Zephyr Environmental

BioCarbon Biochar Facility Bulahdelah

Air Quality Assessment

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BIOCARBON

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EXECUTIVE SUMMARY

Zephyr has completed a dispersion modelling assessment for the proposed biochar facility in Bulahdelah. Measurements from a pilot plant have been used in the modelling and predicted ground level concentrations have been estimated for $PM_{2.5}$, SO_2 and NO_2.

The assessment followed a conventional approach using the procedures outlined in the NSW Environment Protection Authority's (EPA) document titled *Approved Methods and Guidance for the Modelling and Assessment of Air Pollutants in NSW* (EPA, 2022).

The dispersion modelling accounts for the local meteorology and terrain information using prognostic modelling techniques to represent local conditions.

Predictions indicate that all modelled substances are well below their individual air quality assessment criterion at all residential receptors as well as on or beyond the boundary.

1 INTRODUCTION

Zephyr Environmental Pty Ltd (Zephyr) has been commissioned by BioCarbon Pty Ltd (BioCarbon) to complete an air quality impact assessment for their proposed operations at 11 Markwell Road, Bulahdelah, NSW (Lot 322 DP 1309245).

The Midcoast Council has requested atmospheric dispersion modelling to be completed using process specific stack testing results. Stack testing has been carried out by Port Hunter Environmental (pHE).

The assessment relies on the use of the computer-based dispersion model (CALPUFF) to predict off site ground level concentrations. To assess potential air quality impacts on nearby receptors, the dispersion model predictions have been compared to relevant regulatory air quality criteria.

The assessment follows a conventional approach using the procedures outlined in the NSW Environment Protection Authority's (EPA) document titled *Approved Methods and Guidance for the Modelling and Assessment of Air Pollutants in NSW* (EPA, 2022), hereafter referred to as the Approved Methods.

2 PROJECT DESCRIPTION

BioCarbon is seeking consent to establish a biocarbon processing facility in Bulahdelah. The facility will process organic biomass waste from the adjacent timber mill, into a number of high-quality carbon-based products. These products are suitable for use in the steel industry as a replacement for coking coal.

BioCarbon proposes to construct a new processing facility on site at SA Relfs Sawmill in Bulahdelah.

The BioCarbon processing facility involves the construction of a large shed for the purpose of storing raw woodchip materials (waste product from the sawmill) and new BioCarbon products (biochar and wood vinegar) manufactured in the processing plant. The proposal relies directly on the existing sawmill's continued operation on the site as it current exists and is therefore an ancillary component of the mill. However timber waste from the mill would no longer need to be transported off-site. These waste materials will instead remain on site to be processed in the BioCarbon facility.

Figure 2-1 shows the location of the site in relation to the immediate surrounding area and nearest residential receptors.

The site lies at the northern end of the Bulahdelah township, situated between the Myall River and a steep ridge that runs north-south to the east of the town. The ridge line reaches about 250 m above the town, decreasing in height in the north to about 70 m above the proposed facility location. Figure 2-2 presents a pseudo three-dimensional representation of these landscape features.

Figure 2-1: Location of the proposed facility and nearest receptors

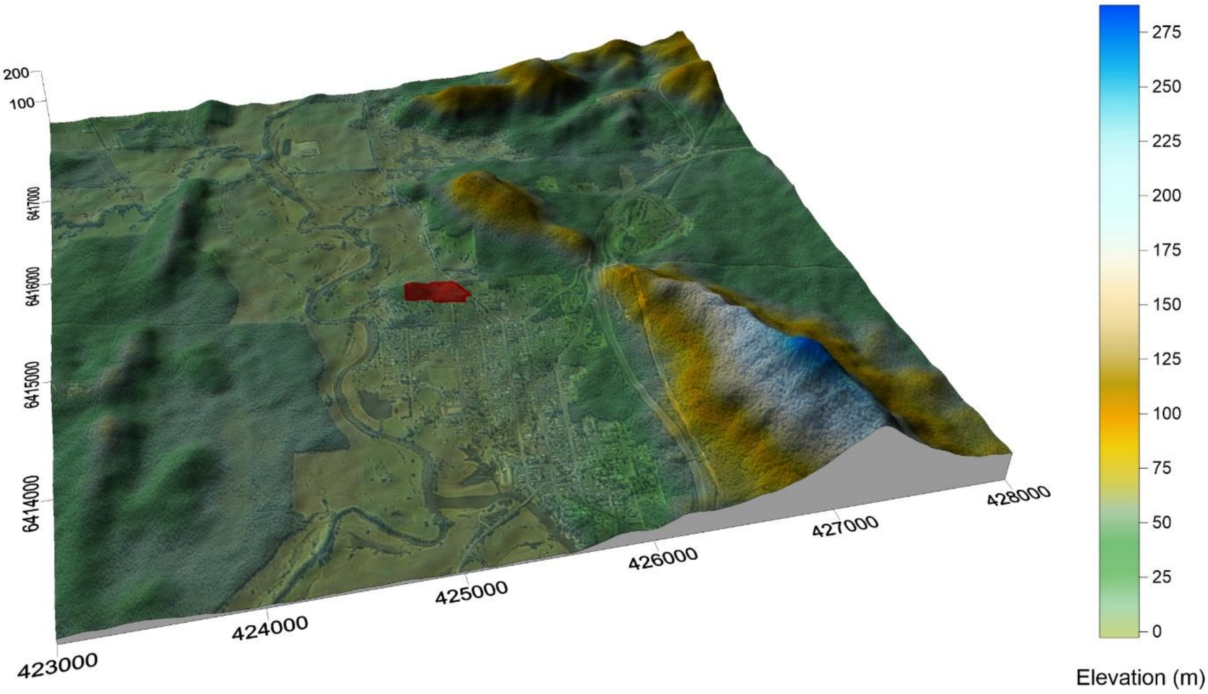

Figure 2-2: Pseudo three-dimensional representation of the local terrain features

3 AIR QUALITY CRITERIA

Each pollutant has a different air quality assessment criterion. For the purposes of this report, these pollutants are particulates (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2) and Nitrogen Dioxide (NO_2).

The NSW EPA air quality assessment criteria for PM_{10}, $PM_{2.5}$, SO_2 and NO_2 are consistent with the revised National Environment Protection Measure for Ambient Air Quality (referred to as the Ambient Air-NEPM) and are presented in Table 3-1.

Table 3-1: NSW EPA impact assessment criteria

Pollutant	Averaging period	Criterion
$PM_{2.5}$	Annual	8 µg/m^3
	24-hour	25 µg/m^3
SO_2	1-hour	215 µg/m^3
	24-hour	57 µg/m^3
NO_2	1-hour	164 µg/m^3
	Annual	31 µg/m^3

4 ASSESSMENT METHODOLOGY

The overall approach to the assessment follows the Approved Methods, that specify how assessments based on the use of air dispersion models should be completed. They include guidelines for the preparation of meteorological data to be used in dispersion models and the relevant air quality criteria for assessing the significance of predicted concentrations due to the Project.

The air dispersion modelling conducted for this assessment is based on an advanced modelling system using the CALMET / CALPUFF model. The local meteorology has been modelled for the year 2024 (most recent year and complete dataset) using the Weather Research Forecasting (WRF) and CALMET models, as described in Sections 4.1 and Section 4.2, respectively.

There are no local meteorological monitoring stations in the vicinity of the Project. The nearest sites are 50 km to the southwest at Williamtown, or at Taree 60 km to the north. Given the absence of this information and the complex terrain features in the area, as discussed in Section 2, it is important to provide a robust representation of the local meteorology to capture the impact these terrain features will have on emissions from the Project and their dispersion along the valley. The combination of the WRF and CALMET models provide this.

Outputs from WRF are entered into CALMET, a meteorological pre-processor recommended for use in non-steady state conditions. From this, a 1-year representative meteorological dataset was compiled, suitable for use in the 3-dimensional plume dispersion model CALPUFF as described in Section 4.3.

Details on the model configuration and data inputs are provided in the following sections.

4.1 WRF

WRF is a sophisticated mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications.

To provide data for the atmospheric dispersion modelling, WRF modelling was completed for the period 1 January 2024 to 31 December 2024 (inclusive). The process of developing the WRF datasets involved a nested approach centred on the BioCarbon site. The resolution and extent of each grid is outlined in Table 4-1. The WRF prognostic model was modelled to a resolution of 1 km.

Table 4-1: WRF modelling parameters

Grid	Resolution	Extent
1	9 km	702 x 891 km
2	3 km	516 x 696 km
3	1 km	64 km x 64 km

In order to run, WRF requires:

- Initialisation datasets
- Geospatial inputs
- Selection of options to set the model.

The initialisation datasets and the selection of options are detailed in Appendix A.

4.2 CALMET

CALMET is a meteorological pre-processor that includes a wind field generator containing objective analysis and parameterised treatments of slope flows, terrain effects and terrain blocking effects. The pre-processor produces fields of wind components, air temperature, relative humidity, mixing height and other micro-meteorological variables to produce the three-dimensional meteorological fields that are utilised in the CALPUFF dispersion model (i.e. the CALPUFF dispersion model requires meteorological data in three dimensions). CALMET uses the meteorological inputs in combination with land use and geophysical information for the modelling domain to predict gridded meteorological fields for the region.

CALMET was run with a grid domain of 4 km x 4 km, with a 100 m grid resolution. Gridded wind fields generated by WRF were used as the initial guess field for CALMET.

4.3 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 pollutants across released puffs and takes into account the complex arrangement of emissions from point, area, volume and line sources (Scire, Strimaitis, & Yamartino, 2005).

The site is located on the northern edge of the small town of Bulahdelah and local area is rural with several scattered residences outside the town. Model predictions of ground level concentrations were made across the domain at gridded receptors at a spacing of 20 m x 20 m.

5 LOCAL METEOROLOGY

Wind speed and direction are important parameters for plume dispersion. The temporal variation of wind directions determines the spatial pattern of average ground level concentrations. Wind speed influences the initial dilution of the plume as it leaves the source, with higher wind speeds generally resulting in lower plume concentrations.

As discussed in Section 4, the WRF model was used to model the local meteorology, which was considered necessary given the measured datasets from the Bureau of Meteorology were some distance from the site. Figure 5-1 and Figure 5-2 present the annual and seasonal windroses, respectively, for the 2024 modelling year.

The predominant directions are winds from the north northeast and southeastern quadrants. The winds from the north-northeast quadrant are predominantly lower speeds, likely indicative of drainage flow down the slopes in this direction from the site.

The strongest winds are from the west and west southwest, occurring predominantly during winter. The annual average wind speed is moderate at 3.0 m/s, with calm conditions generally occurring most frequently in the autumn months approximately 6 % of the time.

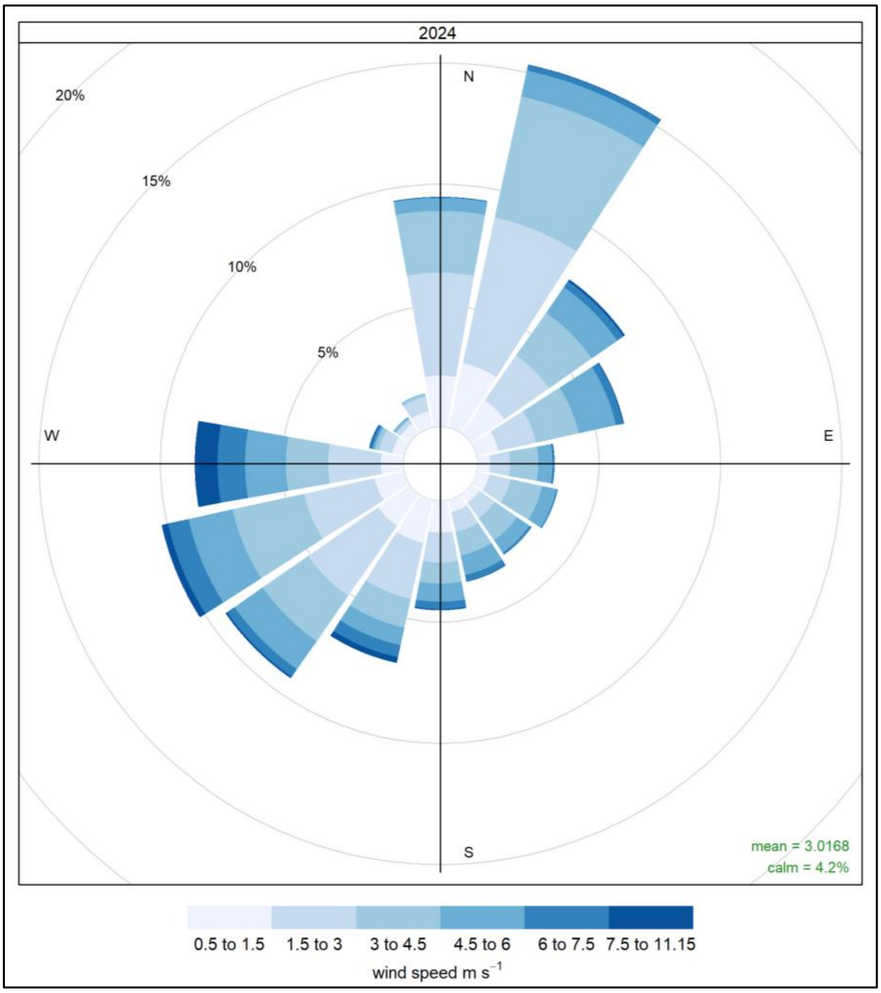

Figure 5-1: Annual windroses at the site for 2024

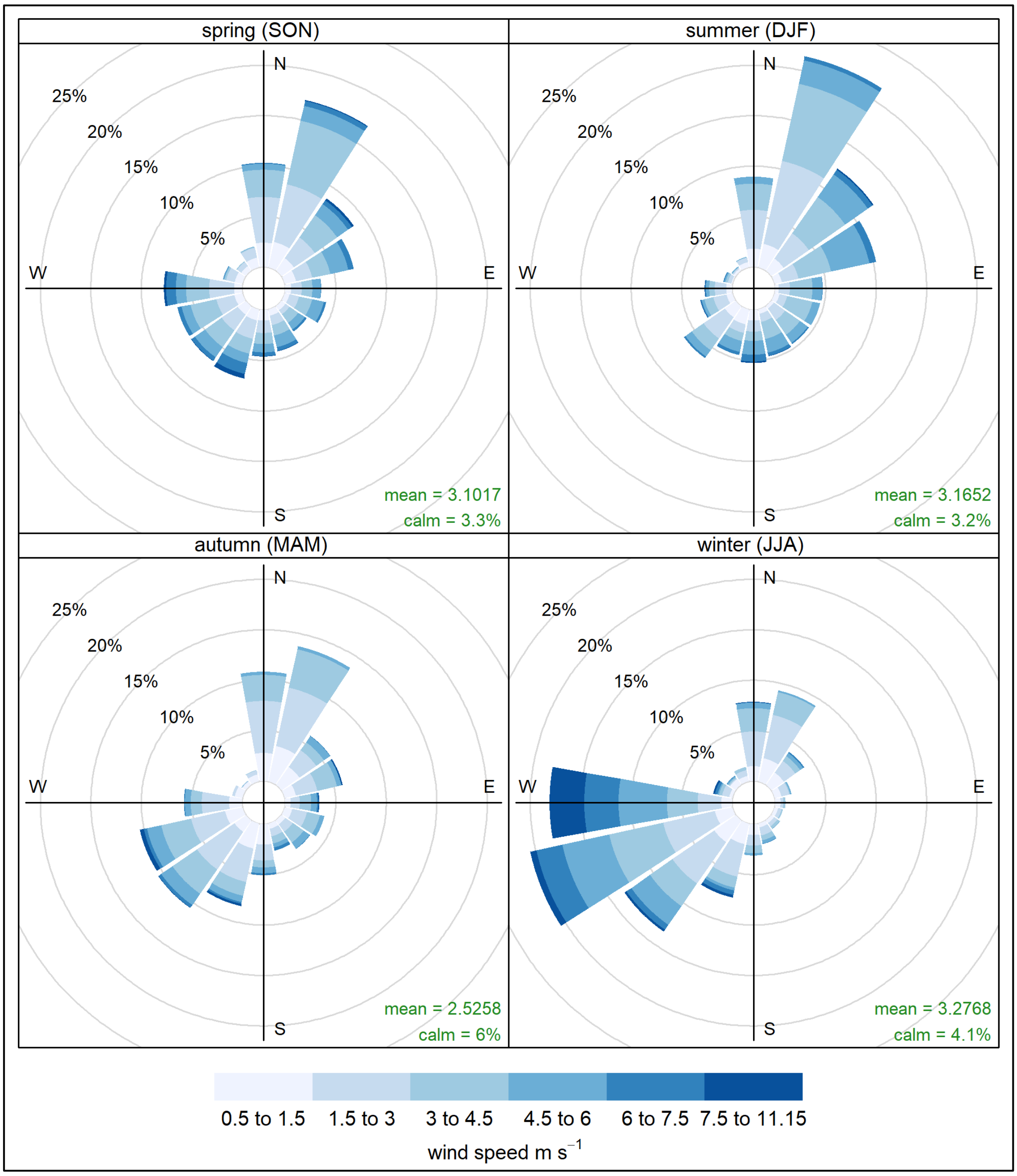

Figure 5-2: Seasonal windroses at the site for 2024

6 EMISSIONS TO AIR

Stack testing has been carried out by Port Hunter Environmental at a pilot plant. The report containing these results is attached in Appendix B and provide in-stack concentration and emission rates for total solid particles, SO_2 and NO_2, measured at the pilot plant.

While the in-stack concentrations will be the same at the proposed facility, it is estimated that the volumetric flow rate will be 20 times higher than at the pilot stack. To account for this increase in flow rate, and to maintain a reasonable exit velocity, the stack diameter at the proposed facility has been increased to 2.2 m. Table 6-1 lists the stack and emission parameters for the proposed stack. The emission rates based on these parameters are summarised in Table 6-2, and have been calculated using the same in-stack concentrations as measured at the pilot plant.

Table 6-1: Stack emission parameters

Stack co-ordinates (UTM, m)	Stack height (m)	Exit temperature (K)	Stack tip diameter (m)	Flow rate (Am^3/s)	Exit velocity (m/s)
425435 (east) 6415377 (north)	11	550.8	2.2	57.0	15

Table 6-2: Pollutant emission rates

Pollutant	In-stack concentration		Mass emission rate (g/s)
	N mg/m^3	A mg/m^3	
$PM_{2.5}$	2.2	1.09	0.062
SO_2	20	9.91	0.565
NO_X	19	9.42	0.537

7 ASSESSMENT OF IMPACTS

7.1 Particulate matter ($PM_{2.5}$)

Figure 7-1 and Figure 7-2 present the maximum 24-hour average and annual average site contribution contour plots for $PM_{2.5}$. There are no $PM_{2.5}$ monitoring data in the vicinity of Bulahdelah to estimate what the cumulative concentrations would be, but the predictions from the biochar facility are so low they would be unlikely to contribute to an exceedance of the EPA assessment criteria. The predictions from the biochar facility are well below their relevant EPA assessment criteria of 25 µg/m³ and 8 µg/m³, respectively.

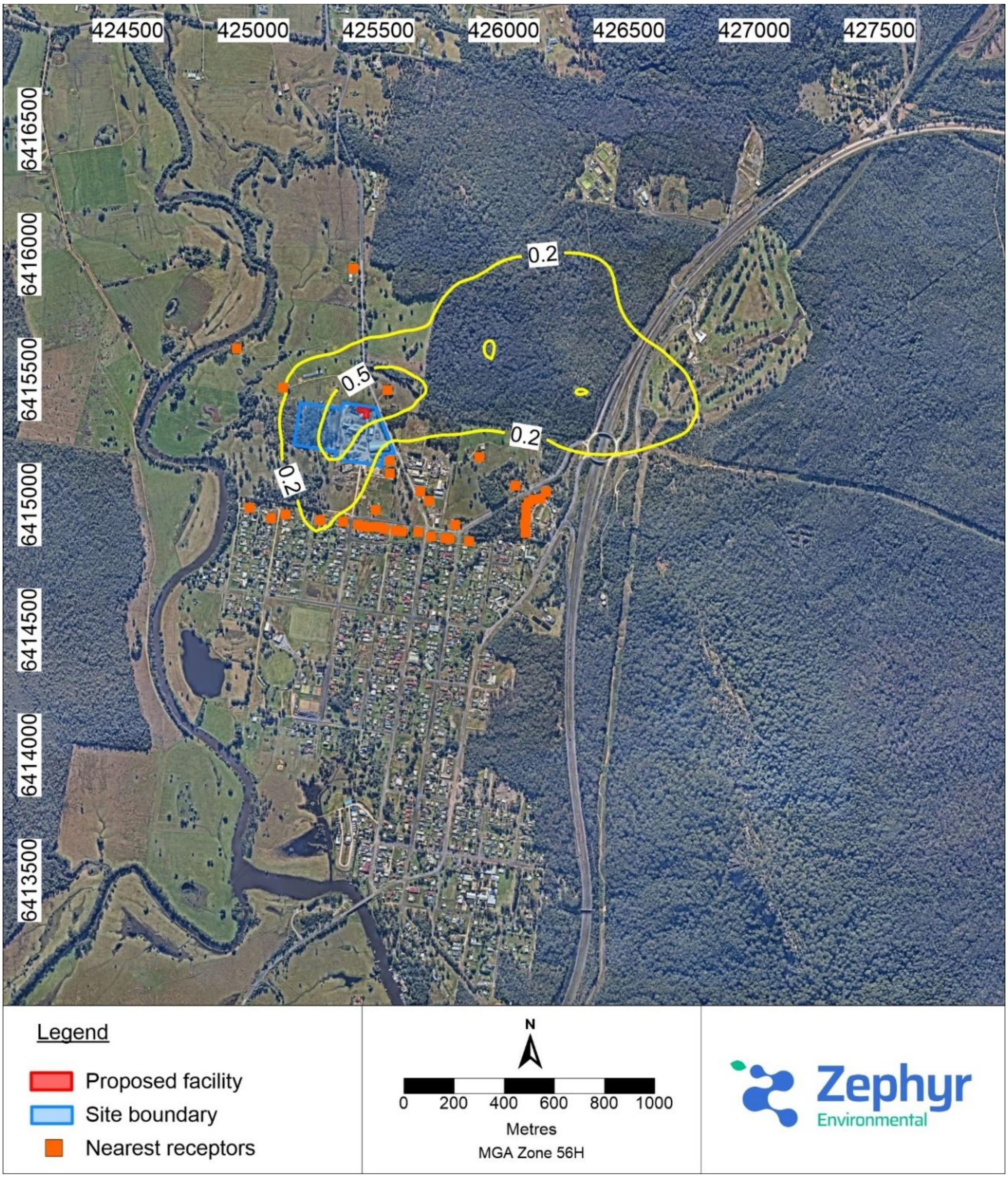

Figure 7-1: Predicted maximum 24-hour average ground level $PM_{2.5}$ concentration (µg/m³)

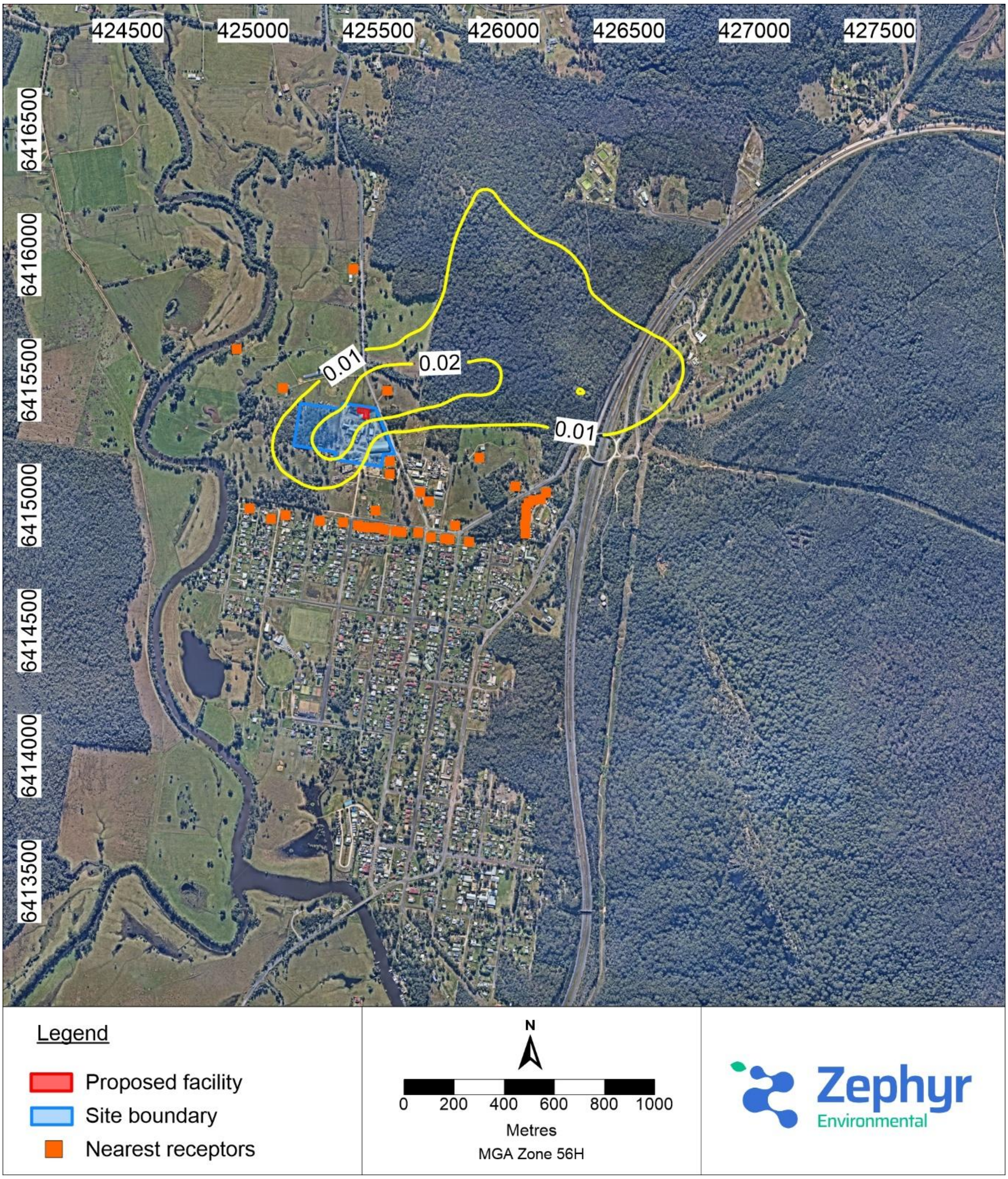

Figure 7-2: Predicted annual average ground level $PM_{2.5}$ concentration (μg/m^3)

7.2 Sulfur dioxide

Figure 7-3 and Figure 7-4 present the maximum 1-hour and 24-hour average site contribution contour plots for SO_2. The predictions from the biochar facility are well below their relevant EPA assessment criteria of 215 µg/m³ and 57 µg/m³, respectively.

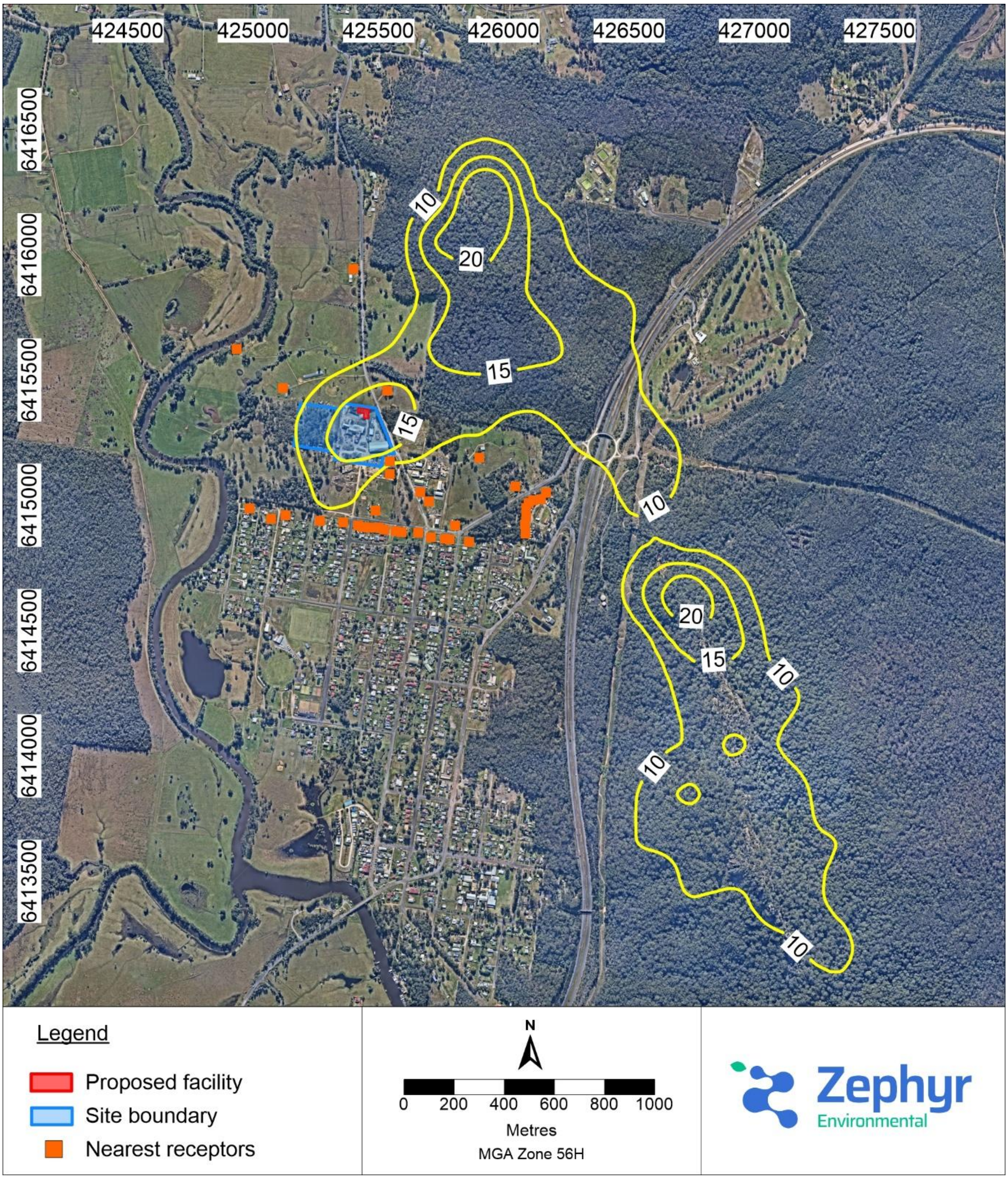

Figure 7-3: Predicted maximum 1-hour average ground level SO_2 concentration (µg/m³)

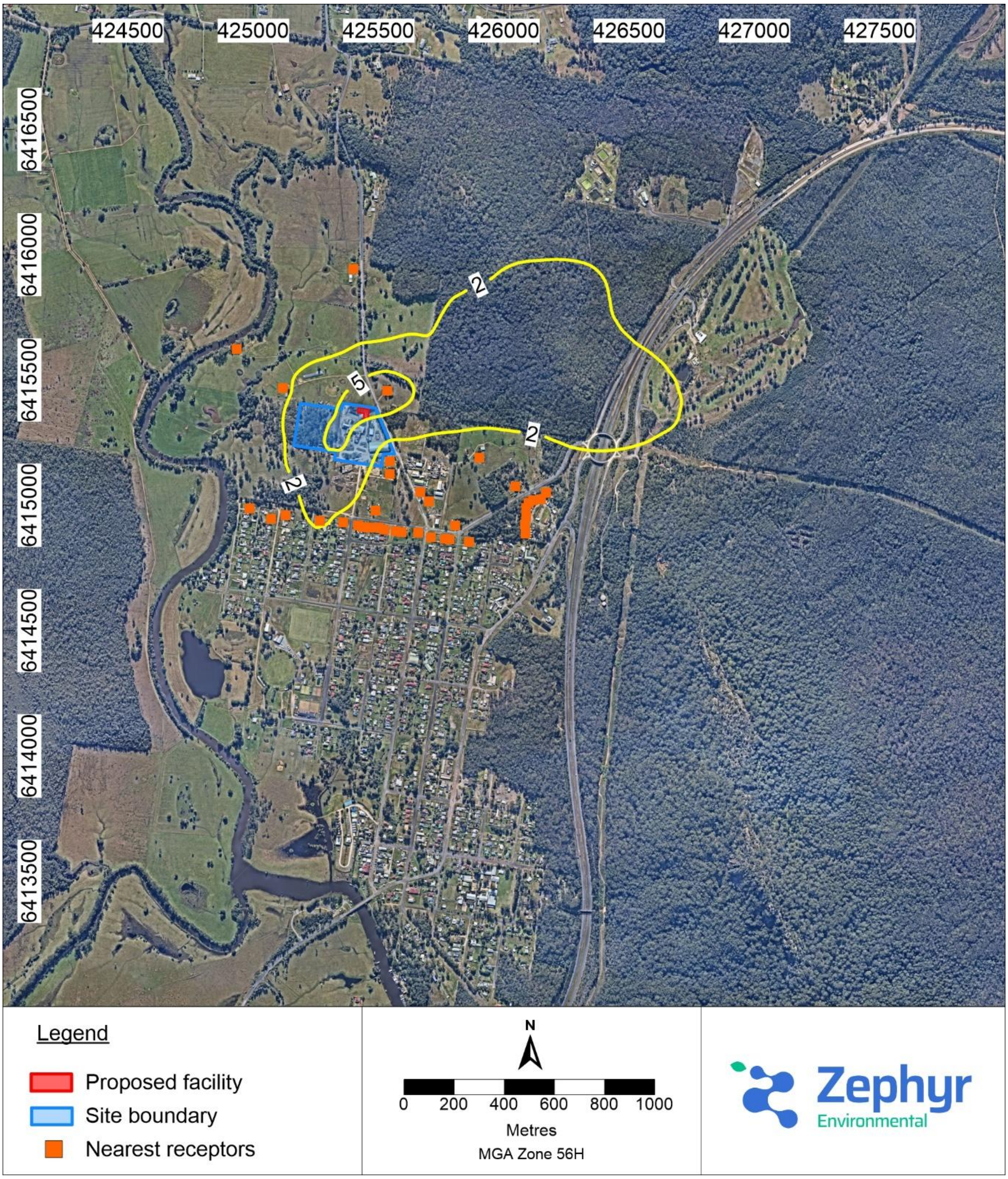

Figure 7-4: Predicted maximum 24-hour average ground level SO_2 concentration (µg/m^3)

7.3 Nitrogen dioxide

Figure 7-5 and Figure 7-6 present the maximum 1-hour average and annual average site contribution contour plots for NO_2. The predictions from the biochar facility are well below their relevant EPA assessment criteria of 164 µg/m^3 and 31 µg/m^3, respectively.

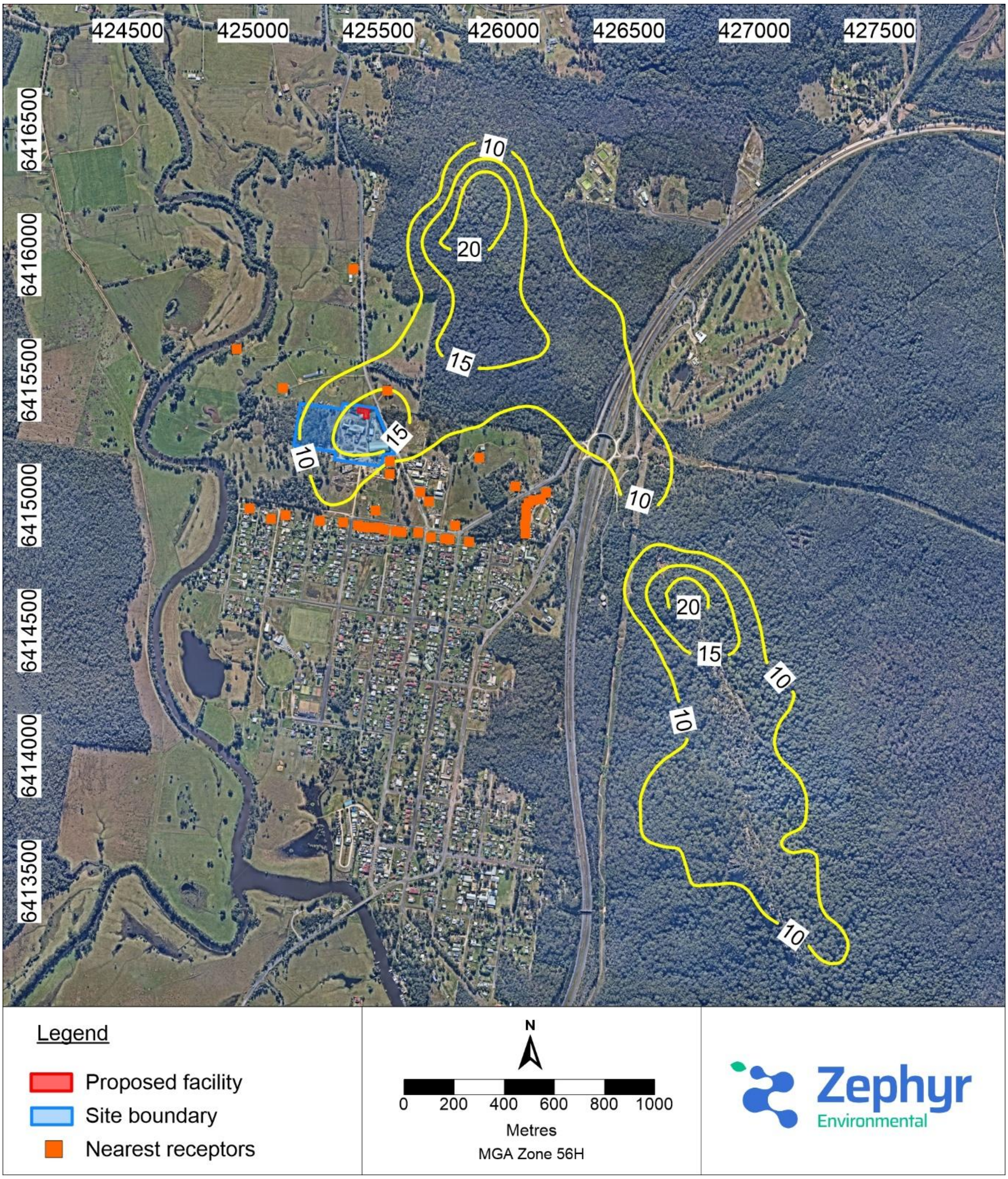

Figure 7-5: Predicted maximum 1-hour average ground level NO_2 concentration (µg/m^3)

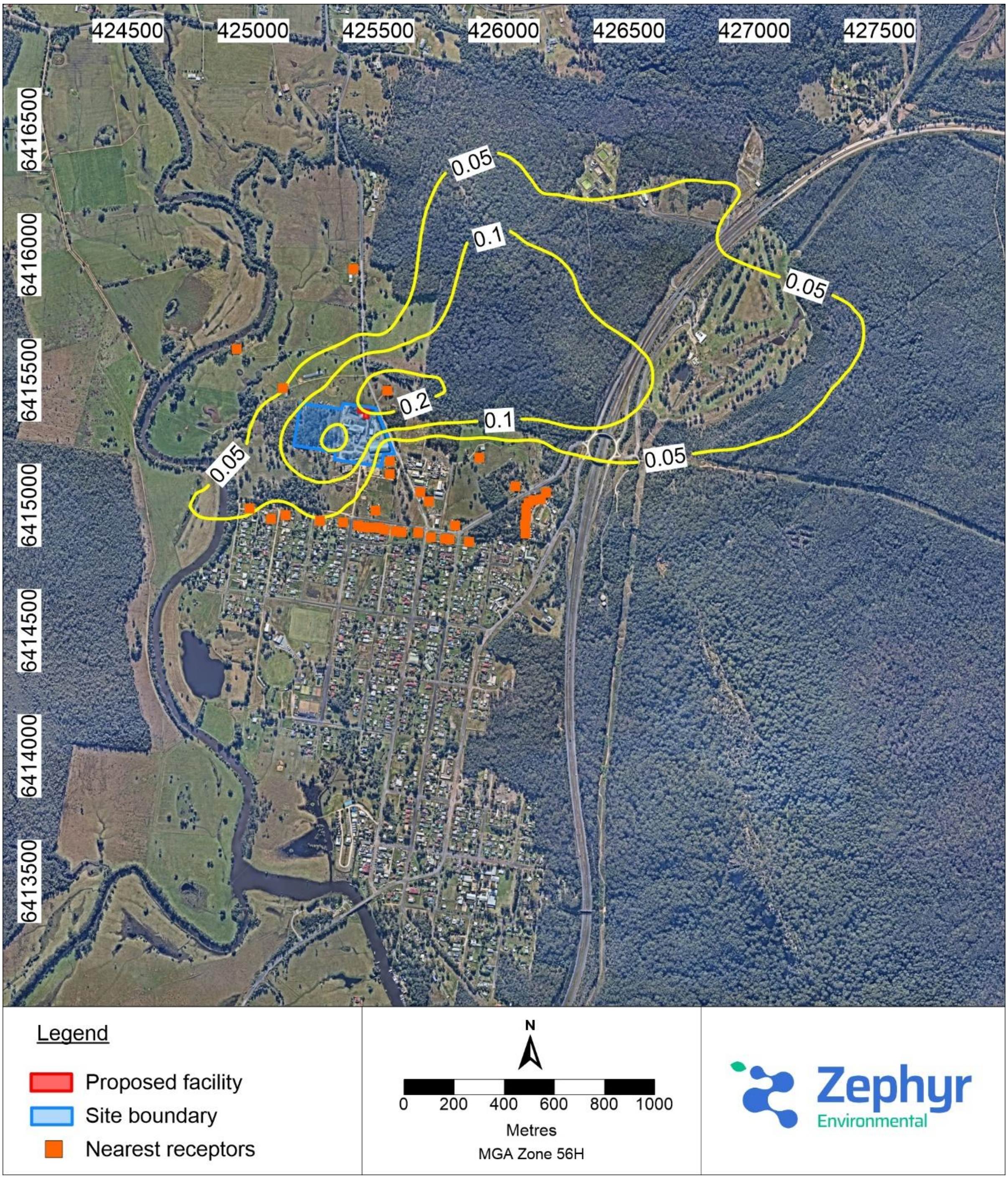

Figure 7-6: Predicted annual average ground level NO_2 concentration (µg/m^3)

8 CONCLUSIONS

Zephyr has completed a dispersion modelling assessment for the proposed biochar facility in Bulahdelah. Measurements from a pilot plant have been used in the modelling. Predicted concentrations have been presented for $PM_{2.5}$, SO_2 and NO_2, following a conventional approach using the procedures outlined in the NSW EPA's Approved Methods

The dispersion modelling accounts for the local meteorology and terrain information using prognostic modelling techniques to represent local conditions.

Predictions indicate that all modelled substances are well below their individual air quality assessment criterion at all residential receptors.

9 REFERENCES

NSW EPA (2022). Approved Methods for the Modelling and Assessment of Air Pollutants in NSW. NSW Environment Protection Authority, Sydney. https://www.epa.nsw.gov.au/publications/air/22p3963-approved-methods-for-the-modelling-and-assessment-of-air-pollutants-in-nsw

Scire, Strimaitis, & Yamartino (2005). A User's Guide for the CALPUFF Dispersion Model (Version 5). Melbourne: Earth Tech Inc.

Appendix A

WRF Technical Report

Weather Research and Forecasting (WRF) Technical Report

11 April 2025

Document details

Document title	WRF Technical Report
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Release Date	11 April 2025
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Reviewer	Jane Barnett
Client	Biocarbon

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1 INTRODUCTION

Meteorological data is required for all manner of applications but is often unavailable near to the area of interest. A process known as prognostic modelling can be used to synthesise a meteorological dataset for subsequent use. The dataset should be representative of the local conditions and should be completed using a model that is well validated in making accurate predictions.

The Weather Research Forecasting (WRF) model is at the forefront of prognostic models and is well validated in the scientific literature to produce meteorological data (Witha, et al., 2019; Solbakken, Birkelund, & Samuelsen, 2021; Cowan & Chilton, 2022; Machado, Martin, & Wong, 2024). The WRF model was designed as a numerical weather prediction model and is widely-used tool in meteorological modelling. The WRF model is designed to simulate and predict weather patterns by using complex mathematical equations and high-resolution data (Skamarock, et al., 2008).

Developed through a collaborative effort involving the (United States) National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), and other institutions, WRF features two dynamical cores, a data assimilation system, and a software architecture that supports parallel computation and system extensibility. The WRF model can simulate a wide range of meteorological phenomena across scales from tens of metres to thousands of kilometres, making it highly versatile for various applications

By running simulations with the WRF model, it is possible to reconstruct and analyse past meteorological conditions as well as to generate forecasts for various weather conditions, such as temperature, precipitation, and wind, which are essential for planning and decision-making in fields ranging from agriculture to disaster management. The analyses are crucial for assessing changes in climate over time and for validating climate models used in predicting future scenarios.

The model can be used with reanalysis datasets to downscale data from global weather datasets to local conditions. Atmospheric data obtained from WRF can be used to evaluate meteorological conditions against site observations and can also serve as input for higher-resolution models like CALMET.

Zephyr Environmental Pty Ltd (Zephyr) was engaged by Biocarbon Pty Ltd to run the WRF prognostic model and produce CALMET compatible files for a project location located at -32.4˚, 152.2˚ for the 2024 calendar year

This report details the setup of WRF model.

2 WRF MODELLING

WRF is a widely used three-dimensional numerical meteorological model which contains non-hydrostatic dynamics, and a variety of physics options for parameterizing cumulus clouds, microphysics, the planetary boundary layer, and atmospheric radiation.

The WRF model offers different options for the representation of convective processes, turbulent transports, evolution of surface temperature and soil moisture, and soil–air interaction as described in Table 2-1.

WRF requires:

- Definition of modelling period
- Selection of initialisation dataset
- Definition of domain parameters
- Geospatial inputs
- Selection of options.

This WRF modelling was completed using WRF version 4.6.0.

2.1.1 Modelling period

WRF modelling was completed for the requested period 1 January 2024 to 31 December 2024 (inclusive).

2.1.2 Initialisation datasets

The WRF model requires initialisation conditions to provide the boundary conditions for the model which are then processed to finer resolutions through an understanding of atmospheric physics, geospatial information and the interaction of the atmosphere with the land. Many datasets are available globally which can be used within the WRF model.

Our experience is that the data from the European Centre for Medium Weather Forecasts (ECMWF) global reanalysis dataset, known as ERA5 provides an output that compares well to observed data. This is because the ERA5 dataset is a reanalysis dataset which has assimilated a great deal of observational data, including surface pressure, sea level pressure, geopotential height, temperature, sea surface temperature, soil values, ice cover, relative humidity, u- and v- wind components, vertical motion, vorticity, winds and in-situ data such as moisture from radiosondes and pressure from surface observations. Also included in these datasets are additional precipitation data, profiler data, dropsondes, pilot balloons, aircraft temperatures and winds, land surface and moisture data and cloud motion vectors from geostationary satellites.

The ERA5 dataset provides information both for the surface conditions and 137 mandatory vertical levels. There are over 25 different variables including geopotential height, temperature, relative humidity and u- and v- wind components.

Data from the ERA5 dataset is available globally every hour on a 27 km grid, however data were extracted from the dataset every 3 hours to minimise download time without loss in fidelity of the data.

2.1.3 Domain parameters

The process of developing the output required for applications such as atmospheric dispersion models using WRF requires the use of a nested approach. 1 km is the highest resolution that it is recommended WRF be used for such applications. Where higher resolution is required, WRF output can be passed through diagnostic models to further resolve higher resolution terrain and land use, however this will require alternative output formats.

As discussed, the selected initialisation dataset was the ERA5 dataset, and this has an initial resolution of approximately 27 km. The WRF user guide recommends that the factor for nested grids is between 3 and 5, however a grid with the resolution equal to the initialisation data is not required. Thus, the modelled grids corresponded to resolutions of 9 km, 3 km and 1 km.

The locations of the modelled grids are shown in Figure 2-1.

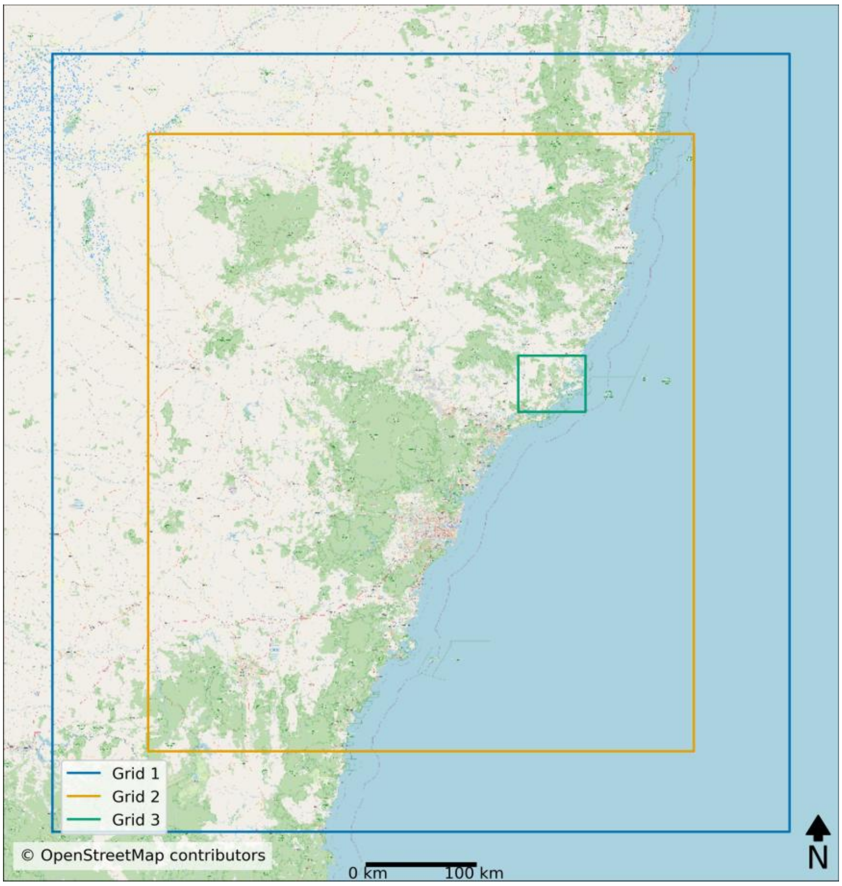

Figure 2-1: Extent of grids used in WRF

2.1.4 Geospatial WRF inputs

WRF geospatial inputs are available from the US National Center for Atmospheric Research (NCAR) with default sets of static data for terrain, vegetation/land use and soil type. NCAR distributes various resolutions of global terrain and land-use data bases to support WRF simulations. The data bases are:

- 5-arc-minutes (approximately 9.25 km in mid-latitudes)
- 2-arc-minutes (approximately 4.00 km in mid-latitudes)
- 30-arc-seconds (approximately 0.900 km in mid-latitudes)
- 15-arc-seconds (approximately 0.450 km in mid-latitudes), which is only available for MODIS land use category.

Experience with WRF has determined that improved agreement with observed data can be achieved where locally collected land use and terrain data are used.

2.1.4.1 Land use

For the Subject Site, land use inputs to the WRF model were obtained from three sources:

- Copernicus dynamic land cover dataset for 2019
- Global map of Local Climate Zones (LCZ) that describes the heterogeneous urban land surface
- National vegetation information system (NVIS) that has greater detail on Australian Vegetation.

The three datasets were used as the:

- Copernicus dynamic land cover data provides the most recent dataset of land cover for Australia
- Copernicus dynamic land cover data does not provide significant detail on levels of vegetation on barren land within more remote regions;
- Copernicus dynamic land cover data does not differentiate between forest types or even between desert land or tropical / temperate rainforest in areas labelled for conservation.
- Copernicus dynamic land cover data does not differentiate between areas of urban height that allow for the use of urban physics schemes which can alter the flow of winds and impact temperature within urban areas.

Once these databases were combined, they were then translated into the MODIS 21 category plus LCZ options as required by WRF.

Figure 2-2 provides the land use data for the innermost grid of the model surrounding the Subject Site as used by WRF.

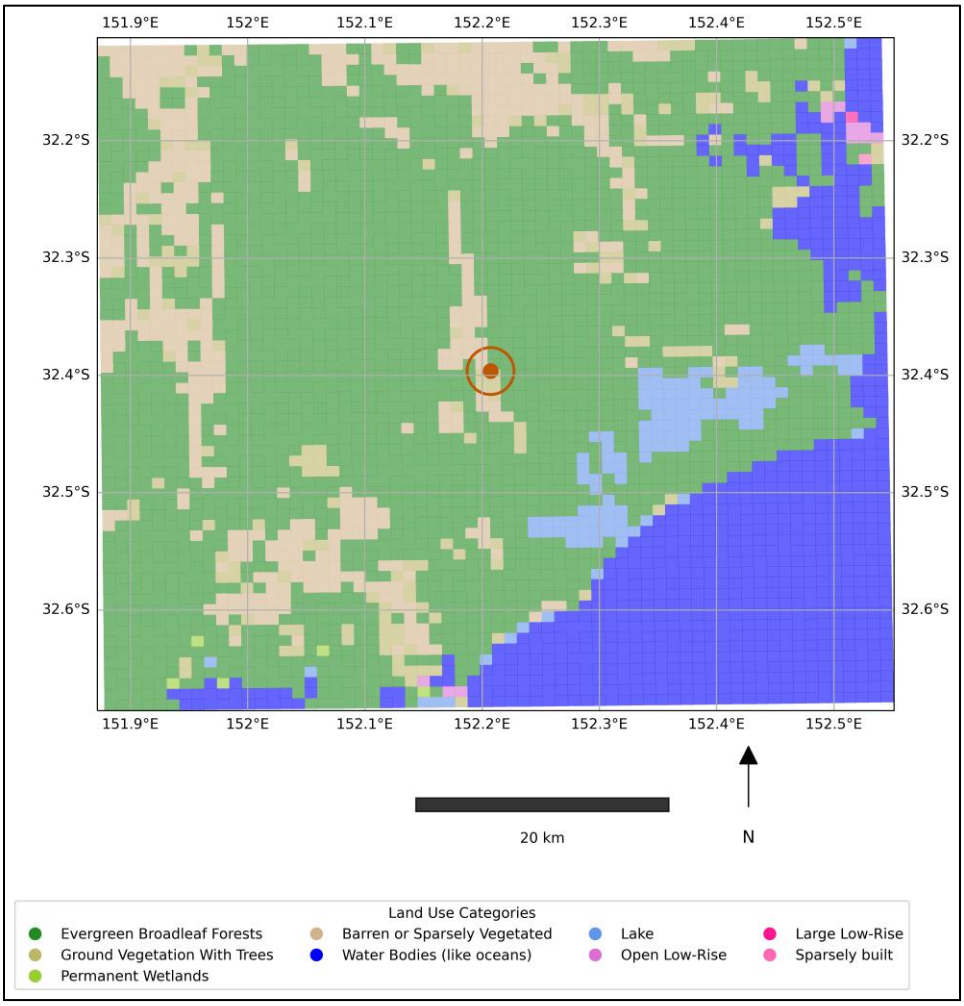

Figure 2-2: Land use surrounding the Subject Site

2.1.4.2 Terrain

For terrain, the AW3D30 dataset, recognised as one of the most accurate global digital terrain models, was used.

Figure 2-3 provides the terrain for the innermost grid of the model surrounding the Subject Site.

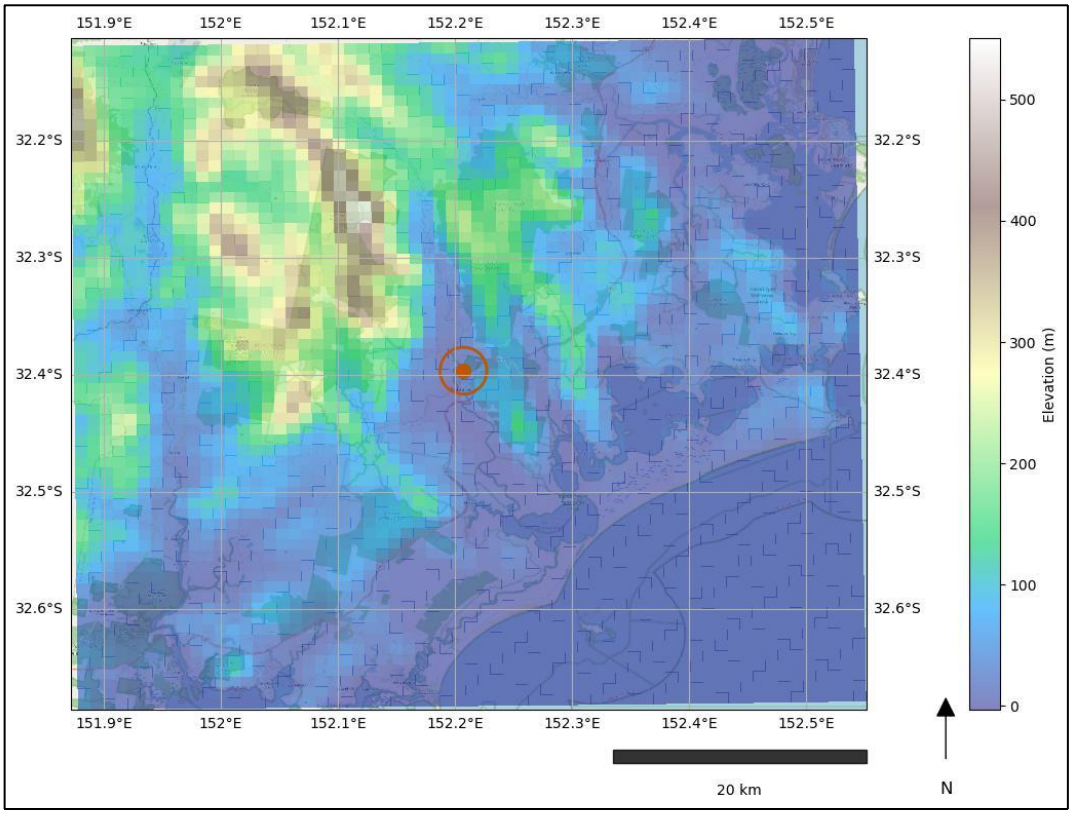

Figure 2-3: Terrain from AW3D30 surrounding the Subject Site

2.1.5 Selected WRF options

Various physical schemes which describe the interaction of the land and the atmosphere and the behaviour of the atmosphere are available within the WRF system (Table 2-1).

Table 2-1: Brief WRF parametrisation options description

Process	Description
Radiation	Radiation Parameterizations: These schemes represent the transfer of radiation in the atmosphere. Examples include: ▪ RRTMG (Rapid Radiative Transfer Model for General Circulation Models) used to calculate the radiative transfer of electromagnetic radiation through a planetary atmosphere (Iacono, et al., 2005) ▪ Dudhia scheme: Dudhia (1989) shortwave and Rapid Radiative Transfer Model (RRTM) longwave radiation schemes (Mlawer, Taubman, Brown, Iacono, & Clough, 1997). ▪ CAM (Community Atmosphere Model) scheme
Planetary Boundary Layer	▪ The Yonsei University (YSU), a nonlocal scheme that includes countergradient flux terms that enables realistic development of a well-mixed layer (Hong & Pan, 1996). ▪ The Mellor–Yamada–Janjic (MYJ) a local implementation of the Mellor–Yamada 2.5 scheme (Janjic, 2002).
Convection	▪ The Grell–Devenyi (GRELL) that includes convective effects from ensembles generated with different closure assumptions (Grell & Devenyi, 2002). ▪ The Kain–Fritsch (KF), based on a simplified cloud model that also includes shallow convection (Kain, 2004). ▪ The Betts–Miller–Janjic (BMJ) in which deep convection is similar to other adjustment schemes except that it uses a thermodynamic profile that results from mixing the convectively unstable layer. This scheme has been used extensively in weather forecasts at the National Centers for Environmental Prediction (NCEP) and has been improved over the years (Betts 1986; (Janjic, 1994; Betts, 1986).
Soil models	▪ NOAH, a four-layer model that forecasts soil moisture and temperature. It includes a time-varying green vegetation fraction, soil type and snow cover with up to two vertical layers (Chen & Dudhia, 2001). ▪ The Rapid Update Cycle (RUC) land surface model: a six-level soil model to calculate soil fluxes on the basis of time-dependent solutions for temperature and moisture in soil. It includes the effect of evapotranspiration from vegetation and complex canopies (Smirnova, Brown, & Benjamin, 1997). ▪ The 5-layer thermal diffusion scheme and the five-layer soil model are both simplified land surface models based on the MM5 soil temperature model. The 5-layer thermal diffusion scheme uses a fixed deep-layer temperature and does not account for vegetation effects, while the five-layer soil model predicts ground surface

Process	Description
	temperature at five levels with constant soil moisture determined from seasonal and soil type tables. Both models use constant soil moisture and do not vary moisture through model integration (Dudhia, 1996).
Microphysics	▪ Eta–Ferrier (Ferrier, et al., 2002): This scheme is formulated for grid scales that are not able to explicitly resolve clouds and it is computationally efficient. Microphysics parameterizations are used to simulate the processes of cloud formation, precipitation, and related phenomena. ▪ Thompson: A new bulk microphysical parameterization (BMP) has been developed for use with WRF. Compared to earlier single-moment BMPs, the new scheme incorporates a large number of improvements to both physical processes and employs numerous techniques found in far more sophisticated spectral/bin schemes using look-up tables. This scheme is a new scheme with ice, snow and graupel processes suitable for high-resolution simulations.
Cumulus	These parametrisation schemes represent the effects of deep convection and cumulus clouds, including: ▪ Kain-Fritsch (KF) scheme ▪ Betts-Miller-Janjic (BMJ) scheme ▪ Grell-Freitas (GF) scheme ▪ Tiedtke scheme
Ocean and Ice Parameterisations	▪ OASIS (Ocean-Atmosphere Sea Ice Scheme) ▪ GFS (Global Forecast System) ice and ocean schemes
Urban Physics	▪ Urban Canopy Model (UCM); single layer ▪ Building Environment Parameterisation (BEP): This is a multi-layer urban canopy model that allows for buildings higher than the lowest model levels. ▪ Building Energy Model (BEM); adds heating and air-conditioning to BEP

Table 2-2 provides a listing of the options selected within the WRF setup for this simulation. Further discussion on the selected options is provided below.

Table 2-2: WRF modelling specifications used in the simulation

Metric	Grid 1	Grid 2	Grid 3
Horizontal grid spacing	9 km	3 km	1 km
Number of grid points	78x 99	172 x 232	64 x 64
Extent (km x km)	702 x 891	516 x 696	64 x 64
Initial conditions	ERA5 from ECMWF	Grid 1	Grid 2
Physics suite	Conus		
Microphysics	Thompson		
Cumulus	Tiedtke		
Longwave radiation	Rapid Radiative Transfer Model for General Circulation Models		
Shortwave radiation	Rapid Radiative Transfer Model for General Circulation Models		
Planetary boundary layer	Mellor–Yamada–Janjic		
Surface layer	Mellor–Yamada–Janjic		
Land and Soil Model (LSM)	Noah		
Urban Physics	Building Environment Parameterisation		
Top of model (hPa)	5000		
Number of landuse categories	60		
Number of soil layers	4		
Number of vertical levels	38		
Damping depth (meters)	5000		

The selections detailed in Table 2-2 from the available options detailed in Table 2-1 were made for the following reasons:

- Physics suite: Conus - WRF offers two physics suites, Conus and Tropical. The Conus physics suite is for locations with a temperate to cold (but not polar) climate. The Subject Site sits comfortably within this climatic zone.
- Microphysics: Thompson - A new bulk microphysical parameterization (BMP) has been developed for use with WRF. Compared to earlier single-moment BMPs, the new scheme incorporates a large number of improvements to both physical processes and employs numerous techniques found in far more sophisticated spectral/bin schemes using look-up tables. This scheme is a new scheme with ice, snow and graupel processes suitable for high-resolution simulations. This is therefore the latest scheme available and considered to be the most accurate of those available within the model.
- Shortwave and Longwave Radiation: Rapid Radiation Transfer Model (RRTMG) - This a recent version of the rapid radiation transfer model (RRTM) with random cloud overlap (RRTMG). RRTMG provides more sophisticated cloud treatment and better suited for climate applications than RRTM (option 1). RRTMG also handles cloud fraction whereas RRTM is binary in terms of yes or no for whether cloud cover exists. Based on available guidance, this scheme is considered to be a highly accurate and efficient method. This scheme also incorporates the effects of the comprehensive absorption spectrum taking water vapour, carbon dioxide and ozone into account. This scheme handles better cloud interactions with the Thompson MP scheme.
- Land Surface Model: NOAH – To incorporate the air-soil interaction in the WRF simulation, the Noah Land-Surface Model (LSM) was chosen. Seasonally varying vegetation and soil type are used in the model to handle evapotranspiration. The LSM model also has the effects such as soil conductivity and gravitational flux of moisture. The land-surface model is capable of predicting soil moisture and temperature in four layers (10, 30, 60 and 100 cm thick), as well as canopy moisture and water-equivalent snow depth. This is the default land surface model in WRF.
- Planetary Boundary Layer (PBL): Yonsei University (YSU) - This scheme has the enhanced stable boundary layer diffusion algorithm is also devised that allows deeper mixing in windier conditions. It has the ability to predict & simulates vertical mixing. This scheme also seems to show better performance during stable conditions. This scheme is used for WRF analyses with resolutions of 1 km grid resolution.
- Cumulus Parameterization: Kain-Fritsch in 9 km, 3 km resolution grids - This scheme generally focuses on column moisture, temperature tendencies and surface convective rainfall. It is recommended that cumulus parameterization should not be used at grid sizes < 5-10 km, as the smaller grid size is sufficient to resolve updrafts and downdrafts. Therefore, this scheme will not be used for WRF analyses with resolutions less than 3 km grid resolution.
- Urban Physics: Building Environment Parameterisation - This is a multi-layer urban canopy model that allows for buildings higher than the lowest model levels and maintains model stability whilst using the urban physics schemes.

3 WRF DATA POST PROCESSING

The WRF model provides a three dimensional output that is not directly compatible with dispersion models such as CALMET. Lakes Software provides the CALPUFF modelling suite which includes CALWRF. The CALWRF program reads the WRF-ARW model output and creates a 3D.DAT file suitable for input into CALMET.

The CALWRF program has been used to process data centred on the project location (-32.4˚, 152.2˚ for the 2024 calendar year to provide a 50 km x 50 km grid at 1 km resolution.

The results are output as monthly files which were then used as input to the CALMET preprocessing program as discussed in the body of the main document.

4 MODEL LIMITATIONS AND UNCERTAINTY

WRF is a numerical model and a sophisticated tool used for simulating and forecasting of weather conditions. Despite its advanced capabilities, there are inherent limitations and uncertainties that can affect the accuracy and reliability of its outputs. Understanding these limitations is crucial for interpreting model results and applying them effectively as well as selecting the parametrisation schemes that will best fit the model to real conditions. The key factors that contribute to these uncertainties are detailed in Table 4-1 . Each of these factors can introduce errors or biases into the model predictions, and recognizing their impact helps in evaluating the overall performance and validity of WRF simulations.

Table 4-1: WRF limitations and uncertainties

Limitation	Description
Spatial variability of systematic errors	The accuracy of WRF simulations can be limited by the resolution of the model grid. Higher resolution grids provide more detailed simulations but are computationally expensive. Lower resolution grids might miss fine-scale atmospheric features. Accuracy of atmospheric models are also still limited in region with high topography complexity (Singh, et al., 2021). These issues are of lower concern in locations where the topography and land use is non-complex.
Diurnal cycle of systematic errors	Systematic errors (biases) are associated with several variables such as forecast time, and time of day averaged over all experiments (i.e., for the ensemble mean) (Ruiz, Saulo, & Nogues-Paegle, 2010).
Parameterisation Schemes	WRF uses various parameterization schemes to represent physical processes (e.g., convection, cloud formation) that occur at scales smaller than the model grid. The choice of parameterization can significantly impact model outputs and introduce uncertainties (Yu, Bai, Chen, & Shao, 2022). To overcome this, the approach has been to use default parameterisation schemes where available which are those which are best validated in the literature.
Initial and Boundary Conditions	The accuracy of WRF forecasts depends on the quality of the initial and boundary conditions, which are derived from global reanalysis datasets. Errors in these conditions can propagate into the model outputs (Figurski, Nykiel, Jaczewski, Baldysz, & Wdowikowski, 2022). As discussed, Zephyr has found that the ERA5 dataset appears to introduce the least errors of the globally available initial conditions datasets tested due to the reanalysis basis of the data.
Topographic and Land Surface Representations	WRF's accuracy can be affected by how it represents topography and land surface characteristics, such as effects on radiation and diurnal variations of the surface sensible heat flux. Inaccurate representations of surface features can lead to errors in simulating local weather patterns (Arthur, Lundquist, Mirocha, & Chow, 2018). To overcome this, Zephyr has used the most recent land use and terrain data.
Model Calibration and Validation	WRF models need to be calibrated and validated against observational data. Calibration errors and limitations in validation data can impact the reliability of the model outputs (Gneiting, 2014). It is important that this is completed prior to use in a dispersion model.
Computational Limitations	High-resolution simulations require significant computational resources. Limited computational power can constrain the model's ability to perform long-term or very fine-scale simulations (Vourlioti, et al., 2023).

Whilst every care has been taken in the setup of the WRF model, the model has been set up as described in this document and in use of this data the disclaimer is accepted.

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Appendix B

Emissions testing report

pHE

Port Hunter Environmental

Solutions Together

BioCarbon Bulahdelah – Emissions Testing Report March 2025

Report No.:	1260-0
Job No.:	1260
Date:	26 March 2025
Report To:	BioCarbon Australia
Attention Of:	John Mellowes
Prepared By:	Port Hunter Environmental (pHE)
Approved By:	Nick Stanning

Port Hunter Environmental (pHE)

5/11 McIntosh Drive, Mayfield West NSW 2304, Ph 02 4967 7880,

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NATA
WORLD RECOGNISED ACCREDITATION

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Where site inspections, testing or fieldwork have taken place, the report is based on the information made available by the client or their nominees during the visit. The validity and comprehensiveness of supplied information has not been independently verified and, for the purposes of this report, it is assumed that the information provided to pHE is both complete and accurate. It is further assumed that normal activities were being undertaken at the site on the day of the site visit(s), unless explicitly stated otherwise.

Contents

List of Tables

1.0 Introduction

pHE was appointed by BioCarbon Australia to conduct a series of measurements to determine air emissions from the Pilot Plant Stack at their Markwell Road, Bulahdelah facility. Measurements were requested for internal due diligence and modelling purposes.

Testing was conducted on 12th of March 2025 to investigate emission concentrations for the following parameters:

- Carbon Monoxide;
- Dry Gas Density;
- Velocity;
- Moisture;
- Nitrogen Oxides;
- Oxygen;
- Volatile Organic Compounds;
- Sulfur Dioxide;
- Temperature; and
- Total Solid Particles (TP).

Laboratory analysis was conducted by the following NATA accredited laboratories for the specified tests:

- pHE NATA accreditation number 21069, performed the following analysis:
  - Nitrogen Oxides;
  - Total Particulates (TP); and
  - Moisture.
- ALS Environmental NATA accreditation number 825, performed the following analysis detailed in report number: EN2504436:
  - Sulfur Dixide; and
  - VOC.

1.1 Non-NATA Accredited Testing

pHE conducted Smoke determination as per NSW EPA Method TM-37. pHE do not hold NATA accreditation for this method.

2.0 Sampling Plane Requirements

The criteria for sampling planes are specified in AS 4323.1-2021.

Table 1: Criteria for Selection of Sampling Planes (AS 4323.1)

Type of flow disturbance	Minimum distance upstream from disturbance, diameters (D)	Minimum distance downstream from disturbance, diameters (D)
Bend, connection, junction, direction change, stack silencer, flow straightener, stack exit	*>2D*	*>6D*
Louvre, butterfly damper (partially closed or closed)	*>3D*	*>6D*
Axial fan	*>3D*	*>8D (see Note)*
Centrifugal fan	*>3D*	*>6D*

NOTE: The plane should be selected as far as practicable from an axial fan. Flow straighteners may still be required to ensure that the selected position meets the criteria listed in Items (a) to (e) below:

An ideal sampling plane shall also meet criteria contained in items (a) to (e)

a. *The gas flow shall be in the same direction at all points along each sampling traverse;*

b. *The gas flow profile at the sampling plane shall be steady, evenly distributed and not have a cyclonic or swirl component which exceeds an angle of 15º to the duct axis, when measured near the periphery of a circular sampling plane;*

c. *The temperature difference between adjacent points of the survey along each sampling traverse shall be less than 10% of the absolute temperature in kelvin, with the temperature at any point differing by less than 10% from the mean;*

d. *The ratio of the highest to lowest pitot tube differential pressure difference across the sampling plane shall not exceed 9:1. The ratio of highest to lowest gas velocities shall not exceed 3:1. For isokinetic testing with the use of impingers, the gas velocity ratio across the sampling plane should not exceed 1.6:1.*

e. *The differential pressure at all sampling points shall be greater than or equal to 5 Pa. Sampling planes with differential pressures less than 5 Pa do not conform with this document.*

In addition, the gas temperature at the sampling plane should be above the dewpoint.

The sampling plane did not meet the criteria listed in Table 1 in relation to the minimum distances from the upstream or downstream disturbances for an ideal sampling plane. Correction factors were applied to the sampling location in accordance with AS4323.1 by adding additional sampling points along the sampling traverse, as indicated in Table 3.

Even with the addition of the additional sampling points the sample location is a non-conforming sampling plane.

3.0 Methodology

3.1 Test Methods

pHE conducts stack emissions testing as per procedures outlined in the Australian Standards and NSW EPA approved methods (which are based off USEPA methods). The following methods are accredited with NATA (accreditation number 21069) and are approved for the sampling and analysis of gases. All sampling and analysis is conducted according to the methods in **Table 2**.

Table 2: pHE's NATA Accredited Testing Methods and Measurement Uncertainty

NSW EPA Approved Methods	Method	Method Title	Measurement Uncertainty
TM-1	AS4323.1	Selection of sampling positions	N/A
TM-2	USEPA Method 2	Determination of stack gas velocity and volumetric flow rate (type s pitot tube)	9%
TM-3	USEPA Method 8	Determination of sulfuric acid mist and Sulfur Dioxide emissions from stationary sources	12%
TM-11	USEPA Method 7E	Nitrogen dioxide (NO_2) or Nitric Oxide (NO)	11%
TM-15	AS4323.2	Determination of total particulate matter – isokinetic manual sampling – gravimetric method	14%
TM-22	USEPA Method 4	Determination of moisture content in stack gases	18%
TM-23	USEPA Method 3	Gas analysis for the determination of dry molecular weight	11%
TM-24	USEPA Method 3A	Carbon Dioxide (CO_2) in stack gases	11%
TM-25	USEPA Method 3A	Oxygen (O_2) in stack gases	11%
TM-32	USEPA Method 10	Carbon Monoxide (CO) in stack gases	11%
TM-34	USEPA Method 18	Volatile Organic Compounds	15%

Note: Measurement Uncertainty has been calculated to two standard deviations or a confidence limit of 95% (coverage factor = 2)

3.2 Equipment Calibrations

pHE has a calibration schedule to ensure the emission testing equipment is maintained in good order and with known calibration. Equipment used in this project was calibrated according to the procedures and frequency identified in the pHE calibration schedule. Details of the schedule and the calibration calculations are available on request.

4.0 Sample Location

4.1 Sampling Location Summary

Table 3 provides a summary of the location sampled by pHE on 12th March 2025.

Table 3: Sampling Location Summary

Discharge Description	Pilot Plant Stack
Duct Shape	Circular
Construction Material	Metal
Duct Diameter (mm)	1200
Minimum No. Sampling Points	12
Sampling Ports	1
Min. Points/Traverse	12
Distance from Upstream Disturbance	2.3D
Type of Disturbance	Diameter Change
Distance from Downstream Disturbance	0.4D
Type of Disturbance	Stack Exit
Sampling Location Status	Non-conforming[3]
Correction Factors Applied	Yes
Total No. Points Sampled	16
Points/Traverse	16

*AS 4323.1:2021 Stationary Source Emissions Method 1 – Selection of sampling positions
[1] AS 4323.1 Section 4.2.2
[2] AS 4323.1 Section 4.2.3
[3] AS 4323.1 Section 4.2.4
D = Diameters

4.2 Process Operating Conditions

On the day of testing, the plant operating conditions and production rate were considered typical by BioCarbon personnel.

5.0 Results

A summary of results obtained from emissions testing performed on 12th March is provided in **Table 4**.

Tables 5 & 6 show the calculated gas concentrations & mass emission rates respectively. **Tables 7 and 8** present detailed results along with gas stream properties during the testing period for:

- Total Particulate;
- Sulfur Dioxide; and
- Speciated Volatile Organic Compounds.

Emission concentrations are converted to standard conditions of 0°C, dry gas and 1 atmosphere pressure for comparison with appropriate guideline levels.

pHE has a calculated limit of uncertainty in regards to results. The estimation of measurement uncertainty in source testing is calculated to provide an indication of the precision of the measurement result and a degree of confidence in the range of values the reported result may represent. The measurement of uncertainty is shown in **Table 2**.

Field sheet data including the smoke inspection work sheet is provided in **Appendix 1,** with analytical laboratory reports provided in **Appendix 2. Appendix 3** presents the raw and calculated gas data recorded on site.

Table 4: Pilot Plant Stack Results Summary, 12 March 2025

Parameter	Units	Measured Result
Carbon Monoxide	mg/m^3	6
Dry Gas Density	kg/m^3	1.30
Flow (0^0C, dry gas, 1 atm pressure)	m^3/s	1.4
Moisture	%	3.8
Nitrogen Dioxide (Equivalent)	mg/m^3	19
Oxygen	%	17.4
Sulfur Dioxide	mg/m^3	20
Temperature	°C	277.6
Total Particulate (TP)	mg/m^3	2.2
Smoke	minutes	<0:01
Velocity	m/s	2.5
Volatile Organic Compounds	mg/m^3	<0.19

Table 5: Pilot Plant - Calculated Gas Data, 12 March 2025

Parameter	Units	Measured Result	Regulatory Limit
Time Sampled	hh:mm	12:59 – 14:01	-
Date Sampled	dd-mm-yyy	12-03-2025	-
Nitrogen Oxide	mg/m^3	12	-
Nitrogen Dioxide	mg/m^3	<2	-
Oxides of Nitrogen	mg/m^3	12	-
Equivalent Nitrogen Dioxide	mg/m^3	19	-
Carbon Monoxide	mg/m^3	6	-
Oxygen	%	17.4	-

Table 6: Pilot Plant - Calculated Mass Emission Rates, 12 March 2025

Parameter	Units	Measured Result	Regulatory Limit
Time Sampled	hh:mm	12:59 – 14:01	-
Date Sampled	dd-mm-yyy	12-03-2025	-
Stack Gas Flowrate (0°C, dry gas, 1 atm pressure)	m^3/s	1.4	-
Nitrogen Oxide	mg/s	17	-
Nitrogen Dioxide	mg/s	<1.4	-
Oxides of Nitrogen	mg/s	17	-
Equivalent Nitrogen Dioxide	mg/s	27	-
Carbon Monoxide	mg/s	8	-

Table 7: Pilot Plant - Total Particulate, Sulfuric Acid Mist (as SO_3) and Sulfur Dioxide (as SO_2), 12 March 2025

Sampling Conditions:				
Stack internal diameter at test location	1200	mm		
Stack gas temperature (average)	277.6	ºC	550.8	K
Stack pressure (average)	1018	hPa		
Stack gas velocity (average, stack conditions)	2.5	m/s		
Stack gas flowrate (stack conditions)	2.8	m^3/s		
Stack gas flowrate (0°C, dry gas, 1 atm pressure)	1.4	m^3/s		
Total Particulate Testing				
Test Period	12:50	-	14:10	
Total Particulate Mass	1.75	mg		
Gas Volume Sampled	0.797	m^3		
Total Particulate Emission*1	2.2	mg/m^3		
Total Particulate Mass Emission Rate*2	3.0	mg/s		
Regulatory Limit	N/A			
Sulfuric Acid Mist (H_2SO_4 as SO_3) Testing				
Test Period	12:50	-	14:10	
Sulfuric Acid Mist (H_2SO4 as SO_3) Mass	2.0	mg		
Gas Volume Sampled	0.753	m^3		
Sulfuric Acid Mist (H_2SO_4 as SO_3) Emission*1	2.7	mg/m^3		
Oxygen measured value	3.6	mg/s		
Regulatory Limit	N/A			
Sulfur Dioxide (SO_2 as SO_2) Testing				
Test Period	12:50	-	14:10	
Sulfur Dioxide (SO_2 as SO_2) Mass	15	mg		
Gas Volume Sampled	0.753	m^3		
Sulfur Dioxide (SO_2 as SO_2) Emission*1	20	mg/m^3		
Sulfur Dioxide (SO_2 as SO_2) Mass Emission Rate*2	27	mg/s		
Regulatory Limit	N/A	mg/m^3		
Moisture Content (%)	**3.8**			
Gas Density (dry at 1 atmosphere)	**1.30**	**kg/m^3**		
Dry Molecular Weight	**29.2**	**g/g-mole**		

Notes *1 Emission concentration at Standard conditions of 0°C, 1 atm, dry gas.
*2 Mass emission rate determined from pre and post sampling flow measurements and the respective test moisture content. See Q_{std} in field sheets and final calculations "Stack Analysis - Final Calculations" for each test.

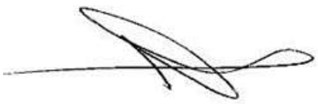
Table 8: Pilot Plant - Speciated Volatile Organic Compounds Results, 12 March 2025

Analyte	Sample µg	Blank µg	Sample Blank Corrected µg	(mg/m³)	mg/s
Acetone	<2.0	<2.0	<2.0	<0.19	<0.27
1,1-dichloroethane	<1.0	<1.0	<1.0	<0.096	<0.13
2-Butanone	<1.0	<1.0	<1.0	<0.096	<0.13
Chloroform	<1.0	<1.0	<1.0	<0.096	<0.13
Benzene	<1.0	<1.0	<1.0	<0.096	<0.13
1-heptene	<1.0	<1.0	<1.0	<0.096	<0.13
n-heptane	<1.0	<1.0	<1.0	<0.096	<0.13
Trichloroethene	<1.0	<1.0	<1.0	<0.096	<0.13
MIBK	<1.0	<1.0	<1.0	<0.096	<0.13
Toluene	<1.0	<1.0	<1.0	<0.096	<0.13
2-hexanone	<1.0	<1.0	<1.0	<0.096	<0.13
Chlorobenzene	<1.0	<1.0	<1.0	<0.096	<0.13
Ethyl Benzene	<1.0	<1.0	<1.0	<0.096	<0.13
m- & p-xylene	<2.0	<2.0	<2.0	<0.19	<0.27
o-xylene	<1.0	<1.0	<1.0	<0.096	<0.13
Styrene	<1.0	<1.0	<1.0	<0.096	<0.13
Isopropylbenzene	<1.0	<1.0	<1.0	<0.096	<0.13
2-chlorotoluene	<1.0	<1.0	<1.0	<0.096	<0.13
4-chlorotoluene	<1.0	<1.0	<1.0	<0.096	<0.13
1,3,5-trimethylbenzene	<1.0	<1.0	<1.0	<0.096	<0.13
n-decane	<1.0	<1.0	<1.0	<0.096	<0.13
1,2,4-trimethylbenzene	<1.0	<1.0	<1.0	<0.096	<0.13
1,3-dichlorobenzene	<1.0	<1.0	<1.0	<0.096	<0.13
1,4-dichlorobenzene	<1.0	<1.0	<1.0	<0.096	<0.13
1,2-dichlorobenzne	<1.0	<1.0	<1.0	<0.096	<0.13
n-butylbenzene	<1.0	<1.0	<1.0	<0.096	<0.13
Hexachlorobutadiene	<1.0	<1.0	<1.0	<0.096	<0.13
Total	**<2.0**		**<2.0**	**<0.19**	**<0.27**

Note: Where the blank has returned a less than value, the analysed value has been corrected for half of that blank value. i.e. a blank value of <0.5 has had 0.25 subtracted from the analysed value.
Total VOC are Lower Bound results (excluding LOR Values).

6.0 Conclusion

This concludes the stack emissions testing report. If there are any questions relating to this sampling event, please do not hesitate to contact either Nick Stanning or Sharn Crosdale of pHE.



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