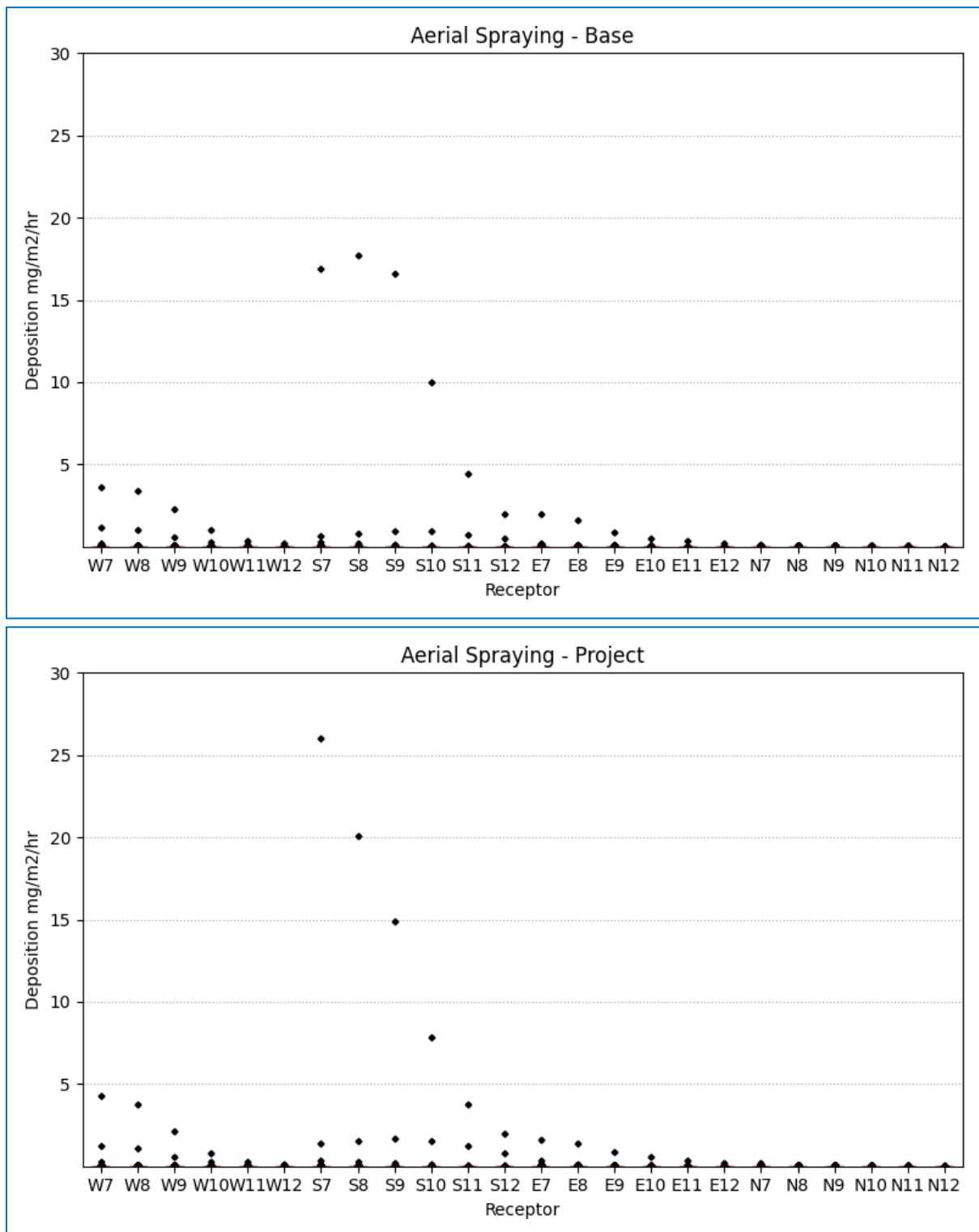


Figure 5.22: Statistics²¹ of hourly deposition rates at the discrete receptors for the base (top) and project (bottom) at the 24 adjacent receptors

²¹ As described by the box and whisker plot.

5.2.2.3 Cumulative (Area A and Area B)

The results presented in this section shows the worst-case impacts of simultaneous aerial spraying at both Area A and Area B. The concentration and deposition contours show:

- the dispersion pattern between the base and project are very similar, with only minor differences between the two scenarios (Figure 5.23)
- maximum hourly deposition, the patterns for the base and wind farm cases are largely similar in both pattern and spatial extent (Figure 5.24).

The statistics of hourly deposition rates at the discrete receptors 500m, 1,000m, 2,000 m, 3,000 m, 4,000 m and 5,000 m to the north, east, south and west of both potential spray areas for the base case and project are shown as box and whisker²² plots in Figure 5.25 and Figure 5.26:

- the receptors to the east of Area 1 (E1 – E6) still have the highest deposition rates for both the base and project scenarios followed by receptors to the south of Area 1 (S1 – S6)
- compared to Area A spraying in isolation (see Figure 5.19), the cumulative (Area A and B) spraying scenario shows a slight increase in deposition at the southern (S1-S6) receptors for both the base and project cases.
- compared to B spraying in isolation (see Figure 5.22), the cumulative spraying scenario shows a slight increase in deposition at the northern (N1-N6) receptors for both the base and project cases.

Figure 5.27 shows deposition rates by wind direction and wind speed 1 km from the spray areas for the base and project respectively. The figures show that:

- for the base case, as expected highest deposition (yellow to red) occurs with winds less than 4 m/s blowing directly from the spray areas to the receptors (Figure 5.27).
- the project results are similar to the base case with the exception of the receptors to the east and south of Area A where some deposition occurs with east-southeasterly winds (Figure 5.27).

Additional meteorological conditions associated with highest deposition at the eight receptors nearest each spray area are shown in Table 3. Highest deposition occurs with wind speed lower than 4 m/s and under moderately unstable (2) to neutral (4) stability²³ conditions. However, no relationship is found between temperature, relative humidity and deposition rates at the discrete receptors.

²² In the box and whisker plot the box shows the first quartile to the third quartile of the data. The whiskers show data lying within 1.5x the inter-quartile range (the difference between the 75th and 25th percentiles of the data) from the box. Points are beyond the end of the whiskers.

²³ The stability of the atmosphere determines the amount of mixing that occurs

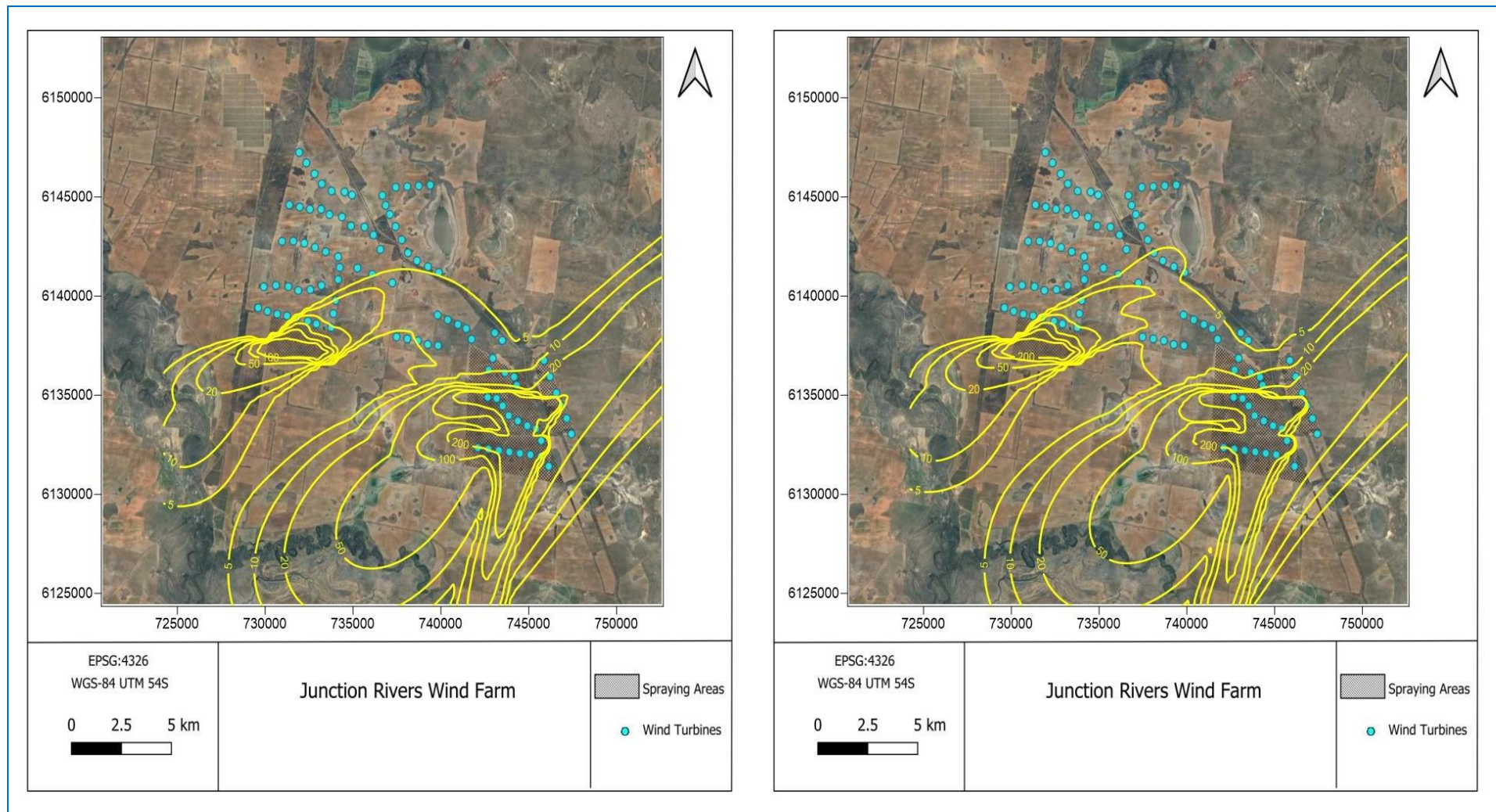


Figure 5.23: Predicted maximum 1-hour cumulative aerial spraying (Area A and B) concentration contour ($\mu\text{g}/\text{m}^3$) – Base (left) and Project (right). Units in $\mu\text{g}/\text{m}^3$

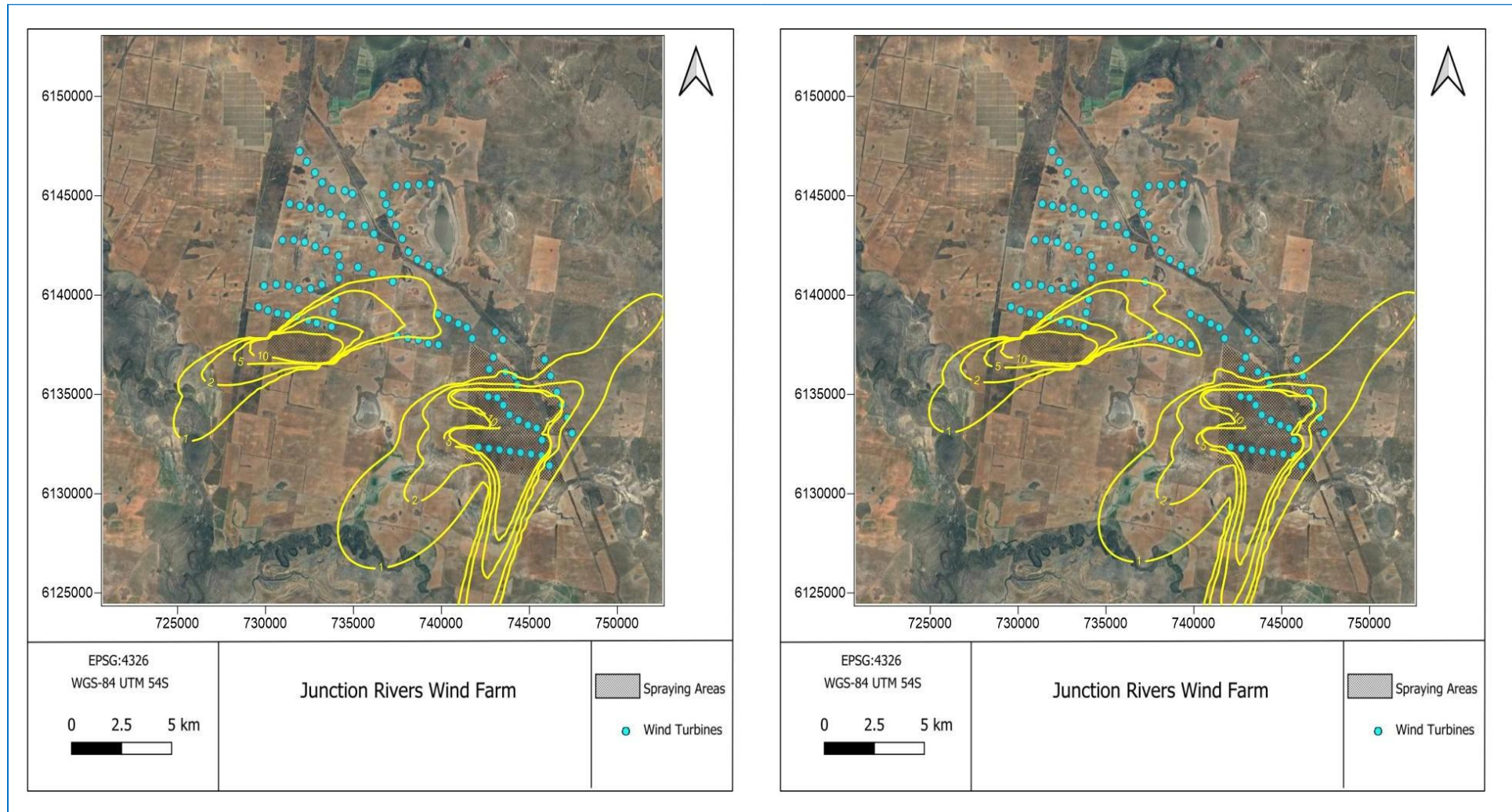


Figure 5.24: Predicted maximum 1-hour cumulative aerial spraying (Area A and B) deposition contour (mg/m^2) – Base (left) and Project (right). Units in $\text{mg}/\text{m}^2/\text{hour}$

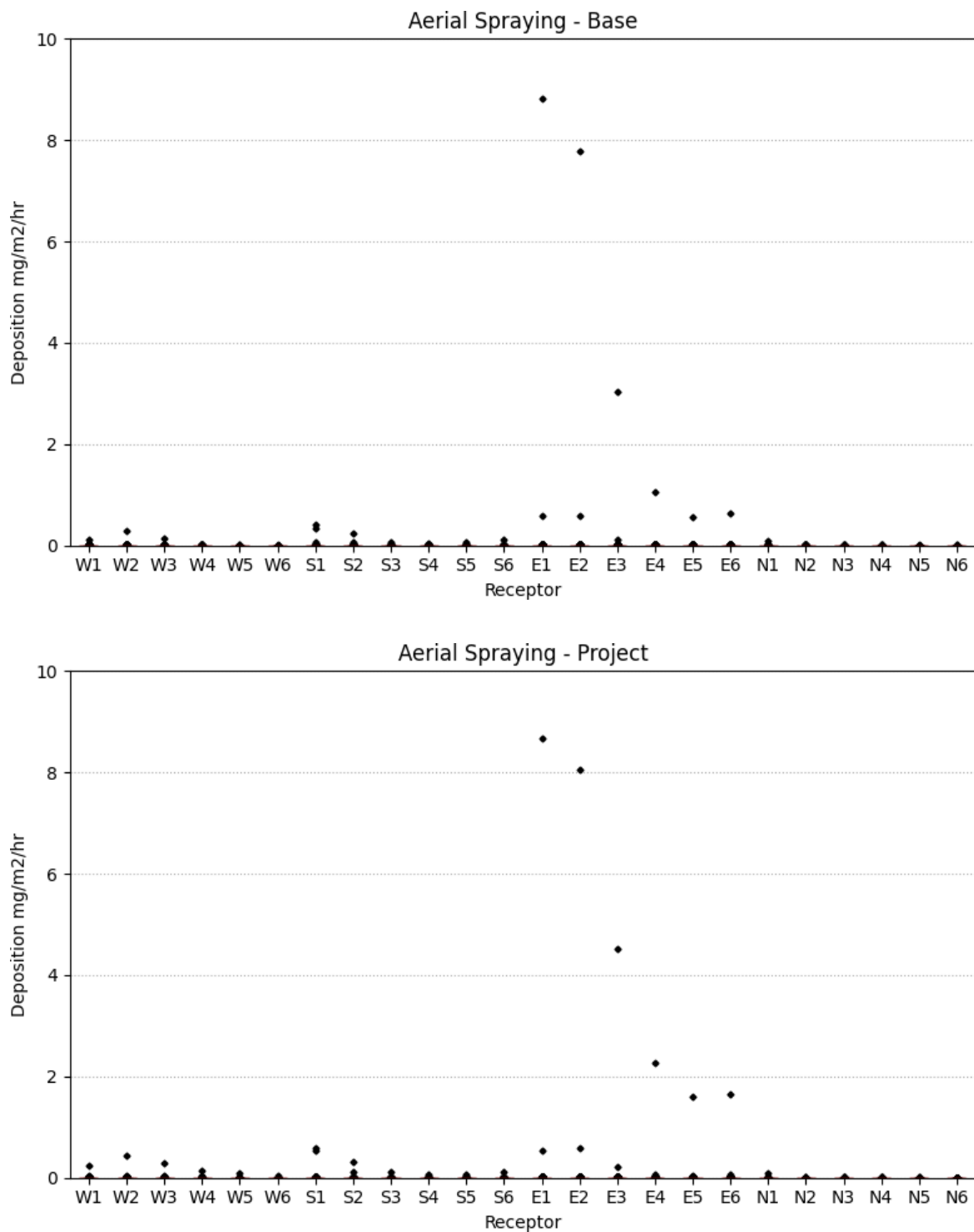


Figure 5.25: Statistics²⁴ of hourly deposition rates at the discrete receptors for the base (top) and project (bottom) at the adjacent receptors to Area A

²⁴ As described by the box and whisker plot.

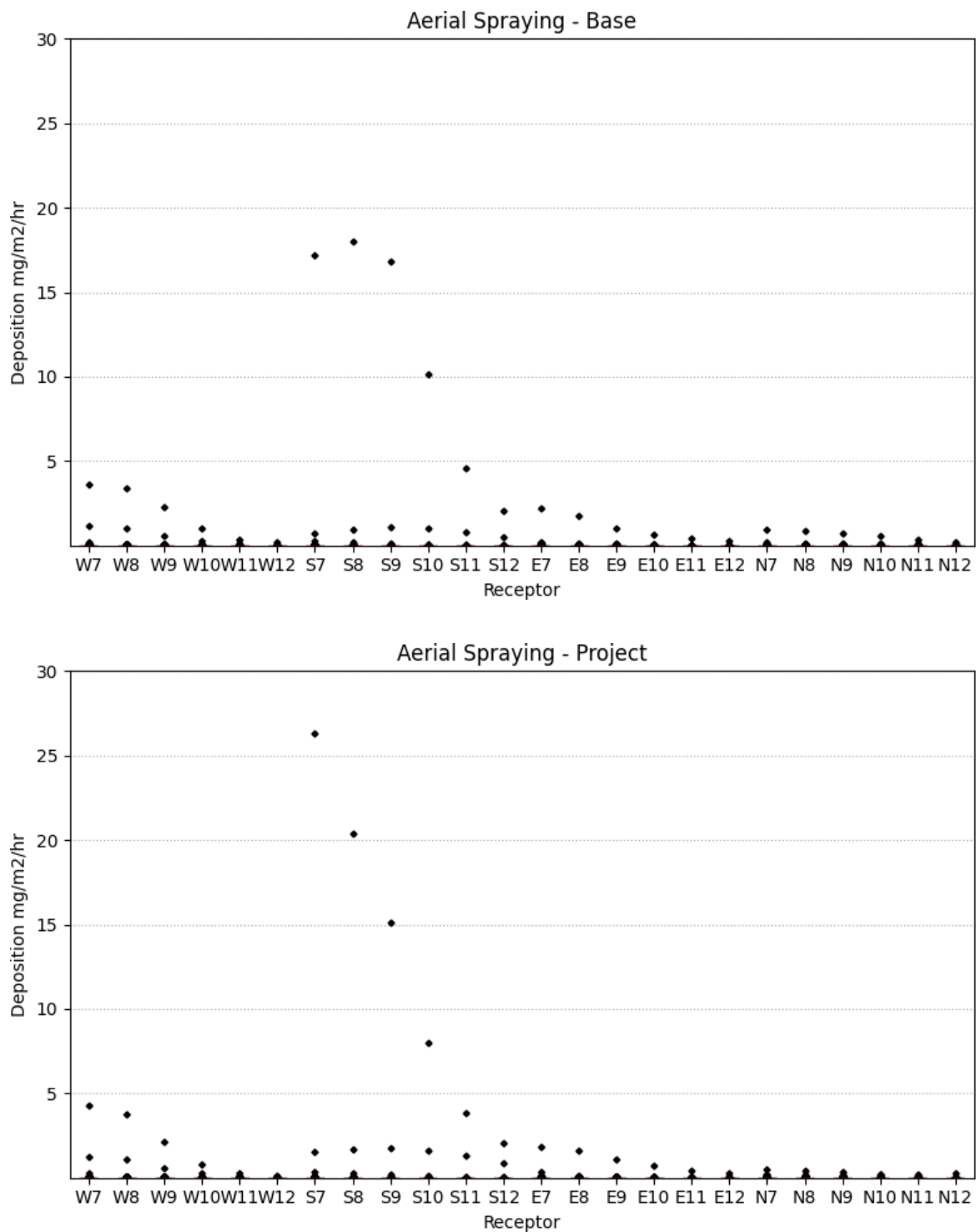


Figure 5.26: Statistics²⁵ of hourly deposition rates at the discrete receptors for the base (top) and project (bottom) at the adjacent receptors to Area B

²⁵ As described by the box and whisker plot.

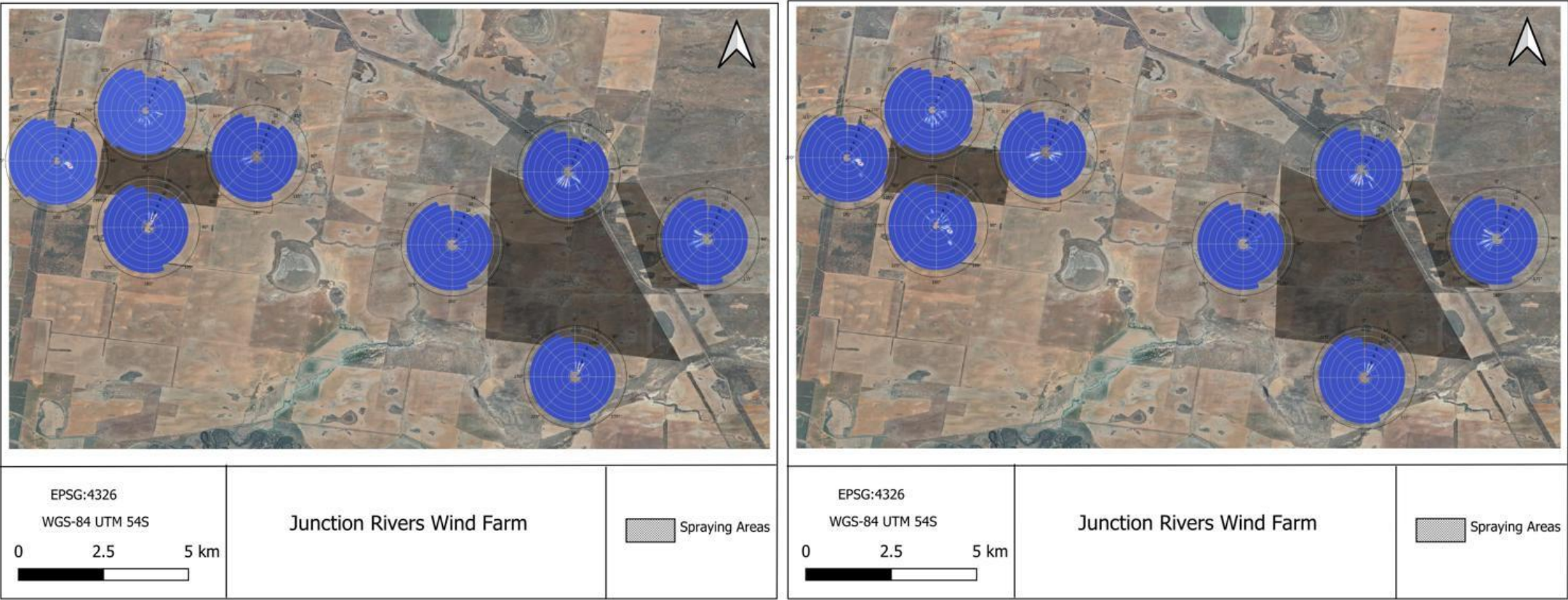


Figure 5.27: Deposition rates by wind direction and speed²⁶ at the 1km receptors – Base (left) and Project (right)– Project

²⁶ The figure shows the deposition rate in colour (blue to red increasing) by wind direction (circle) and wind speed in 2 m/s increments (arcs within circle)

Table 3: Meteorological conditions associated with maximum deposition.

Receptor	Wind Speed (m/s)	Temperature (°C)	Relative Humidity (%)	Stability
W1	1.6	12.6	65	2
N1	2.7	19.2	88	4
E1	2.7	19.2	88	4
S1	1.6	16.6	52	2
W7	1.6	12.6	65	2
S7	2.7	19.2	88	4
E7	4.0	16.5	75	4
N7	2.0	18.3	88	3

5.2.3 Volatilisation

5.2.3.1 Area A

The contours attributed to volatilisation of chemicals after ground spraying operations over Area A show:

- the dispersion patterns for concentrations are slightly different between the base and wind farm cases with dispersion primarily along a west-east axis for the former and an east-southeast to west-northwest axis for the latter (Figure 5.28)
- for maximum hourly deposition (Figure 5.29), the patterns for the base and wind farm cases show some differences, especially to the east and northwest of the potential spraying area.

The change in deposition rates from the base to project assessed at the discrete receptors 500 m, 2,000 m, 3,000 m, 4,000 m and 5,000 m to the north, east, south and west of the potential spray area (Figure 5.30) show:

- that highest deposition rates occur at the nearest receptor to the south (S1) and the north (N1) to the spray area
- discrete receptors generally show a decrease in deposition rates with the project.

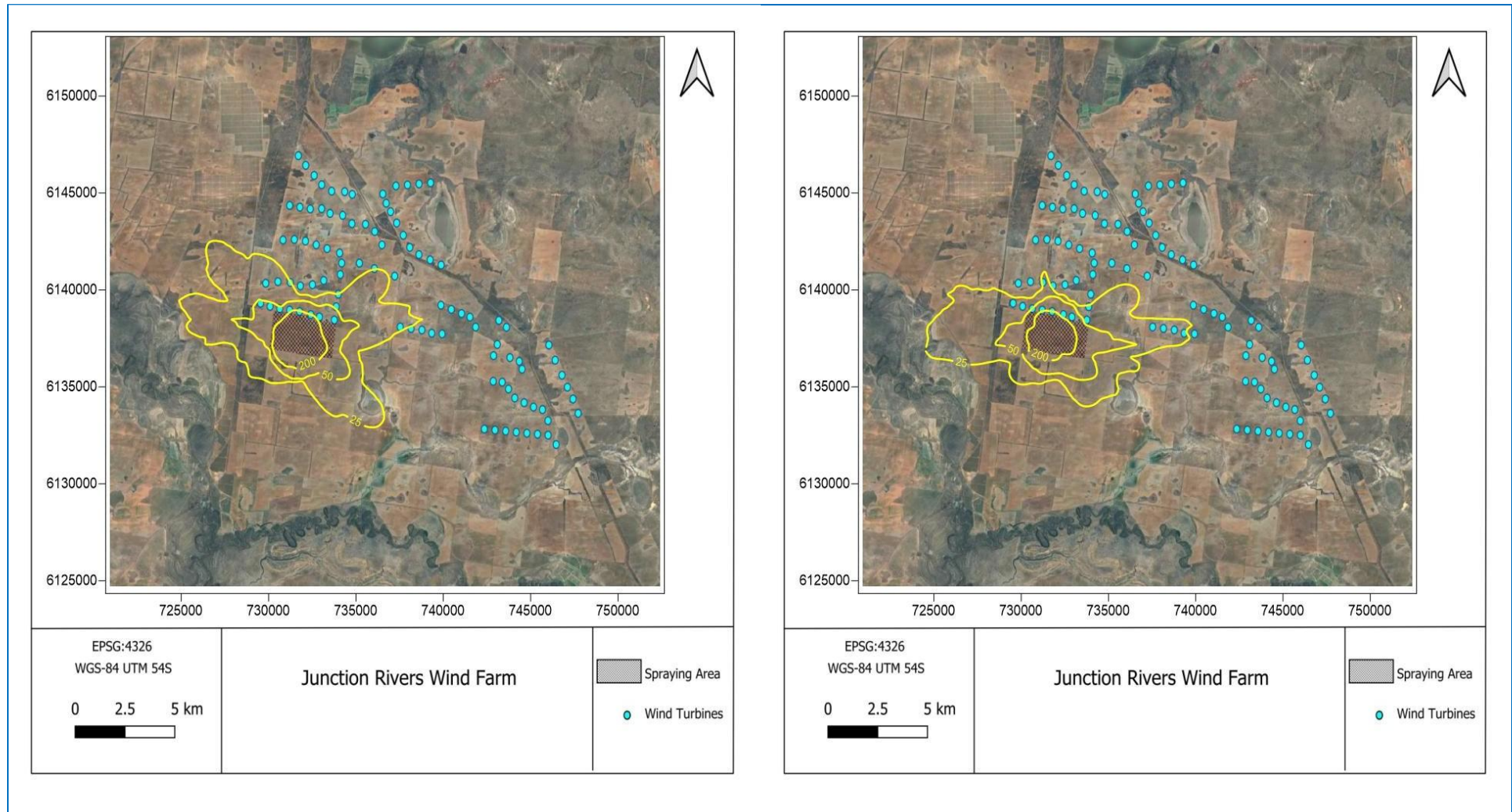


Figure 5.28: Predicted maximum 1-hour volatilised concentration contour ($\mu\text{g}/\text{m}^3$) – Base (left) and Project (right). Units in $\mu\text{g}/\text{m}^3$

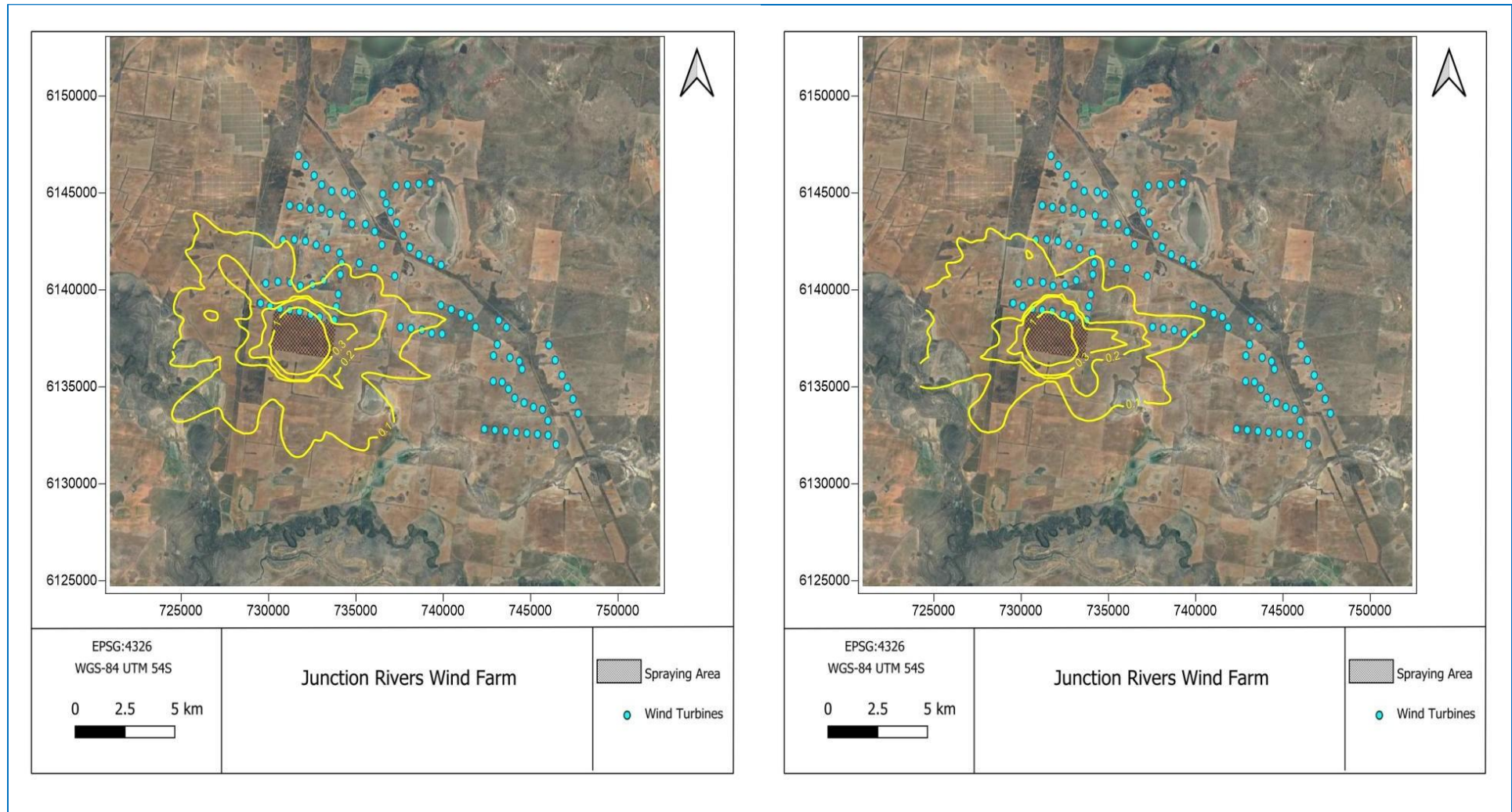


Figure 5.29: Predicted maximum 1-hour volatilised deposition contour (mg/m²) – Base (left) and Project (right). Units in mg/m²/hour

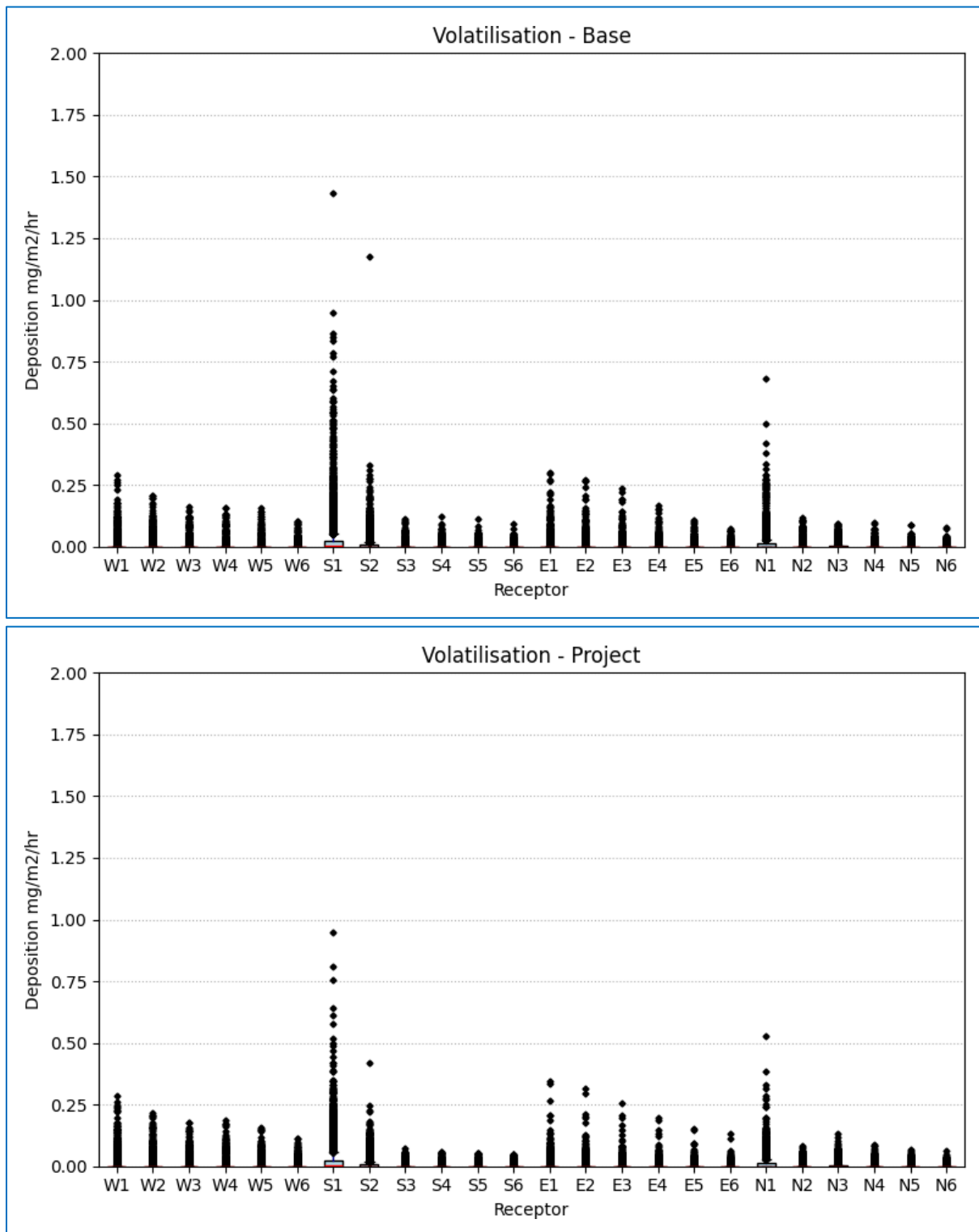


Figure 5.30: Statistics of hourly volatilisation deposition rates at the discrete receptors for the base (top) and project (bottom) at the 24 adjacent receptors

5.2.3.2 Area B

The contours attributed to volatilisation of chemicals after ground spraying operations over Area B show:

- the dispersion patterns for concentrations are slightly different between the base and project cases, most notably the reduced dispersion to the south-southeast for the project (Figure 5.31)
- for maximum hourly deposition, the patterns for the base and wind farm cases show some differences, with a mainly reduced footprint for the project (Figure 5.32).

The change in deposition rates from the base to project assessed at the discrete receptors 500 m, 2,000 m, 3,000 m, 4,000 m and 5,000 m to the north, east, south and west of the potential spray area (Figure 5.33) show:

- that highest deposition rates occur at the receptor between 500 m and 1.5 km to the north of the spray area
- discrete receptors generally show a decrease in deposition rates with the project.

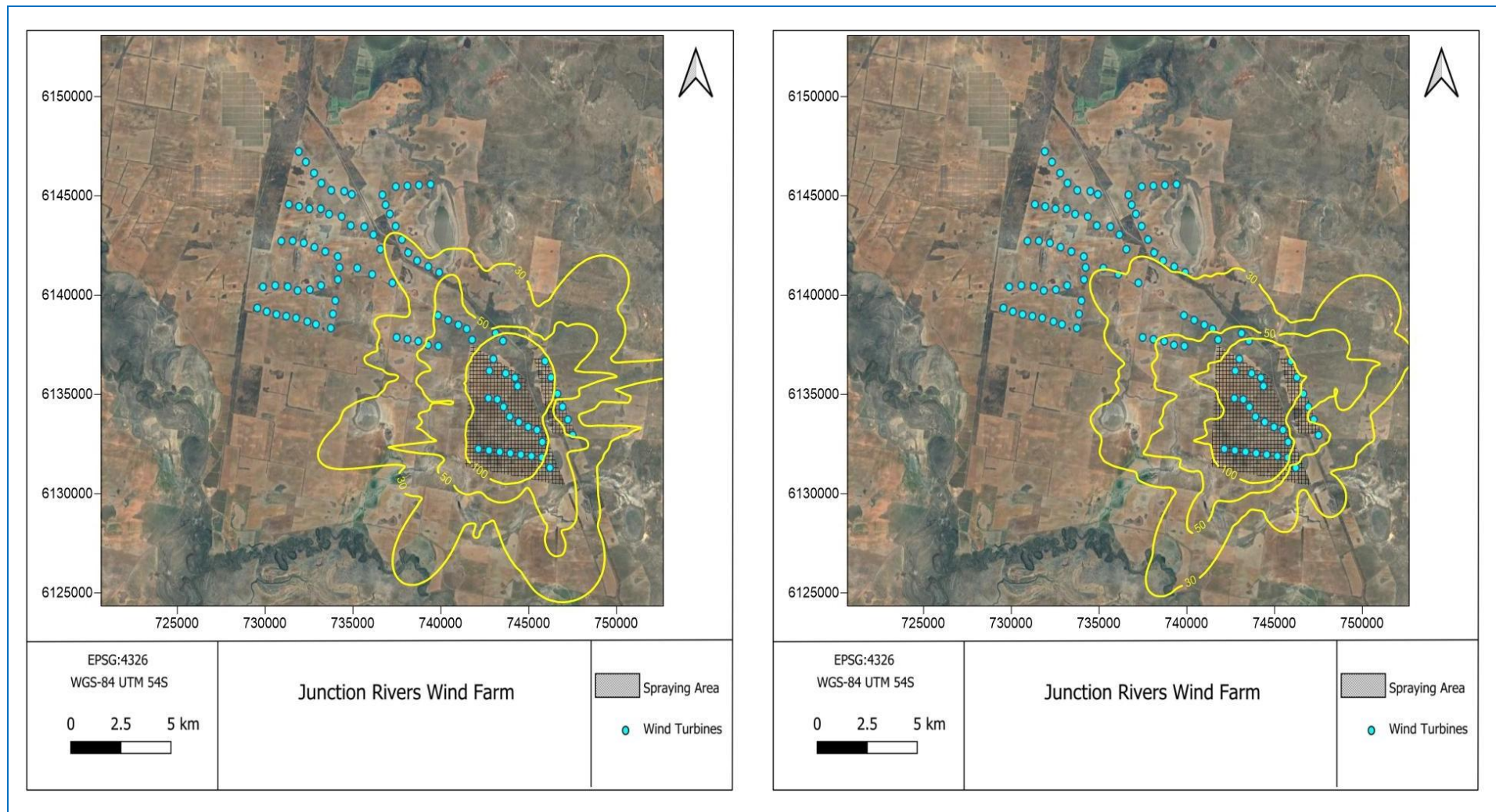


Figure 5.31: Predicted maximum 1-hour volatilisation concentration contour ($\mu\text{g}/\text{m}^3$) – Base (left) and Project (right). Units in $\mu\text{g}/\text{m}^3$

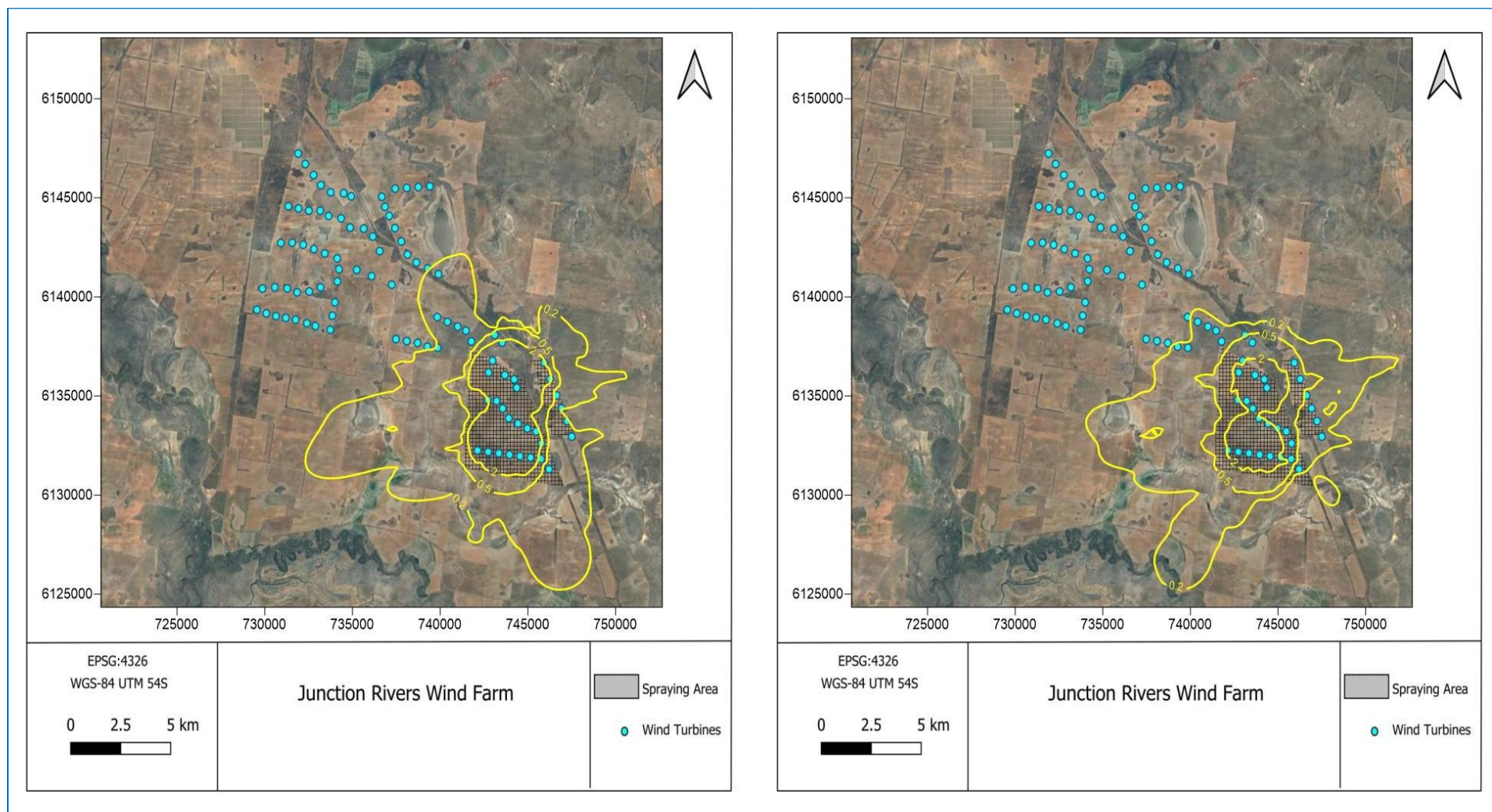


Figure 5.32: Predicted maximum 1-hour volatilisation deposition contour (mg/m²) – Base (left) and Project (right). Units in mg/m²/hour

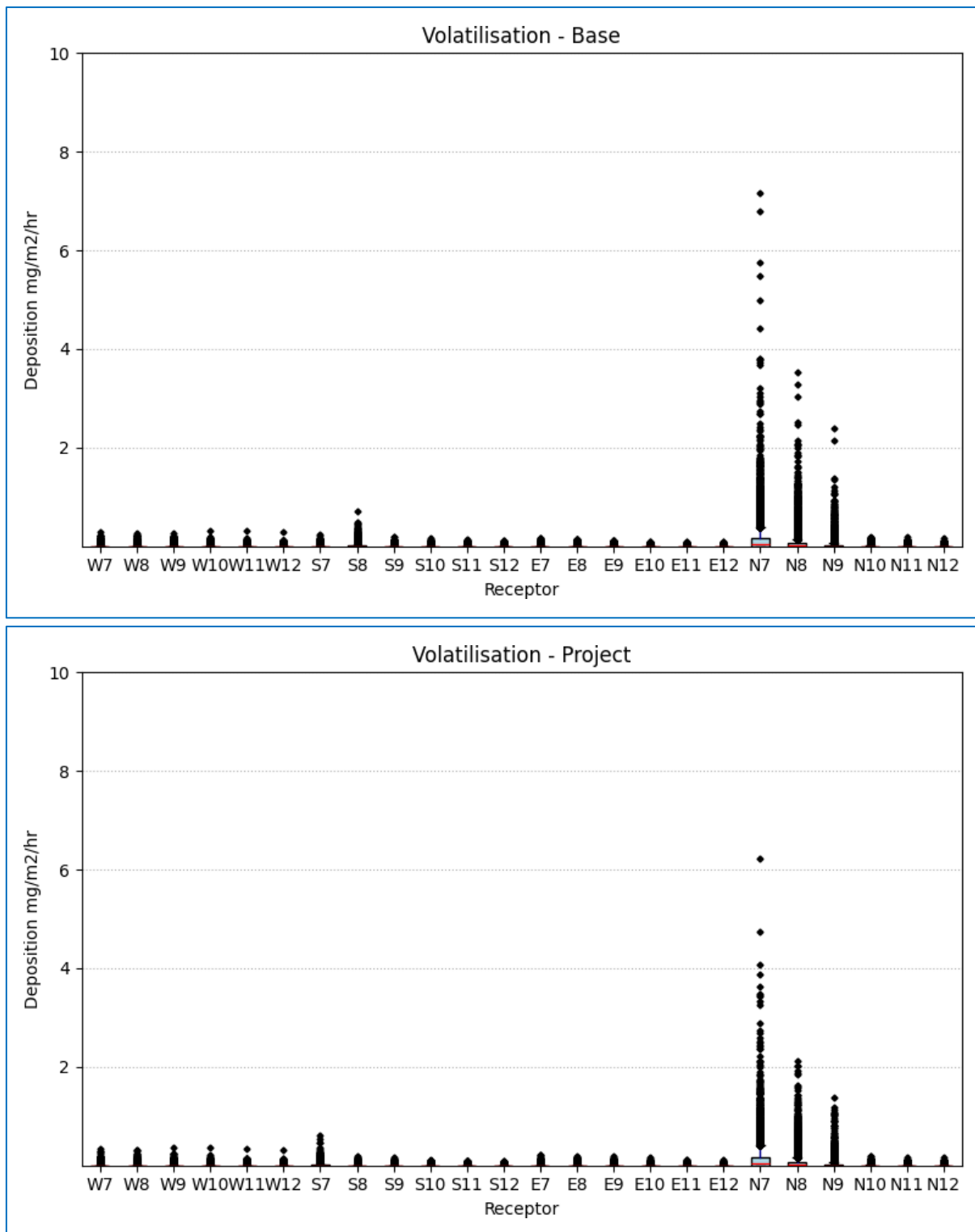


Figure 5.33: Statistics of hourly deposition rates at the discrete receptors for the base (top) and project (bottom) at the 24 adjacent receptors

6 Conclusions

Windlab Developments Pty Ltd (Windlab) proposes to construct and operate the Junction Rivers wind farm in the south-west of New South Wales. To support with the delivery of the Response to Submissions and address concerns raised in public submissions, Windlab needs to assess the possible impact of the wakes of the turbines at the proposed wind farm on potential spray drift during surface and aerial application and due to volatilisation of chemicals deposited in the ground. The highest potential impact with and without the wind farm at multiple distances downwind are to be determined for multiple wind directions.

This modelling assessment determined the potential effects of the proposed wind farm on the local climate and meteorology. Meteorology for the base case and wind farm scenarios were modelled using the Weather Research and Forecast (WRF) model. The model was statistically validated against surface measurements from the nearest Bureau of Meteorology station, thereby providing confidence in the meteorological data generated.

Ground and aerial spraying emissions were estimated using the AGDISP model and volatilisation emissions were calculated using methodologies outlined in the literature and input into the CALPUFF dispersion model as area sources to simulate ground spraying and volatilisation, and the new spray source type in CALPUFF V7. to simulate aerial spraying. Results of the modelling are conservative, given that spraying activities are modelled for every hour when spraying activities are possible due to suitable meteorological conditions (see Figure 4.1). This is to allow impacts under all suitable meteorological conditions (1,160 hours) to be assessed. In typical use, single pesticide products are used on most crops intermittently and no more than seven times a year, with the most intensively treated crops sprayed between 10 and 20 times per year. This is a highly conservative approach as conversations between the local community and Windlab indicate that chemical spraying follows the crop cycles. Ground spraying occurs no more than twice per year, and aerial spraying has not been conducted in the area for more than 20 years (April 2025).

The operation of the wind farm will only have a small effect on the atmospheric conditions. In particular:

- On an annual basis, the project results in a negligible reduction in wind speed close to ground level (between 0 m and 10 m) where spraying occurs.
- At 120 m above ground, there is a marginal increase in the frequency of light winds, as well as north-easterly winds at 120 m. However, these changes are not expected to affect dispersion on the ground.
- The wind farm has a relatively small impact on the mixing height, surface stability and vertical velocities on an annual time scale.
- Turbulence intensity increases downwind of the proposed wind farm at hub height but decreases at the surface due to decreased vertical shear.

For ground spraying:

- the dispersion patterns for concentration and deposition are slightly different between the base and project cases with dispersion primarily along a west-east axis for the former and an east-southeast to west-northwest axis for the latter.
- deposition rates are highest to the south and to the north of both spray areas
- maximum deposition rates decrease at discrete receptors S1 and S2, E1, E2 and N1 with a small increase in deposition at receptors W1 and W2 with the project. The remaining receptors show negligible difference from the base case.
- This suggests that the presence of wind turbines may decrease deposition beyond the spraying areas due to the decreased surface turbulence

For aerial spraying:

- the dispersion pattern between the base and wind farm cases are similar, with dispersion along a southwest to northeast axis
- the dispersion patterns for concentrations are significantly different to the ground spraying and volatilisation emissions, most likely due to the increased dispersion of the chemicals due to turbulent dispersion within the aircraft wake. (*i.e.* vortices)
- for maximum hourly deposition, the patterns for the base and wind farm cases are similar.
- cumulative spraying (Area A and B) shows minimal overlap between concentration and deposition patterns
- receptors to the east of the spray Area A (E1-E4) have the highest deposition rates and the project only has a negligible impact on deposition rates at the discrete receptors.
- receptors to the south of Area B (S7 - S11) have the highest deposition rates followed by receptors to the west of the spray area (W7-W9) and deposition only to the south (S7-S8) of the spray area increases slightly with the project.
- the cumulative (Area A and B) spraying scenario shows only a negligible increase in deposition at the southern (S1-S6) and at the northern (N1-N6) receptors for both the base and project cases
- there is little cumulative impact of spraying over the two areas
- highest deposition occurs with winds less than 4 m/s blowing directly from the spray areas under moderately unstable to neutral stability conditions.

For volatilisation:

- the dispersion patterns for concentrations are slightly different between the base and wind farm cases
- for maximum hourly deposition, the patterns for the base and wind farm cases show some differences, especially to the east and northwest of the potential spraying area.
- that highest deposition rates occur at the nearest receptor to the south and the north of both the spray areas
- discrete receptors generally show a decrease in deposition rates with the project

The dispersion modelling study suggests that generally, the operation of the wind farm has a neutral impact on deposition. While the deposition rates vary (*i.e.*, slight increase or slight decrease, depending on location), the changes are mostly negligible regardless of the spray activity type or from volatilisation. The cumulative assessment of aerial spraying occurring simultaneously in two of the most affected locations also shows that potential impacts due to the operation of wind farm are minimal. The impacts of spraying simultaneously over two areas show very little cumulative impact.

Two key areas were defined as the location of crop spray activities. These areas are most likely to be affected due to the proximity to the proposed turbine locations and will potentially have the highest impact relative to wind farm operations. Potential impacts outside of the areas assessed are expected to be lower.

It is important to note that the results presented in this report should be treated as relative, rather than absolute. The study has applied conservative assumptions applied to the spraying activities and has assumed that spraying occurs emissions were modelled for every potential hour that spraying is possible (whenever the conditions are conducive). The adoption of best practice methods during spraying will further mitigate and reduce impacts.

Based on the spray drift assessment, there are no indications that crop spraying applications would need to vary when the wind farm is operational, particularly if best practice guidelines are adopted.

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8 Appendices

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Appendix A–Meteorology

A.1: Selection of Representative Meteorological Year for Modelling

This Appendix summarises the analysis undertaken to determine a representative modelling year, based on the review of long term measured data from the nearest BoM climate station at Swan Hill (2012 to 2022 inclusive).

Generally, a minimum of one year of meteorological data is acceptable for dispersion modelling in Australia. The data must, however, adequately represent worst-case meteorological conditions and the data should be assessed in terms of representativeness against climatic averages. In other words, the meteorology for selected years must be deemed representative of the “normal” range of conditions in the area.

To determine the year of meteorological data to use for the dispersion modelling, 11-years of historical hourly²⁷ surface observations from the nearest BoM station at Swan Hill (2012 to 2022 inclusive) were reviewed. The Chi² Goodness of Fit test was used to statistically identify the representative modelling year based on recorded meteorological parameters including wind speed, wind direction, temperature, and rainfall.

The statistical analysis shows that 2020 can be considered largely representative of longer-term average conditions. The meteorological variables affecting dispersion, namely wind speed, wind direction and temperature compare favourably to the long-term average conditions.

The results of the statistical analysis performed to support selection of the representative year is described in the following sub-sections.

Chi² Goodness of Fit test

The Chi² Goodness of Fit test was used to statistically identify the representative modelling year based on recorded meteorological parameters including wind speed, wind direction and temperature. The Chi² Goodness of Fit test is a non-parametric hypothesis test used to determine whether a variable is likely to come from a specified distribution or not. It is often used to evaluate whether sample data (in this case, an individual year) is representative of the full population (e.g. multiple years).

The null hypothesis is that there is no significant difference between hourly values in an individual year and the hourly averages for long term average values. If values fall within the vertical lines (at 5% confidence interval, two tailed), then accept the null hypothesis (Appendix Figure 1).

Wind Direction

The Chi² test results for wind direction for 2012 to 2022 at BoM Swan Hill are compared in Appendix Figure 2. From this figure it is apparent that the wind direction frequency distribution during 2012, 2013, 2014, 2016, 2017, 2018, 2020 and 2021 were not significantly different to the long-term wind direction frequency distribution.

²⁷ Calculated from 1-minute data.

Wind Speed

The basic statistics for average wind speed for the 12-year period and individual years are shown in Appendix Table 1. Overall, there are only small differences between the chosen years, though the average speeds during 2014 and 2017 show the greatest deviations from long term averages. The frequency of stronger (>20 km/h) winds deviate most from the long-term average during 2015 and 2022. The frequency of light winds deviates most from the long-term average in 2019.

Appendix Table 1: Annual wind speed statistics for Swan Hill (2012-2022).

Year	Mean	Standard Deviation	% <5 km/h	% >20 km/h
11-yr average	15.3	8.2	5.9	23.9
2012	15.2	7.9	5.6	23.1
2013	15.3	8.1	5.3	23.9
2014	14.8	8.3	7.0	21.3
2015	15.0	8.0	7.2	22.8
2016	15.6	8.4	5.6	25.2
2017	14.5	7.8	7.0	21.1
2018	15.8	8.6	5.9	26.4
2019	15.8	9.0	7.0	27.0
2020	15.5	8.2	5.3	24.0
2021	15.8	8.2	4.8	26.4
2022	15.1	7.1	4.0	22.1

The Chi² test results for wind speed are presented in Appendix Figure 3. This figure indicates that 2015, 2016, 2018 to 2020 were representative of 11-year average conditions at the 5% confidence interval.

Temperature

The basic statistics for average temperature for the 11-year period and individual years are shown in Appendix Table 2. The average temperature for the years 2012 to 2022 are all within 0.6°C of the 1-year average.

Appendix Table 2: Annual temperature statistics for Swan Hill (2012-2022).

Year	Mean	Standard Deviation	% <5°C	% >35°C
11-yr average	16.6	8.3	6.1	2.2
2012	16.1	8.1	6.4	1.2
2013	16.9	8.2	5.1	2.3
2014	17.0	8.6	6.4	2.9
2015	16.8	8.6	6.1	2.8
2016	16.7	8.2	4.4	2.3
2017	16.6	8.7	7.8	2.0
2018	17.0	8.7	6.6	3.0
2019	17.0	9.0	6.2	4.0
2020	16.0	8.2	7.9	1.4
2021	16.1	7.6	4.9	1.1
2022	16.0	7.5	5.3	0.9

The Chi² test results for temperature are presented in Appendix Figure 4. The hourly temperature frequency distributions during 2019, 2021 and 2022 were significantly different to the long-term frequency distribution.

Rainfall

The annual rainfall at Balranald, available for the extended period 1993-2022, is displayed in Appendix Figure 5. There is some variation in rainfall between each year which is to be expected for the region. Post 2010, the years 2011, 2018, 2019 and 2022 have annual rainfall that fall just outside the 10th and 90th percentile²⁸ long-term (30 year) rainfall totals.

Conclusions

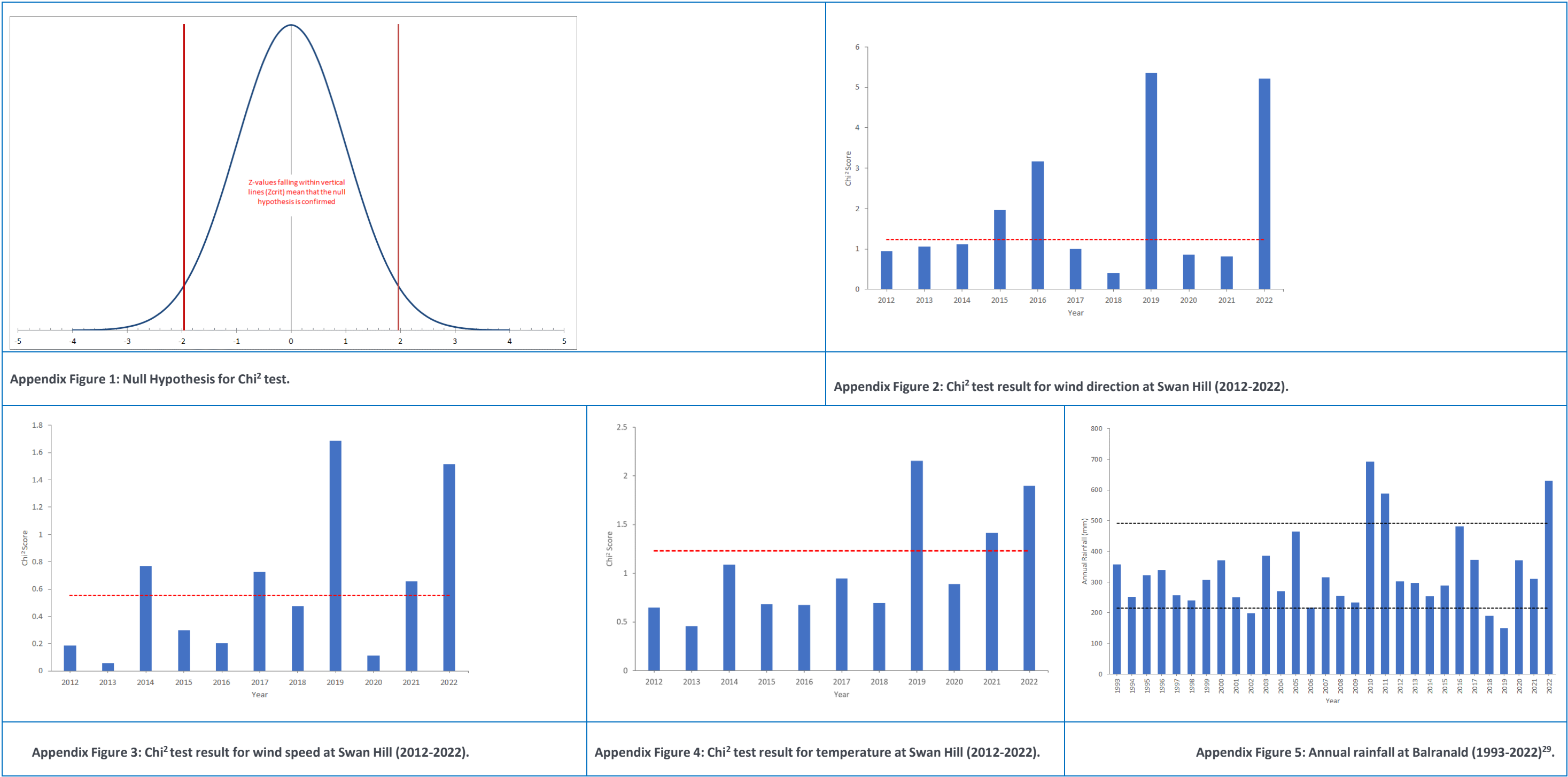
It is important to note that it is highly unusual for multiple climatological parameters to all fall within “representative” levels. With that in mind, the following conclusions can be made for the period reviewed:

- The years 2012-2018 and 2020 are representative of longer-term (11 year) temperature average frequency distribution at the 99% significance level.
- 2012, 2013, 2015, 2016, 2018 and 2020 are representative of longer-term wind speed average frequency distribution at the 99% significance level.
- For wind direction, frequency distributions during 2012, 2013, 2014, 2017, 2018, 2020 and 2021 are representative of longer-term direction frequency distributions at the 99% significance level.

²⁸ The 10th and 90th percentile values are classed as well below and well above average according to the Bureau of Meteorology

- For annual rainfall at Balranald, all years (post 2010) except 2011, 2018, 2019 and 2022 have annual rainfall totals that fall within the longer-term 10th and 90th percentile values.

Based on the above analysis, 2020 is representative of longer-term conditions for all parameters examined.



²⁹ Dotted lines indicate the 30 year 10th percentile (lower line) and 90th percentile (upper line) rainfall values.

A.2: Weather Research and Forecast (WRF) Model Configuration and Validation

Model Configuration

WRF was developed (and continues to be developed) in the United States by a collaborative partnership including the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the National Center for Environmental Prediction (NCEP), the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, the Federal Aviation Administration (FAA) and others.

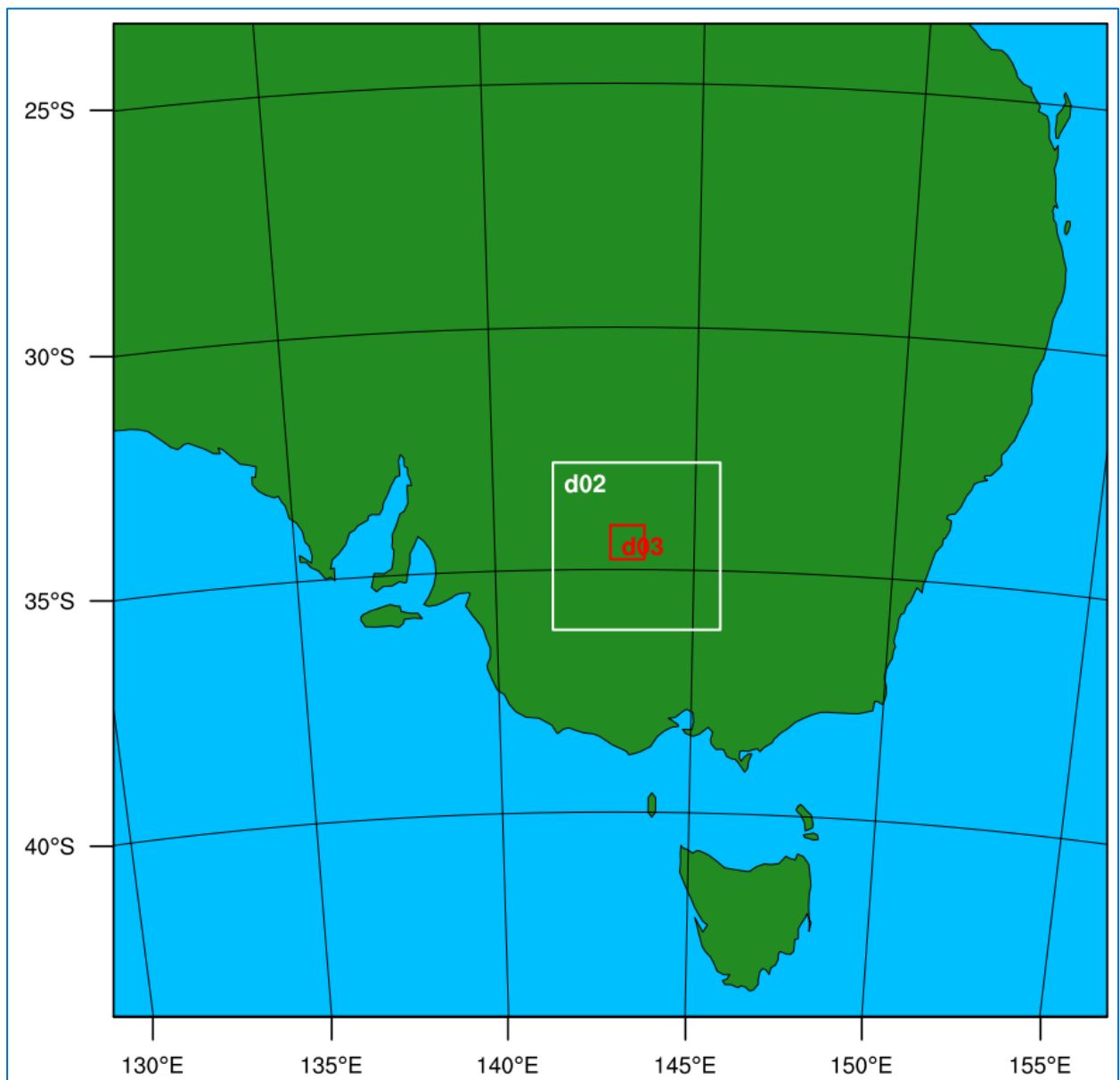
WRF is a fully compressible, Eulerian, non-hydrostatic meso-scale numerical model developed by the National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA) in the United States. WRF is suitable for a broad spectrum of applications across scales ranging from metres to thousands of kilometres. The model utilises global reanalysis³⁰ data to produce fine-scale 3-dimensional meteorological fields that considers local terrain and land-use effects.

WRF was run with a four-nest structure (24 km, 6 km, 1.5 km, 500 m horizontal grid space resolution) centred on 34.4097°S and 143.42238°E. This is shown in Appendix Figure 6. The model vertical resolution consists of 50 hybrid-eta levels³¹.

Physics options in WRF are to represent atmospheric radiation, surface, and boundary layer as well as cloud and precipitation processes. WRF can be run with a variety of model physics options which can lead to varying results and hence it is crucial for the most appropriate model setup for a particular purpose over a given region/domain. The physics options selected for the modelling are based on the results of a sensitivity study undertaken over southeastern Australia, where simulations of 36 combinations of planetary boundary layer physics, surface layer physics, cumulus physics, micro-physics and shortwave/longwave radiation physics schemes were assessed (Evans et. al., 2011). The combination of physics options found to produce the most accurate results, were used in this study, and are summarised in Appendix Table 3.

³⁰ Global modelling using observed climate data for temperature, wind speed, and pressure. The observations are analysed; interpolated onto a system of grids and the model initialised with this data.

³¹ Terrain-following close to the earth's surface and pressure levels higher in the atmosphere.



Appendix Figure 6: Four nest structure, WRF model.

Appendix Table 3: WRF Physics Options Selected for Model.

	Domain 1	Domain 2	Domain 3	Domain 4	Explanatory Notes
mp_physics	4	4	4	4	WRF Single-moment 5-class Scheme
ra_lw_physics	1	1	1	1	Rapid radiative transfer model scheme
ra_sw_physics	1	1	1	1	Dudhia scheme for cloud and clear sky absorption and scattering
Radt	10	10	10	10	Time step for radiation schemes
sf_sfclay_physics	2	2	2	2	MM5 based on MOST
sf_surface_physics	2	2	2	2	Noah land surface model with 6 soil layers
bl_pbl_physics	5	5	5	5	Mellor–Yamada Nakanishi Niino (MYNN) Level 2.5 and Level 3 Schemes
bldt	0	0	0	0	Boundary layer time step (0=every time step)
cu_physics	2	1	0	0	Kain-Fritsch scheme using mass flux approach for domain 1 only.
cudt	5	5	5	5	Cumulus physics time step (minutes)

Six-hourly global final analysis³² synoptic data (from <http://nomads.ncdc.noaa.gov/data/gfsanl/>) was used to initialise the model and provide boundary conditions.

Land-use and terrain data were sourced from the United State Geological Services (USGS) database. Inspection of the land-use indicates an acceptable resolution and category for the model area with shrub land being the dominant vegetation type.

The selection of an appropriate Land Surface Model (LSM) is critically important to provide the boundary conditions at the land-atmosphere interface because:

- The Planetary Boundary Layer (PBL) schemes are sensitive to surface fluxes.
- The cloud/cumulus schemes are sensitive to the PBL structures.
- There is a need to capture mesoscale circulations forced by surface variability in albedo, soil moisture/temperature and land use.

The Noah Land-Surface Model was selected in this case to account for the sub-grid-scale fluxes. This sophisticated scheme provides four quantities to the parent atmospheric model (WRF), namely:

- surface sensible heat flux
- surface latent heat flux
- upward longwave radiation, and
- upward (reflected) shortwave radiation.

³² Final analysis data is global modelled data that has been retrospectively corrected using surface, upper air and satellite measurements.

The model was run without (base scenario) and with wake effects (wind farm scenario).

The WRF model includes a wind farm parameterisation option (Fitch Scheme). In this parametrization the wind turbines are treated as a density function. The parameterization works with the MYNN PBL and modifies the turbulent kinetic energy (TKE) field to include the TKE produced by wind turbines.

WRF requires the thrust coefficients, and the power curve a file called containing:

- True latitude of each wind turbine in degrees
- True longitude of each wind turbine in degrees
- Turbine type

The GW182 7.2MW turbine characteristics provided by Windlab for the modelling were:

- Number and location of turbines
- Hub height of 200 m
- Rotor diameter of 182 m
- Power curve and thrust coefficient data.

Note that it is not recommended to run the parameterisation at model resolutions higher than 5 rotor diameters. Consequently, an inner-most model resolution of 500 m was selected to comply with this recommendation.

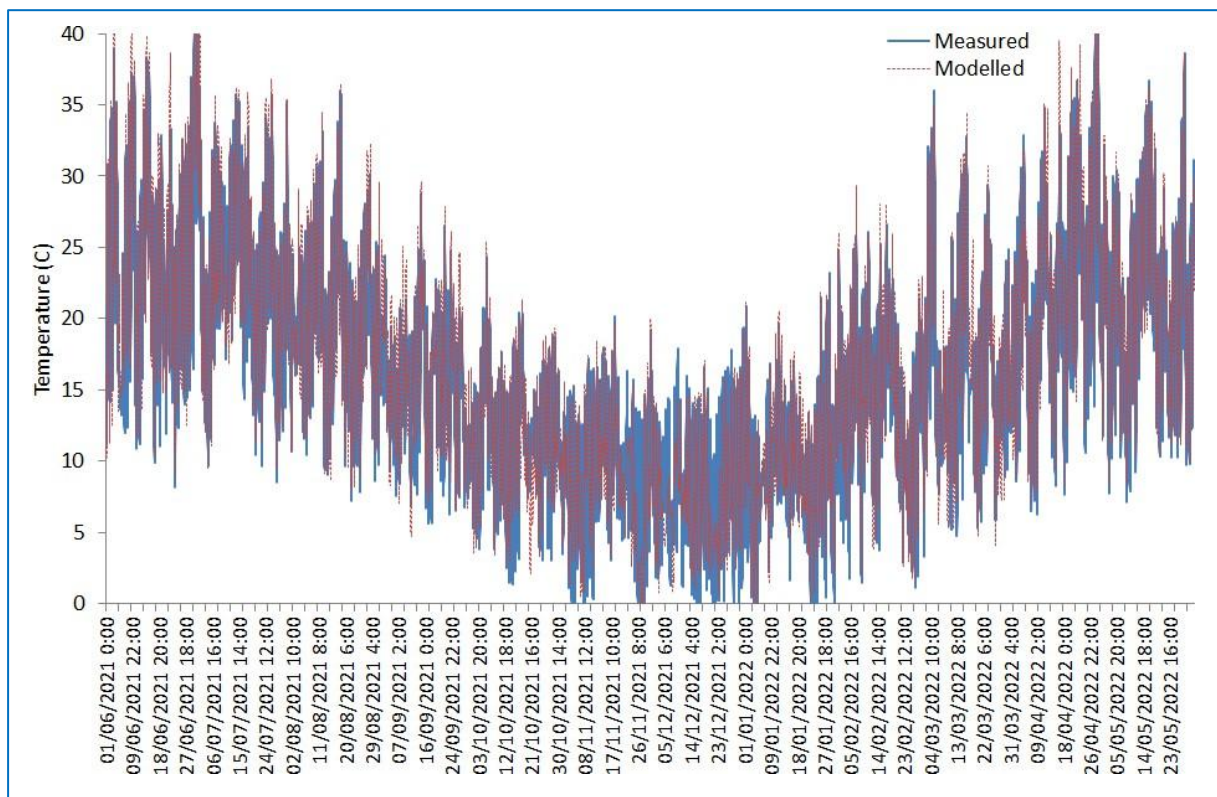
Model Validation

The accuracy of the meteorology generated by WRF was assessed by comparing model output against corresponding measurement data at the Swan Hill weather station located at 35.3766°S and 143.5416°E. For model validation, data plots must accompany any comparison between observed and simulated variables, as such graphic aids lend visual credibility to quantitative comparisons as well as point to possible erroneous computations. Data plots represent the first level of comparative data description and analysis, while summary statistical measures comprise the second level. Objective statistical methods to evaluate meteorological model performance are based on those used by Willmott (1981), Pielke (1984) and CAWCR (2017).

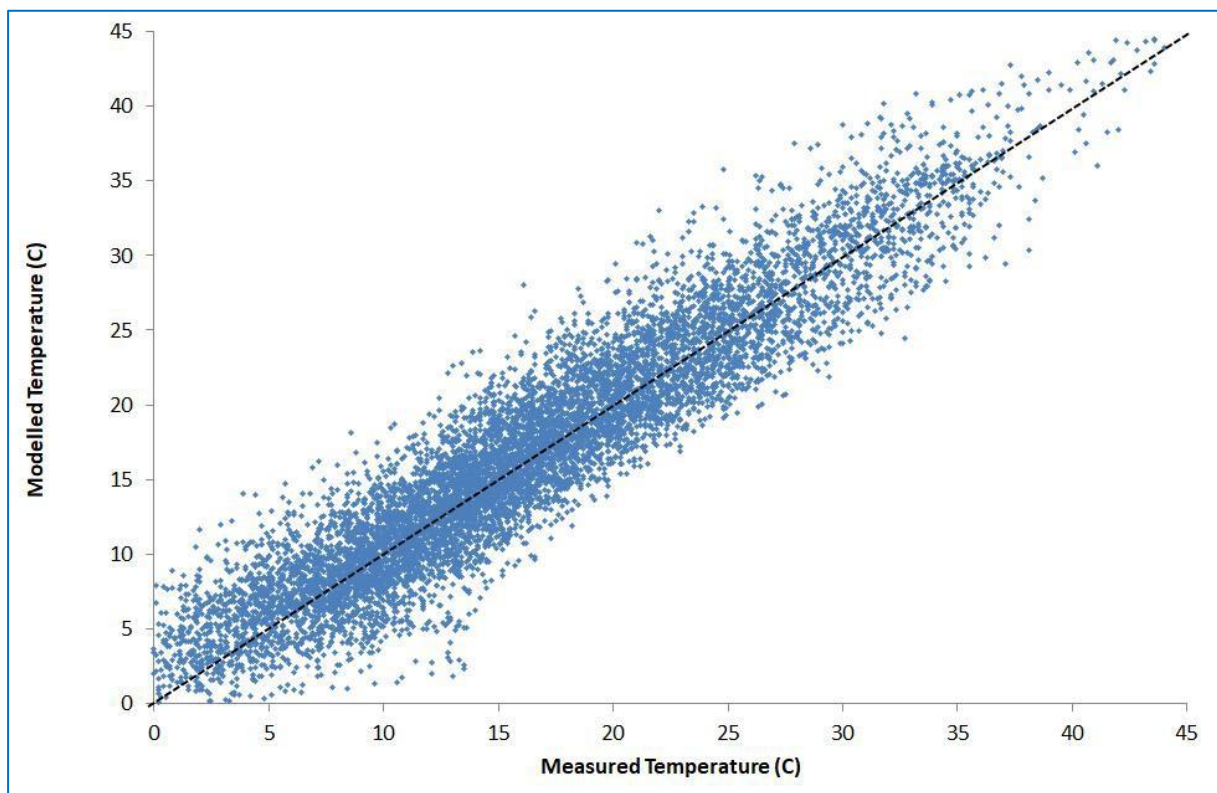
In addition, comparative model performance has been assessed through Taylor diagrams. The Taylor diagram (Taylor, 2001) provides a graphical framework that allows a suite of variables from one or more models to be compared to reference (observational) data. The diagram has been devised to provide a concise statistical summary of how well patterns match each other in terms of their correlation, their root-mean-square difference, and the ratio of their variances. Simulated patterns that agree well with observations will lie nearest the point marked "observed" on the x-axis. These models will have relatively high correlation and low Root Mean Square (RMS) errors. Models lying on the dashed arc will have the correct standard deviation (which indicates that the pattern variations are of the right amplitude). Note that the means of the fields are subtracted out before computing their second-order statistics, so the diagram does not provide information about overall biases but solely characterizes the centered pattern error.

The results for temperature show that:

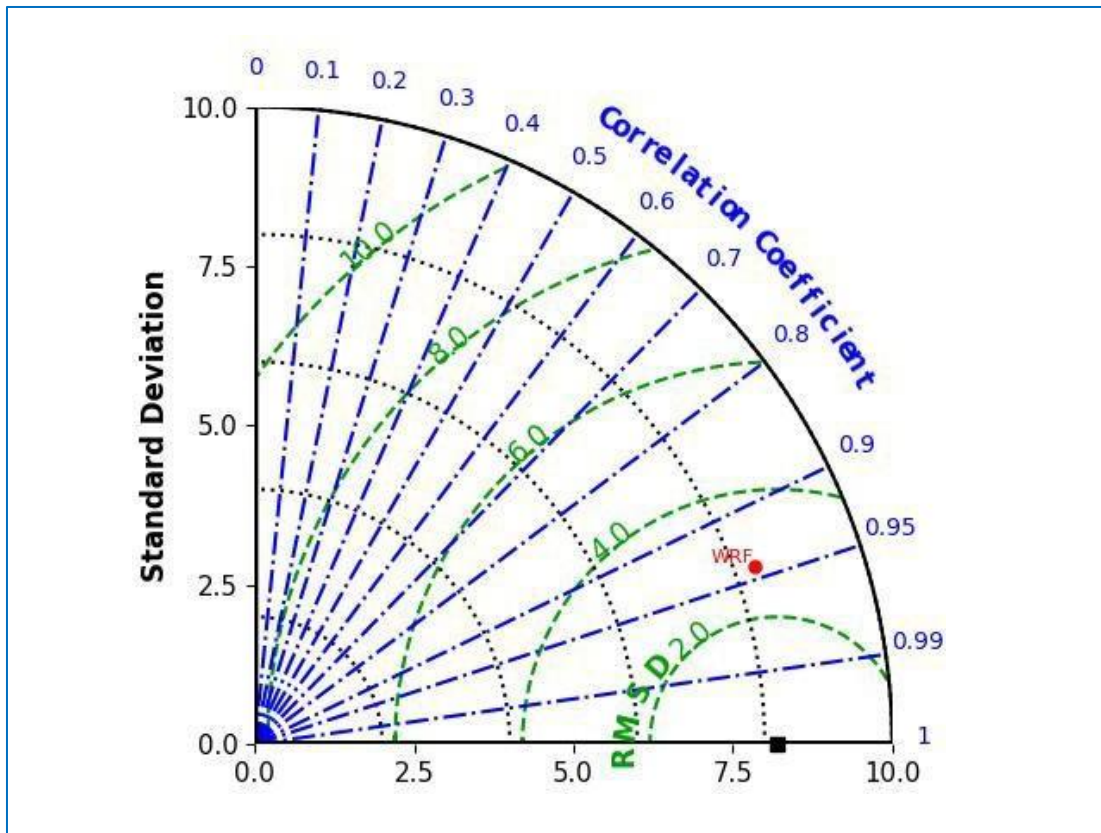
- A time series of hourly WRF modelled and corresponding measured temperature is shown in Appendix Figure 7. Both models appear to reflect trends relatively well, and maxima are generally predicted.
- This is reflected in the scatterplot (Appendix Figure 8), where the scatter of points along the 1:1 line indicates a relatively strong relationship between modelled and measured temperature.
- The Taylor diagram in Appendix Figure 9 shows that WRF has a root mean square errors (RMSE) of approximately 3 and a correlation coefficient of 0.95. In addition, the standard deviation of measured and modelled temperature is comparable.



Appendix Figure 7: Time series of modelled and measured temperature at Swan Hill.



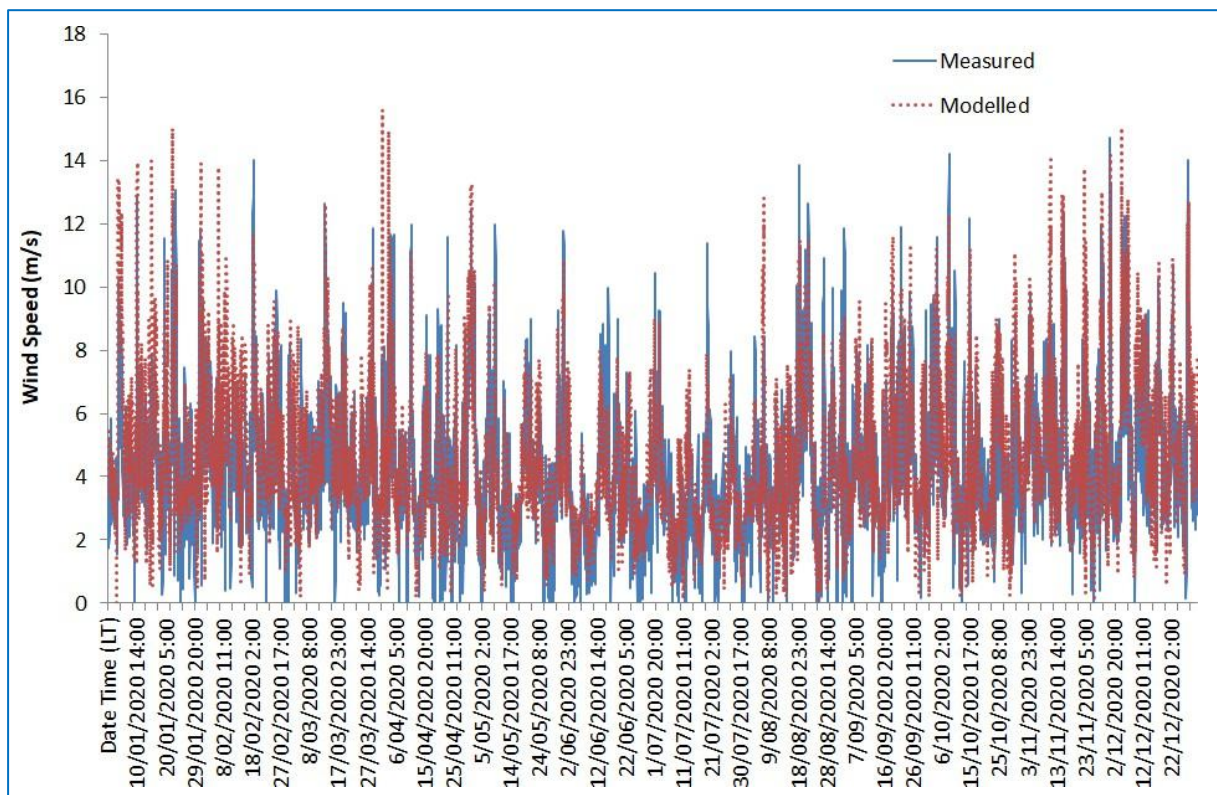
Appendix Figure 8: Scatterplot of modelled and measured temperature at Swan Hill



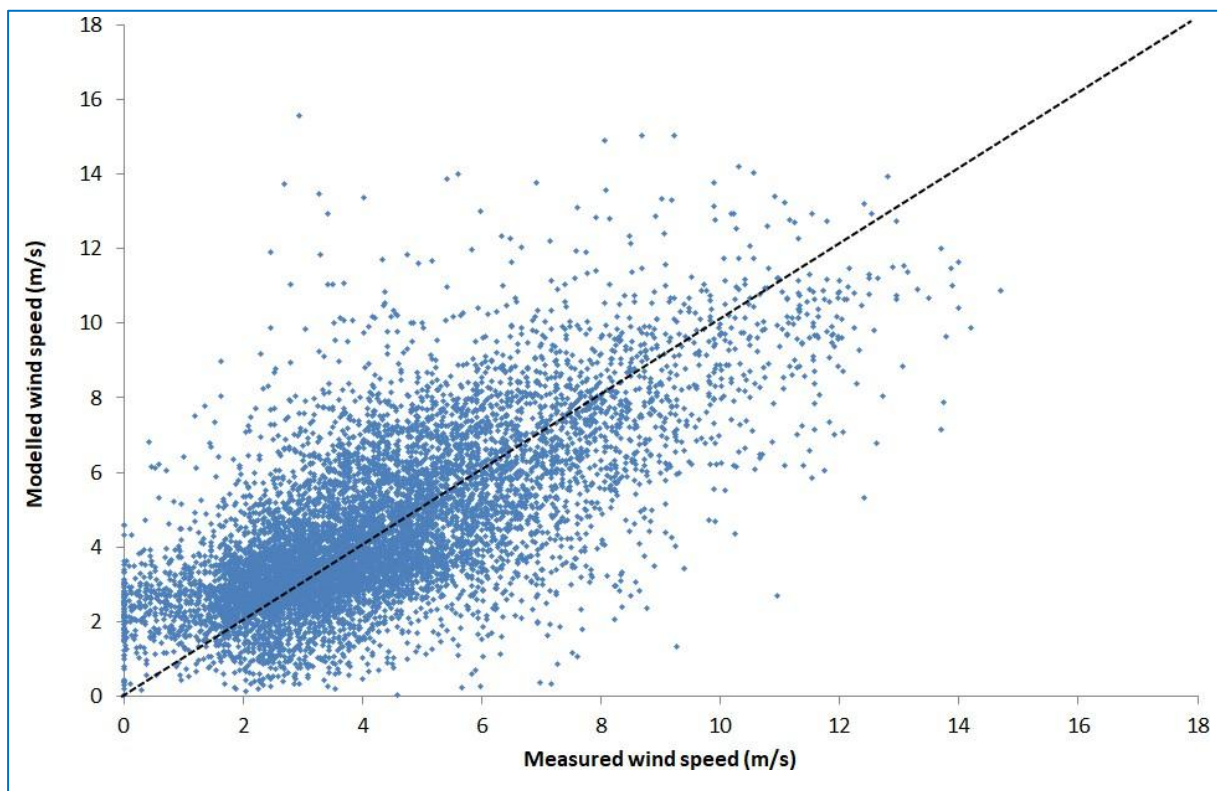
Appendix Figure 9: Taylor diagram displaying a statistical comparison with observations of WRF model temperature forecasts.

For wind speed:

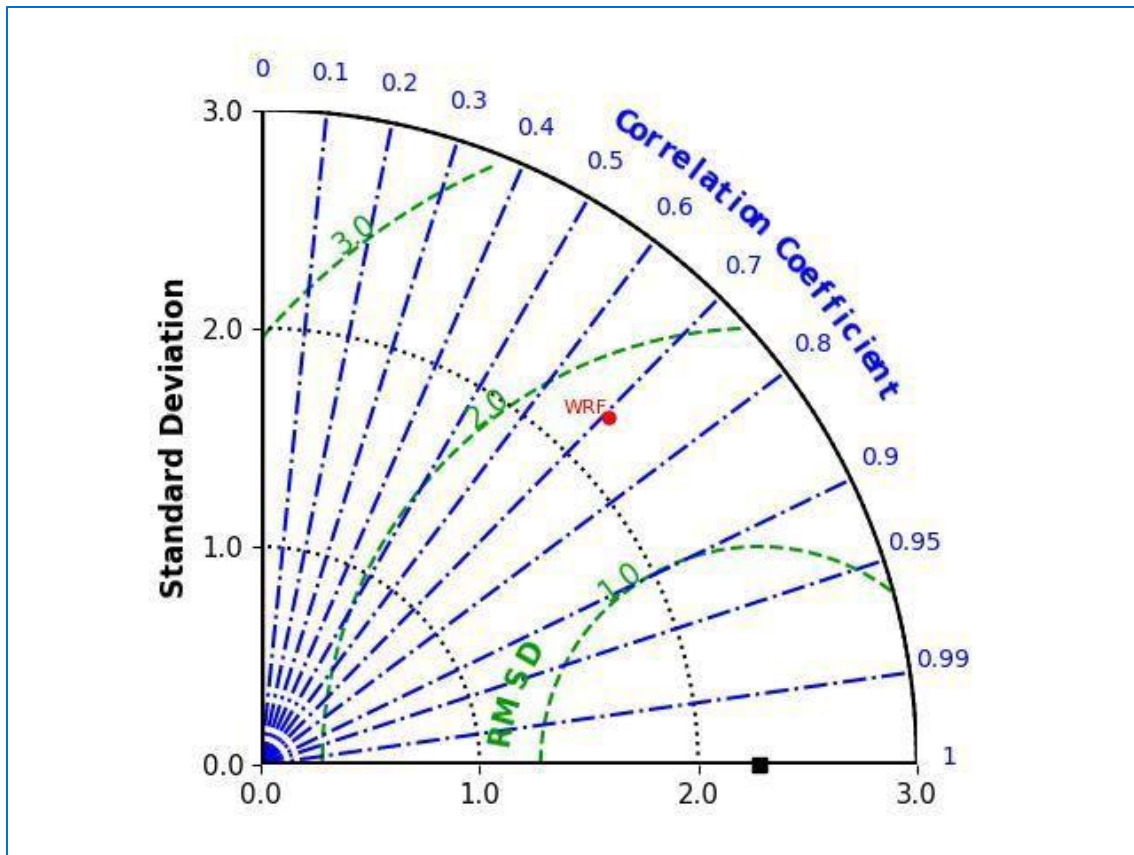
- The time series of hourly modelled and measured wind speed is shown in Appendix Figure 10. WRF reflects the trend and predicts the maximum and minimum wind speeds well.
- This prediction is confirmed by the scatterplot in Appendix Figure 11.
- The Talyor diagram in Appendix Figure 12 shows that while WRF has a correlation coefficient of 0.71, the root mean square errors (RMSE) is less than 2 and the standard deviation is comparable to observed wind speed.



Appendix Figure 10: Time series of modelled at measured wind speed at Swan Hill.



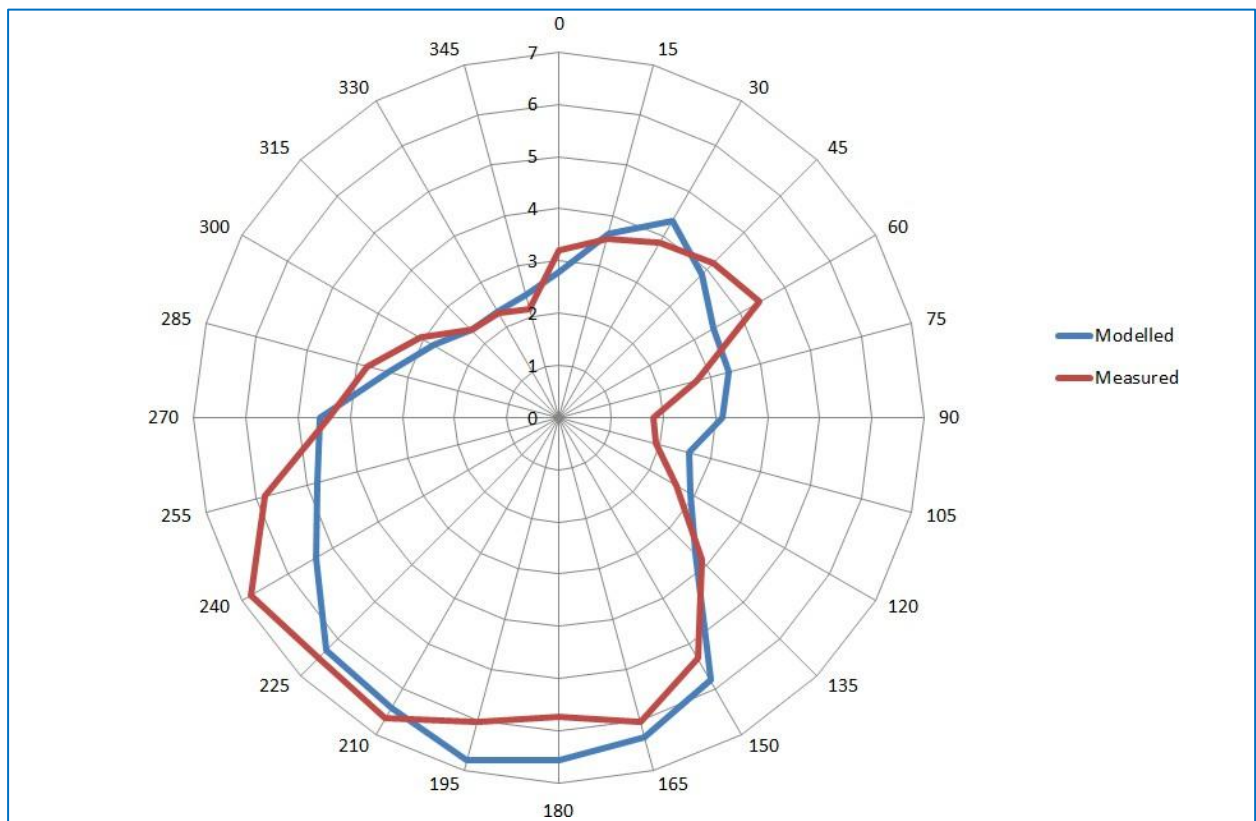
Appendix Figure11: Scatterplot of modelled and measured wind speed at Swan Hill.



Appendix Figure 12: Taylor diagram displaying a statistical comparison with observations of WRF model temperature forecasts.

For wind direction:

- The annual wind direction radar plots (Appendix Figure 13) show that overall, the model predicts the wind directions well, with the model within 1% of the measured direction frequency for all directions.



Appendix Figure 13: Measured (left) and modelled (right) annual wind roses at Swan Hill.

More objective methods to evaluate model performance are assessed using statistical tests that have been specifically developed for this purpose. These tests used are discussed in detail below.

Model Bias

The model bias (MB) is the mean error and is given by:

$$MB = \frac{1}{n} \sum_{i=1}^n (O_i - P_i)$$

Where:

n = the number of pairs of observed data

O_i = the observed value for the i-th hour

P_i = the predicted value for the i-th hour

The ideal value for the bias is zero.

Gross Error

The gross error (GE) is the mean of absolute error and is given by:

$$GE = \frac{1}{n} \sum_{i=1}^n |O_i - P_i|$$

where:

n = the number of pairs of observed data

O_i = the observed value for the i-th hour

P_i = the predicted value for the i-th hour

The ideal value for gross error is zero. GE is greater than MB, representing the expected error for each hourly observation.

Root Mean Square Error (RMSE)

The Root Mean Square Error is given by:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (O_i - P_i)^2}$$

where:

N = the number of pairs of data

O_i = the observed (measured) value for the i-th hour

P_i = the predicted (modelled) value for the i-th hour

While the ideal RMSE value is 0, large errors in a small section of the data may produce a large RMSE even though errors may be small elsewhere.

Index of Agreement

The index of agreement (IOA) is the measure of how well the model estimates departure from the observed mean.

$$IOA = 1 - \frac{N(RMSE^2)}{\{(P - \bar{O}) + (O - \bar{O})\}^2}$$

where:

n = the number of pairs of observed data

O = the observed value

$\bar{O}$ = the mean observed value

The index of agreement has a theoretical range of 0 to 1. The ideal value for IOA is 1.

A set of benchmarks were set for mesoscale model evaluation by Emery *et al.* (2001) and Teschke *et al.* (2001). The purpose of these benchmarks is not necessarily to give a passing or failing grade but to put the results into a proper context (Emery, et al., 2001).

Verification of WRF performance has been conducted by comparing hourly predictions against corresponding measurements at a location corresponding to the Swan Hill weather station between January 2020 and December 2020. Temperature, wind speed and wind direction compared (Appendix Table 5).

Appendix Table 5: Results of statistical validation test at Swan Hill

Variable	Performance Criteria	Benchmark Range	Statistic	
			Score	Benchmark
Wind Speed	RMSE	$<\pm 2$ m/s	1.8	Within
	BIAS	$<\pm 0.5$ m/s	-0.2	Within
	IOA	>0.6	0.8	Within
Wind Direction	Gross error	$<30^\circ$	30	Within
	BIAS	$<10^\circ$	3.6	Within
Temp	Gross error	$<\pm 2$ K	2.3	Outside
	BIAS	$<\pm 0.5$ K	-0.5	Within
	IOA	>0.8	1.0	Within

Based on the results shown in the table, it can be concluded that:

- The model predicts surface temperature with a high degree of skill. Two of the three benchmarks are met.
- The model predicts wind direction with a high degree of accuracy. Both benchmark criteria are met.
- The model predicts wind speed with a moderate to high degree of skill. The three benchmark criteria are met.

The meteorological model performance can therefore be considered acceptable when compared to measurement data.

A.3: Modelled Meteorology

Wind Direction and Speed

Selected meteorological variables were extracted from the gridded WRF model output for a point corresponding to the potential crop spraying area. The general features of the 10 m winds illustrated in the seasonal wind rose diagrams at 10 m and 120 m for the 12-month period from January 2020 – December 2020³³ are shown in Appendix Figure 14.

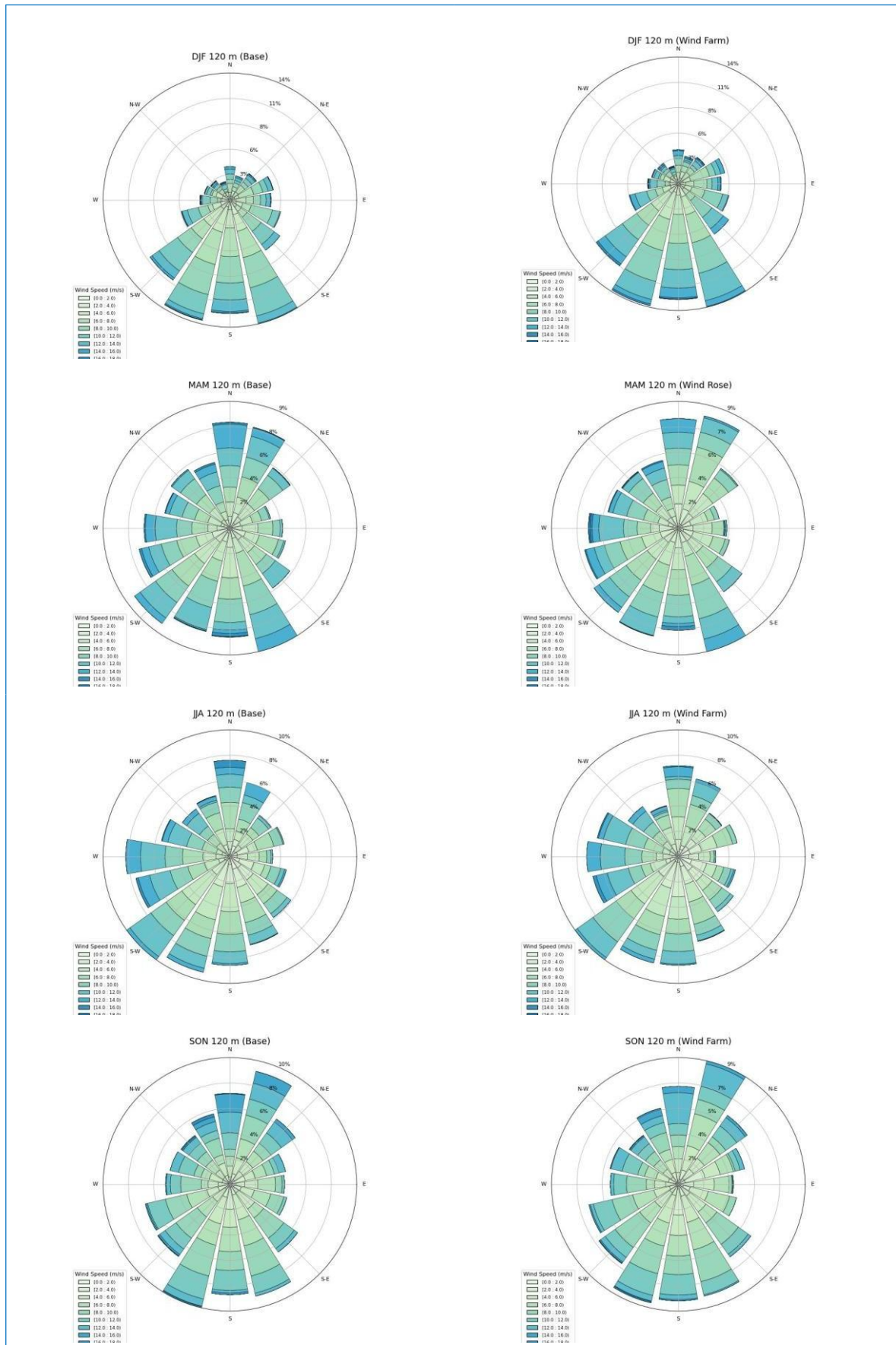
The major features of the wind rose are as follows:

- During summer (DJF), there is little difference in wind directions between the base and wind farm cases at both heights.
- During autumn (MAM), there is an increase in frequency of light northeasterly and south-westerly winds at both 10 m and 120 m
- During the winter months (JJA), lighter winds increase in frequency.
- During spring (SON), lighter winds increase in frequency with the wind farm at 10 m particularly).

³³ The selected representative meteorological year (as determined previously).



Appendix Figure 14: Seasonal wind roses at 10 m. Base case on the left and Wind Farm on the right.

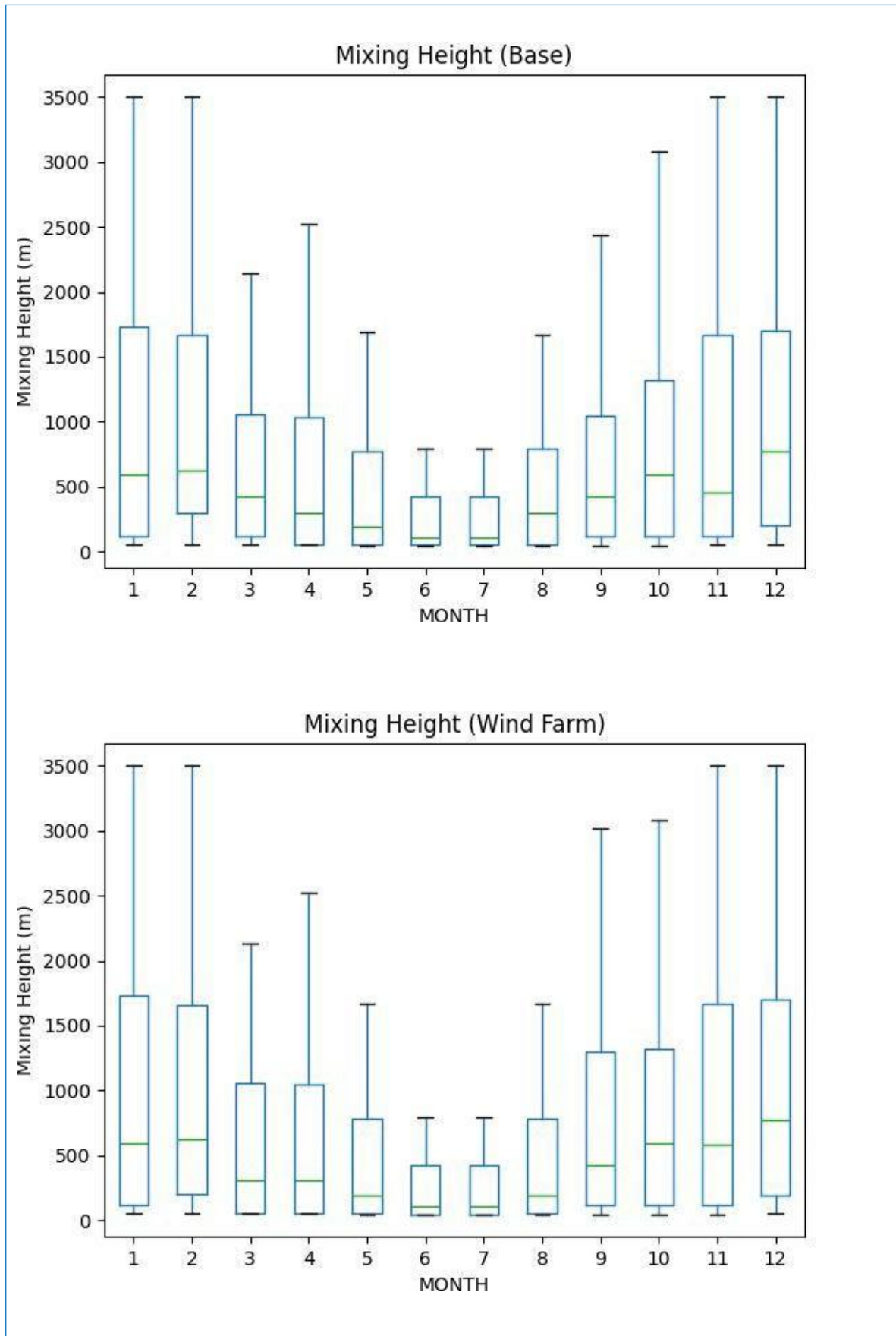


Appendix Figure 15: Seasonal wind roses at 120 m. Base case on the left and Wind Farm on the right.

Mixing Height

A series of internal algorithms within WRF is used to calculate mixing heights for the extracted point where it is assumed that mixing height is formed through mechanical means (wind speed) at night and through a mixture of mechanical and convective means (wind speed and solar radiation) during the day (Scire et al. 2011). During the night and early morning when the convective mixed layer is absent or small, the full depth of the planetary boundary layer (PBL) may be controlled by mechanical turbulence. During the day, the height of the PBL during convective conditions is then taken as the maximum of the estimated (or measured if available) convective boundary layer height and the estimated (or measured if available) mechanical mixing height. It is calculated from the early morning potential temperature sounding (prior to sunrise), and the time varying surface heat flux to calculate the time evolution of the convective boundary layer.

The seasonal average mixing heights are shown in Appendix Figure17. As expected, lowest mixing heights occur during the winter months when solar radiation (and hence convection) is lowest. There is no clear difference between the seasonal base and wind farm mixing height statistics.



Appendix Figure17: Simulated annual statistics. of monthly mixing heights for extracted point Base case (top) and Wind Farm case (bottom).

Stability

An important aspect of pollutant dispersion is the level of turbulence in the lowest 1 km or so of the atmosphere, known as the planetary boundary layer (PBL). Turbulence controls how effectively a plume is diffused into the surrounding air and hence diluted. It acts by increasing the cross-sectional area of the plume due to random motions. With stronger turbulence, the rate of plume diffusion increases. Weak turbulence limits diffusion and contributes to high plume concentrations downwind of a source.

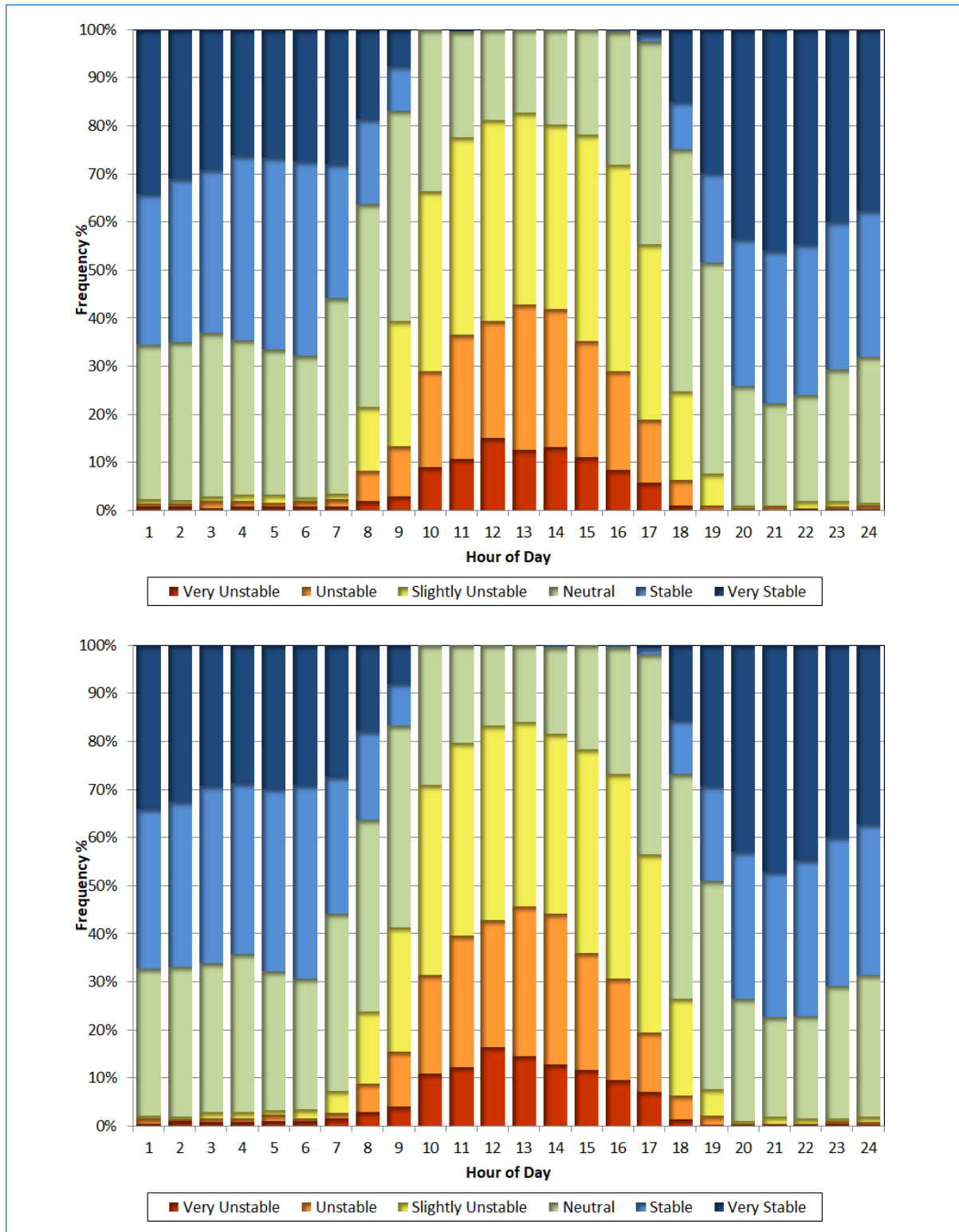
Turbulence is generated by both thermal and mechanical effects to varying degrees. Thermally driven turbulence occurs when the surface is being heated, in turn transferring heat to the air above by convection. Mechanical turbulence is caused by the frictional effects of wind moving over the earth's surface and depends on the roughness of the surface as well as the flow characteristics.

Turbulence in the boundary layer is influenced by the vertical temperature gradient, which is one of several indicators of stability. Plume models use indicators of atmospheric stability in conjunction with other meteorological data to estimate the dispersion conditions in the atmosphere.

Stability can be described across a spectrum ranging from highly unstable through neutral to highly stable. A highly unstable boundary layer is characterised by strong surface heating and relatively light winds, leading to intense convective turbulence and enhanced plume diffusion. At the other extreme, very stable conditions are often associated with strong temperature inversions and light winds, which commonly occur under clear skies at night and in the early morning. Under these conditions, plumes can remain relatively undiluted for considerable distances downwind. Neutral conditions are linked to windy and/or cloudy weather, and short periods around sunset and sunrise, when surface rates of heating or cooling are very low.

The stability of the atmosphere plays a significant role in determining the dispersion of a plume and it is important to have it correctly represented in the dispersion model. CALPUFF uses the Monin-Obukhov Similarity Theory (MOST) to characterise turbulence and other processes in the PBL.

The hourly averaged computed stability is presented in Appendix Figure 18. This plot indicates that the PBL is stable to very stable overnight becoming very unstable (reaching maximum instability between 11:00 am and 4:00 pm) as radiation from the sun heats the surface layer of the atmosphere and drives convection. There is little significant difference on an annual time frame between stability with and without inclusion of the wind farm.



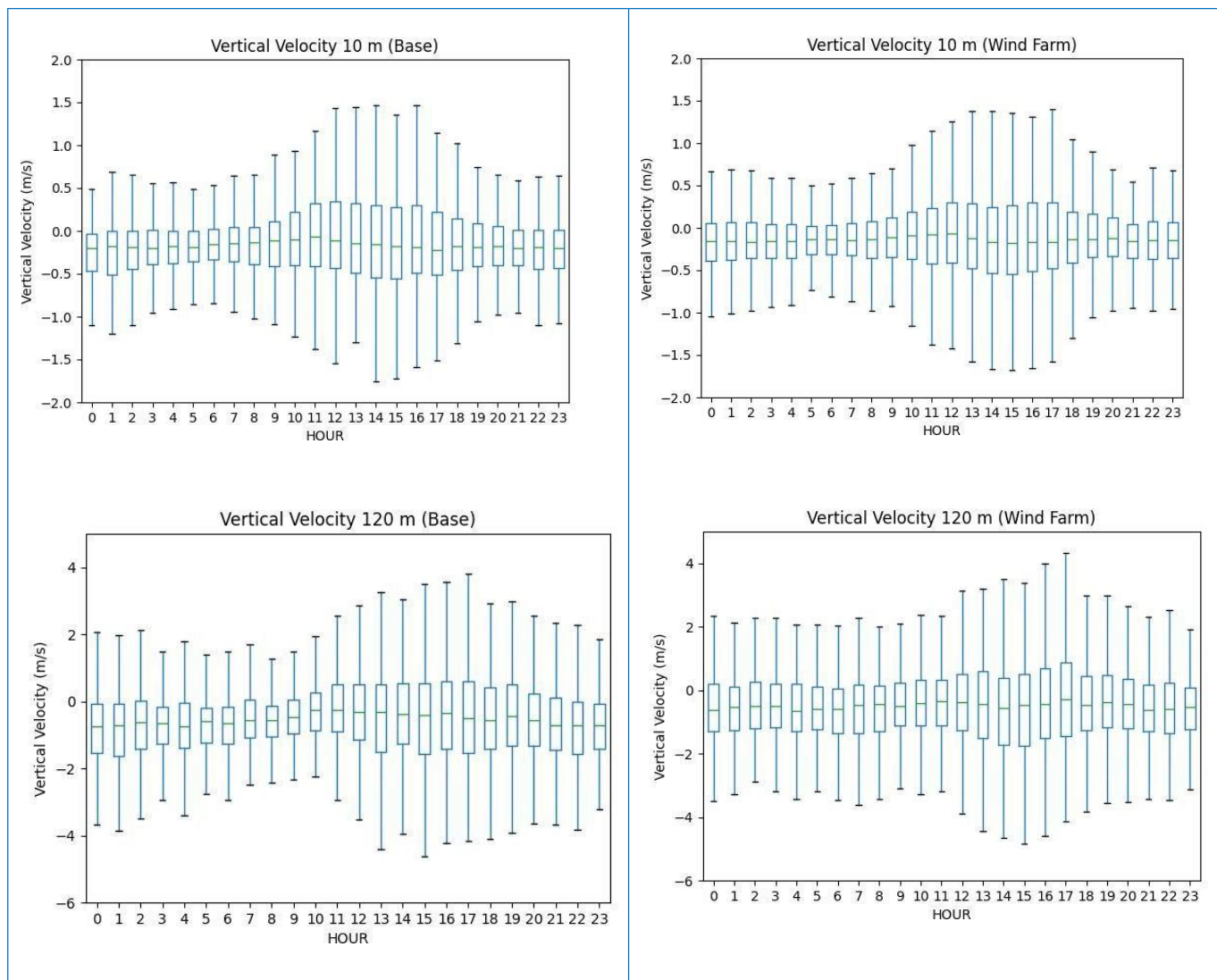
Appendix Figure 18: Hourly statistics of stability on an annual basis for the Base case (top) and the Wind Farm (bottom)

Vertical Velocity

Vertical velocity is the speed of air motion in the upward or downward direction (negative values of vertical velocity indicate upward motion). This parameter is potentially important as a proxy for turbulence (with its associated upward and downward motion) and can be used for assessing the impact of the wind farm on the local meteorology and climate given that the turbines have the capacity to induce turbulence.

The hourly statistics of vertical velocity on an annual basis is presented in Appendix Figure 19 for 10 m and 120 m for the base and wind farm scenarios. The figures show that, as expected, upward (negative) and downward (positive) vertical velocity increases during the day when convection is greatest. At night, these motions are reduced due to the decrease in turbulence. Visual comparison of hourly average vertical velocities for the base and wind farm cases shows that:

- At 10 m, there are only relatively minor differences in vertical velocity, most noticeably for increased maximum negative values at 1 pm with the wind farm.
- At 120 m, the differences between the base and wind farm cases are more apparent with increased upward and downward motion occurring with the wind farm.



Appendix Figure 19: Hourly statistics of vertical velocity on an annual basis for the 10 m (top) and 120 m (bottom) for the Base case (left) and the Wind Farm (right).

Appendix B –Emissions

B.1: AGDISP Model

AGDISP (AGricultural DISPersal) was used to estimate emission rates from both ground- and aerial-based spraying. For input to CALPUFF. AGDISP is based on a Lagrangian particle tracking theory and simulates the release, dispersion, evaporation and deposition onto crop and ground surfaces for multiple particle sizes. The model allows for the selection of two spray options, namely:

- Aerial spraying where the effects of the aircraft wake as well as the air-generated and ambient turbulence are considered (Teske and Curbishley 2002)
- Ground spraying where the simulation of spray drift from ground application of pesticides with boom sprayers are considered (Teske et al, 2001)

A detailed discussion of the mathematics and algorithms utilised by the model are provided in Teske et al. (2009) and Teske et al. (2003).

A number of studies have examined the performance of AGDISP with field observations. A sensitivity analysis and evaluation study of AGDISP and two other spray drift models were performed for Environment Canada (Riley, 1995). The New Zealand Forest Research Institute, Rotorua, New Zealand, compared AGDISP with field results of 12 separate applications over grasslands with 3 separate nozzle types and a 10.3-m release height (Richardson et al, 1995). These researchers concluded that the modelling system was useful in the assessment of the effectiveness of spray equipment and for defining operational and meteorological variables that will minimise drift.

The model settings for the ground and aerial spraying are summarised in Appendix Table 6. Note that as no information on ground or aerial spraying was provided for this study, default model values were used, where available. This approach is valid as the purpose of the study is to determine *relative* change in spraying activities between the wind turbine and no wind turbine scenarios.

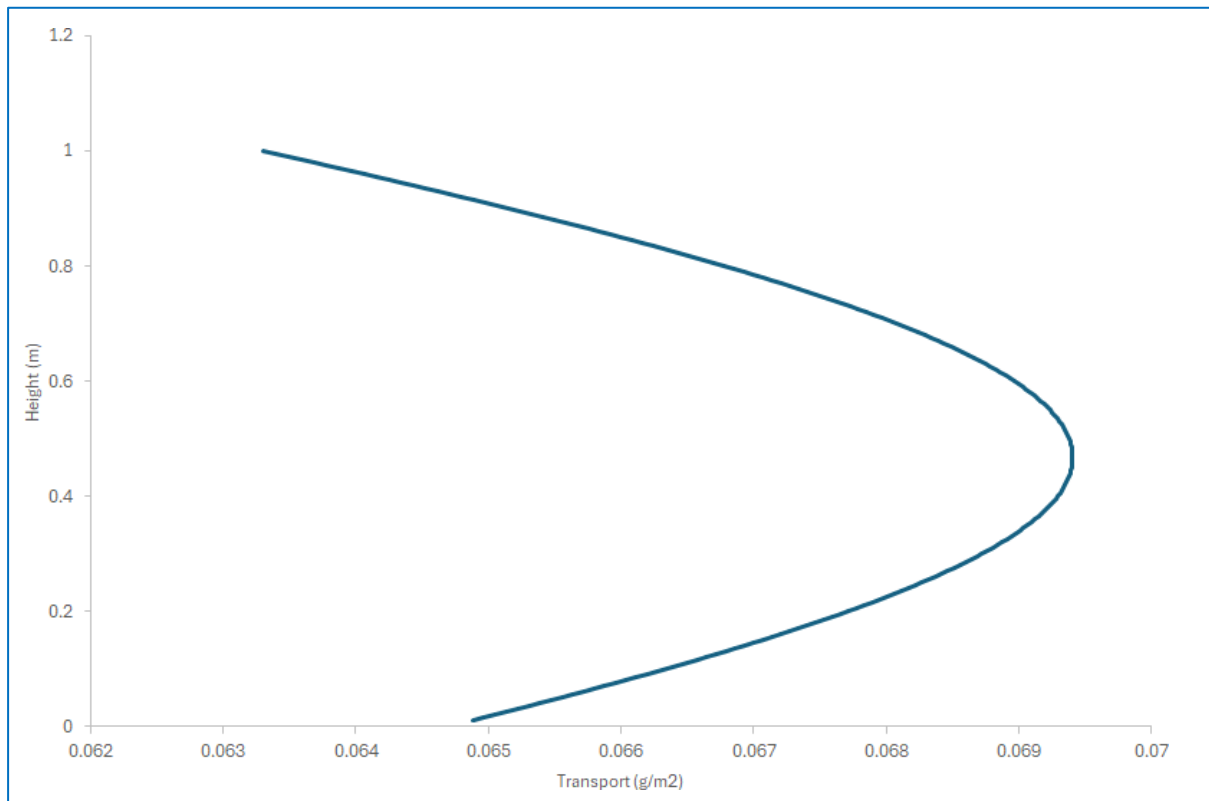
Appendix Table 6: Parameter values used in the model

Parameter	Value	Value
Application method	Ground Spraying	Aerial Spraying
Release height (m)	0.5	4
Wind speed (m/s)	2	2
Particle size distribution	Fine to medium	Fine to medium
Aircraft Type	-	Air Tractor AT-401
Nozzle type	Air injection	-
Speed (m/s)	5.5	53.6
Boom pressure (bar)	5	-
Boom width (m)	11	15
Spray volume (L/ha)	50	18.7
Evaporation ($\mu\text{g}/^\circ\text{C}/\text{s}$)	67.33	67.33

The output of the ground sprayer scenario is produced as spray drift transport (g/m²) with height. (Appendix Figure 20). Dividing by the depth of the spray layer (1 m) produces a concentration with height (g/m³). The vertical flux is then estimated using the gradient (k-theory) approach outline in Lückérath et al. (2022):

$$F_k = -K \frac{dC}{dz}$$

Where F_k is the vertical flux of C and the vertical turbulent diffusivity (k) is estimated at 0.432 (after Hanna, 1968). Integrating vertically produces a vertical flux of $6.42 \times 10^{-6} \text{ g/m}^2/\text{s}$. This emission rate was used in CALPUFF.



Appendix Figure 20: Transport with height, as determined from AGDISP

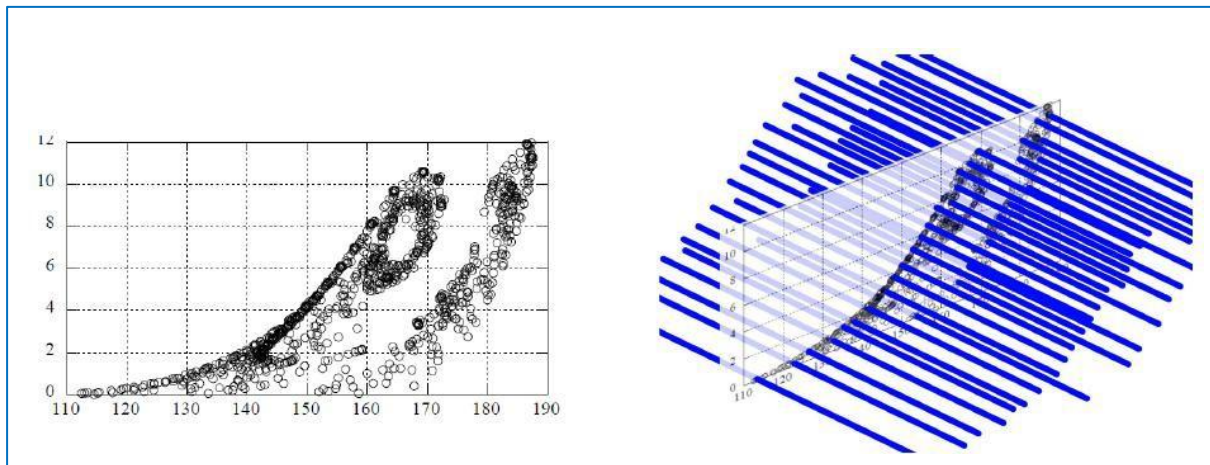
The aerial spraying option in AGDISP produces track locations, droplet diameters and mass emission rates (g/m/s). This is used in CALPUFF after reformatting. The transfer of data to CALPUFF occurs after release when all turbulent vortices have died down and evaporation of the droplet volatile fraction is complete. AGDISP exports the position, elevation, final droplet diameter after deposition immediately after spraying and emissions associated with the range of particle sizes released from each aircraft nozzle (Exponent, 2019).

B.2: CALPUFF

CALPUFF is a multi-layer, multi-species, non-steady state puff dispersion model which can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal. CALPUFF uses three-dimensional meteorological fields computed by the CALMET model, or directly from a prognostic meteorological model such as WRF using the mesoscale model interface (MMIF).

CALPUFF contains algorithms for near-source effects such as building downwash, transitional plume rise, partial plume penetration, and sub-grid scale terrain interactions as well as longer range effects such as pollutant removal (dry deposition), chemical transformation, vertical wind shear, and overwater transport (Scire et al, 2011).

CALPUFF was updated to include a new SPRAY source type in order to represent the distribution of liquid droplets which are generated by aerial spraying applications or similar activities (Exponent, 2019). Theoretically, this new SPRAY source corresponds to a set of line-sources or rods, which are described by the location and height of the endpoints of the flight track and an effective initial vertical and horizontal cross-track distribution at these points Appendix Figure 21. Each rod contains droplets of a single diameter size Mass emissions per unit length per second along the track are provided by AGDISP (DesAutels, 2019; Exponent, 2019).



Appendix Figure 21: Droplet locations at height and crosswind distance³⁴ at AGDISP termination (left) and rods used in the model (right) (source: DesAutels, 2019)

³⁴ This means that the flight is into the page

B.3: Volatilisation

The volatilisation of pesticides from crop surface is determined by vapour diffusion through the laminar boundary layer³⁵. Following the methodology outlined in Ghosh and Crist (2022), the rate of volatilisation is calculated by:

$$J_{vol,pot} = D_a \frac{C_{a,s} - C_{a,t}}{d_{lam}}$$

Where $C_{a,t}$ is the concentration in the turbulent air outside the laminar layer (assumed to be zero) and d_{lam} is the thickness of the laminar boundary layer. The coefficient for diffusion of the pesticide in air at reference temperature is estimated by:

$$D_a = D_{a,ref} \left(\frac{T}{T_{ref}} \right)^{1.75}$$

Where $D_{a,ref}$ is the diffusion of air at reference temperature (T_{ref}) and T is the actual hourly air temperature at the location. The diffusion coefficient in air is estimated after Tucker and Nelkin (1982):

$$D_{a,ref} = 0.001 T^{1.75} \frac{\sqrt{M_r}}{\left(P \left(V_A^{1/3} + V_B^{1/3} \right) \right)^2}$$

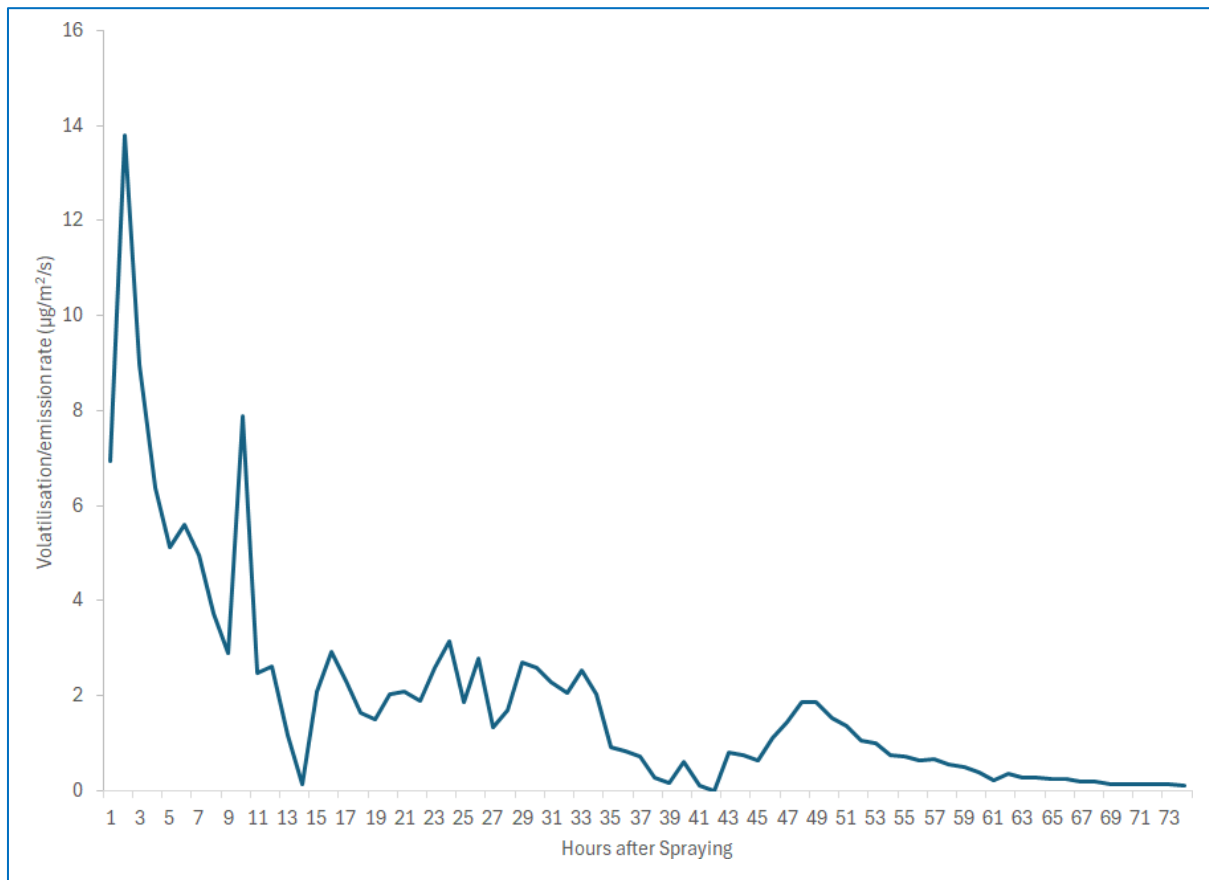
Where T is the temperature, P is pressure in atmosphere, V_A is the diffusion volume of air and V_B is the diffusion volume of the example pesticide (carbofuran) and is estimated as 249.83 cm³/mol. M_r is the function of molecular weight:

$$M_r = \frac{(M_A + M_B)}{M_A M_B}$$

Where M_A is the molecular weight of air (28.97 g/mol) and M_B is the molecular weight of the compound of interest.

For modelling, the rate of volatilisation (J) was activated whenever spraying occurred, according to ideal meteorological conditions for spraying (See Section 4.1). Each time spraying occurred, an initial volatilisation rate was estimated based on the diffusion coefficient calculated for that time step (dependant on ambient temperature, *inter alia*) and the initial concentration determined from AGDISP. The concentration was then reduced by the rate of volatilisation, which in turn impacted upon the volatilisation rate for the next time step until the concentration was reduced to a nominal amount and volatilisation ceased. The volatilisation rate was used as the emission rate in the dispersion model. Appendix Figure 22 shows the volatilisation/emission rate for a single spraying application occurrence.

³⁵ Region close to the surface in which flow is smooth and nonturbulent (typically in the order of 1 mm thick)



Appendix Figure 22: Example volatilisation (emission rate) with time after application.

Appendix C – Dispersion Model Setup

Selected model switches and setting for ground spraying, aerial spraying and volatilisation scenarios are summarised in Appendix Table 7

Appendix Table 7: Selected dispersion model switches and settings

Model Switch/setting	Description	Surface Spraying	Aerial Spraying	Volatilisation
NX	No. X grid cells	40	40	40
NY	No. Y grid cells	36	36	36
NZ	No. vertical layers	10	10	10
ZFACE	Cell face height	0,20,40,80,160,320,640,1200,2000,3000,4000	0,20,40,80,160,320,640,1200,2000,3000,4000	0,20,40,80,160,320,640,1200,2000,3000,4000
DGRIDKM	Grid spacing	0.2	0.2	0.2
MSLUG	Near-field puffs modelled as slugs	No	No	No
MPDF	Probability density function used for convective conditions	No	No	No
SYMIN	Minimum sigma y for a new puff	1.0	1.0	1.0
SXMIN	Minimum sigma x for a new puff	1.0	1.0	1.0
MSPLIT	Puff splitting allowed	Yes	Yes	Yes
MDRY	Dry deposition modelled	Yes (particle)	Yes (gaseous)	Yes (particle)
ISTYPE	Hourly-varying files	Area	SPRAY	Area
Effective height	Height of source agl	0.5	0.1	Varying
WEFF	Effective rise velocity	0.01	NA	0.01
QEMIT	Emission rate unit	g/m ² /s	g/m	g/m ² /s
SIGZ	Initial vertical spread	0.2	Varying	0.03