Hemi Gold Project

Air Quality Assessment

Final Report
Version 2

Prepared for De Grey Mining Limited

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Hemi Gold Project

Final Report

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Signature		

Executive Summary

De Grey Mining Limited (DEG) commissioned Environmental Technologies & Analytics Pty Ltd (ETA) to undertake an air quality assessment at their proposed Hemi Gold Project, located approximately 85 kilometres (km) south of Port Hedland in the Pilbara region of Western Australia.

The purpose of this air quality assessment is to assess the potential air quality impacts, associated with the operations.

Study Overview

The mine and processing facility, which is predicted to have a life of at least 14 years, is expected to process around 10 million tonnes per year (Mtpa) of ore. Mining will be undertaken on a continual basis using standard open cut mining techniques including:

- Drilling and blasting.
- Loading material onto haul trucks for haulage to either waste stockpiles or the Run of Mine (ROM) pad.
- Primary Crushing.

The potential air quality impacts of the Project were determined through a dispersion modelling study, which incorporated prognostic meteorological data, and emissions information estimates for the project based on operating tonnage supplied by DEG. The scope of the modelling assessment is summarised below.

Modelled meteorological period	1 January to 31 December 2015
Model selection	WRF/CALMET/CALPUFF model suite
Key Pollutants	Particulate matter (PM) - including TSP, PM_{10} and $PM_{2.5}$ size fractions, and dust deposition
Meteorological data	Three-dimensional prognostic meteorological data developed using the Weather Research and Forecasting (WRF) model.
Background Air Quality	Published air quality monitoring data for the Pilbara has been reviewed and used as a suitable proxy of existing (baseline) concentrations for key pollutants.
Project Emissions	Emissions from the Project under maximum material handling assumptions formed the basis of the modelling assessment.
Sensitive Receptors	Discrete receptor locations were nominated to represent: • Accommodation village and camp • Heritage sites • Pools.
Model Scenarios	The model scenarios included in the assessment consider the Project in isolation, as well as cumulatively (with background), for particulates (as TSP, PM_{10}, $PM_{2.5}$ and deposition).

Key findings

The key findings of the assessment are:

- At the accommodation village and camp:
  - The model is predicting 24-hour concentrations of both PM_{10} and $PM_{2.5}$ above the relevant criteria.
  - The model is predicting annual average concentrations of both PM_{10} and $PM_{2.5}$ above the relevant criteria at the Accommodation Village.
  - The model is predicting annual average concentrations of PM_{10} above the relevant criteria at the Mt Dove camp.

It is important to note that modelled concentrations above the numerical value is not an indicator of unacceptable impact, but is an indication that the potential risk for impact requires further consideration. For the accommodation village this may necessitate the installation of an ambient monitor for the first 2 – 3 years of mining to verify the actual PM_{10} concentrations at this receptor.

- At the Heritage Sites and Pools:
  - The modelling predicts that the deposition rates will be below the criteria (4 g/m^2/month) at all the receptor locations.

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1 Introduction

1.1 Background

Environmental Technologies & Analytics (ETA) has been engaged by De Grey Mining Limited ("DEG") to complete an air quality assessment for the Hemi Gold Project ("the Project") to assist with documenting the environmental impacts considered in the design of the Project. The Project is located approximately 85 kilometres (km) south of Port Hedland in the Pilbara region of Western Australia (see Figure 1-1).

The Project area is predominately located on the Indee Station Pastoral Lease with the northern miscellaneous licences partially covering the Mundabullandgana Station Pastoral Lease. The Project is located within the Native Title Determination (NTD) area of the Kariyarra people, whose Prescribed Body Corporate is the Kariyarra Aboriginal Corporation. At time of writing a Land Access Agreement is being negotiated for the Project.

A total of five registered Aboriginal Heritage sites, one lodged site and three Other Heritage Places are located across the Project area. Detailed heritage studies are being undertaken across the Project area to further understand the importance of these sites and to determine if any further sites exist.

The Project is forecast to consist of the following components:

- Open cut mining of gold bearing ore from the Hemi deposits.
- The construction and subsequent operation of a 10 million tonnes per annum (Mtpa) processing facility located adjacent to the Hemi deposit, capable of achieving 90% to 94% gold recovery from free milling and semi refractory ores.
- Disposal of process tailings to a surface Tailings Storage Facility (TSF) Integrated Waste Landform (IWL).
- Water supply from the local groundwater aquifer, with accompanying groundwater and surface water management infrastructure to facilitate mine dewatering, bore field abstraction, groundwater reinjection and flood diversion.
- Stockpiling of waste rock to form permanent landforms.
- A village with messing and accommodation capacity for approximately 600 personnel.
- A power supply from the 220 kV network grid approximately 30 km north of the Project area, with supplementary power supply options from an on-tenement solar farm.
- A 12 km sealed access road from the Great Northern Highway.
- An airstrip with capacity for 100 seat jet aircraft.
- Other supporting infrastructure (offices, workshops, waste facilities, laydown areas).

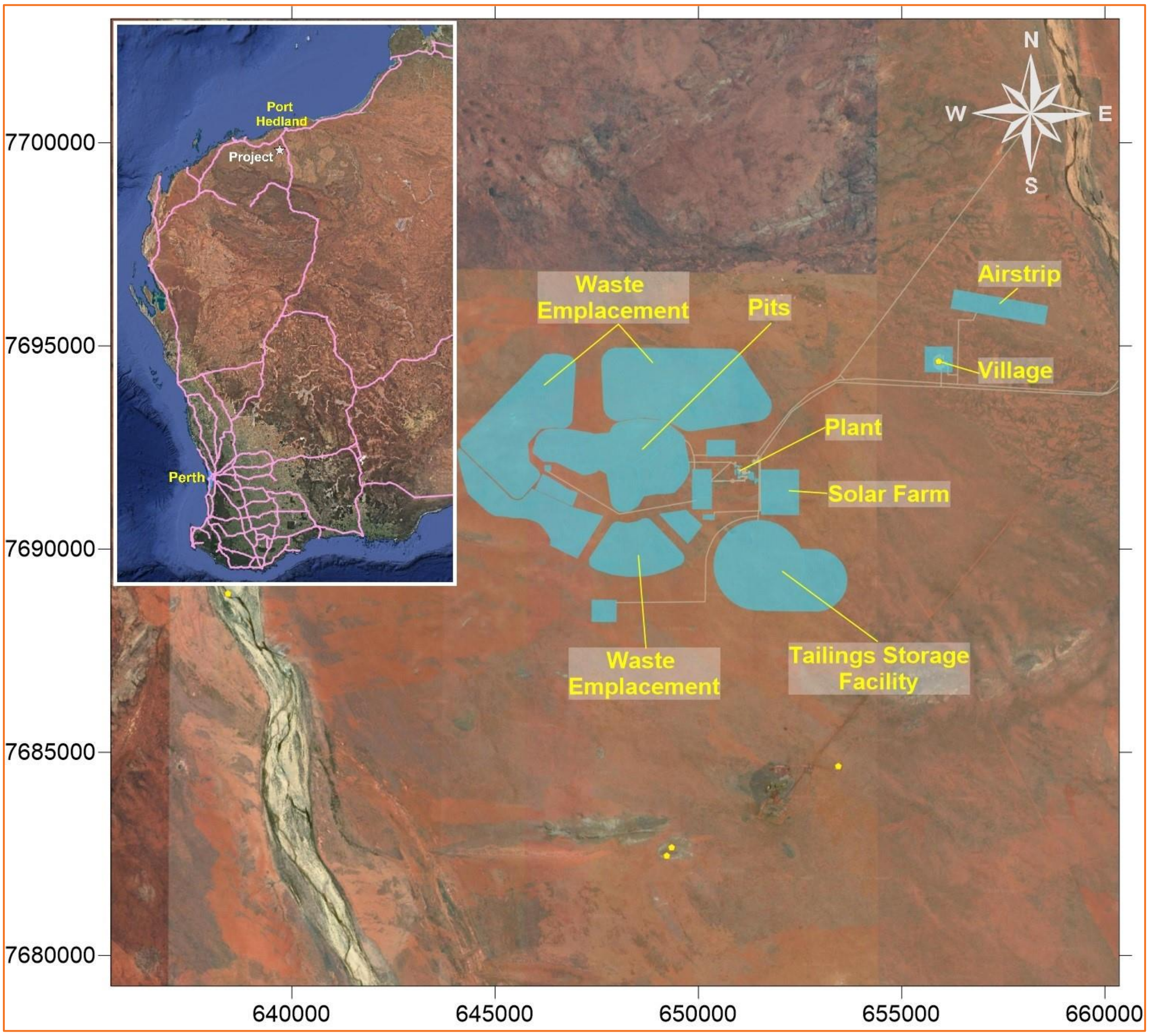

Figure 1-1: Project location and setting.

1.2 Scope of work

The potential air quality impact of the Project has been determined through an atmospheric dispersion modelling study, which incorporated prognostic meteorology, and emissions information estimated for the Project for a defined maximum operational capacity.

Reference has been made to the following key regulatory policy and guidance:

- Air Quality Modelling Guidance Notes (DoE, 2006)
- Guideline - Air Emissions, draft for external consultation (DWER, 2019)
- Guideline - Dust Emissions, draft for external consultation (DWER, 2021)
- Environmental Factor Guideline – Air Quality (EPA, 2020)
- *Environmental Protection Act, 1986, as amended*
- Environmental Protection Act Regulations 1987.

1.3 Structure of report

This report describes the methods and findings of an assessment of the potential impacts to the air environment arising from the Project. The assessment includes:

- Overview of the mine and process (Section 2).
- The study approach and methodology in Section 3.
- Atmospheric dispersion modelling of the emissions using CALPUFF (Section 4).
- Project emission estimation and inventory in Section 5.
- An evaluation of the potential impact from the Project, for particulates (Section 6).
- Conclusions of the assessment are presented in Section 7.

The appendices contain supporting information, specifically:

- The analysis to determine the representative meteorological year for modelling.
- The detailed configuration for WRF and CALMET.
- Emission parameters and emission rates for each source modelled.

2 Process Overview

The Project is a grouping of six proposed pits (Aquila, Brolga, Crow, Diucon, Eagle and Falcon). Ore from these pits will be processed at a single processing facility, which in turn will deposit tailings into a single Tailings Storage Facility (TSF). There will be three waste rock landforms (WRLs) for the receipt of overburden and non-ore-bearing rock.

The Project will mine a refractory arsenopyrite gold ore. Such ores contain ultra-fine gold particles disseminated throughout its gold occluded minerals. These ores are naturally resistant to recovery by standard cyanidation and carbon adsorption processes. The presence of sulphur and arsenic within the ore required the process design to consider the avoidance of acidic tailings and tailings containing soluble arsenic.

A simplified ore processing flowsheet for Project is shown in Figure 1. Ore will be crushed and ground in the ball mill (comminution circuit) before being fed to the flotation circuit. Any gravity recoverable gold will be recovered prior to flotation with the use of a centrifugal concentrator. The flotation circuit will process gold bearing sulphides in the ore producing a “low mass pull” gold rich sulphide concentrate. The Pressure Oxidation (POx) circuit is designed to receive the gold rich sulphide concentrate from the flotation circuit. The POx circuit will have a throughput of 8% (0.8Mtpa) of the comminution circuit.

The POx circuit will convert the sulphide concentrate to a gold bearing residue amenable to standard carbon in leach (CIL) processing. The underflow from flotation is also amenable to standard CIL processing. Both streams will enter the CIL circuit. The solution from the CIL circuit, together with the gravity recovered gold, will flow into the electrowinning circuit, culminating in the production gold bars at the Project site. Tailings from the CIL circuit will be pumped to the tailing storage facility.

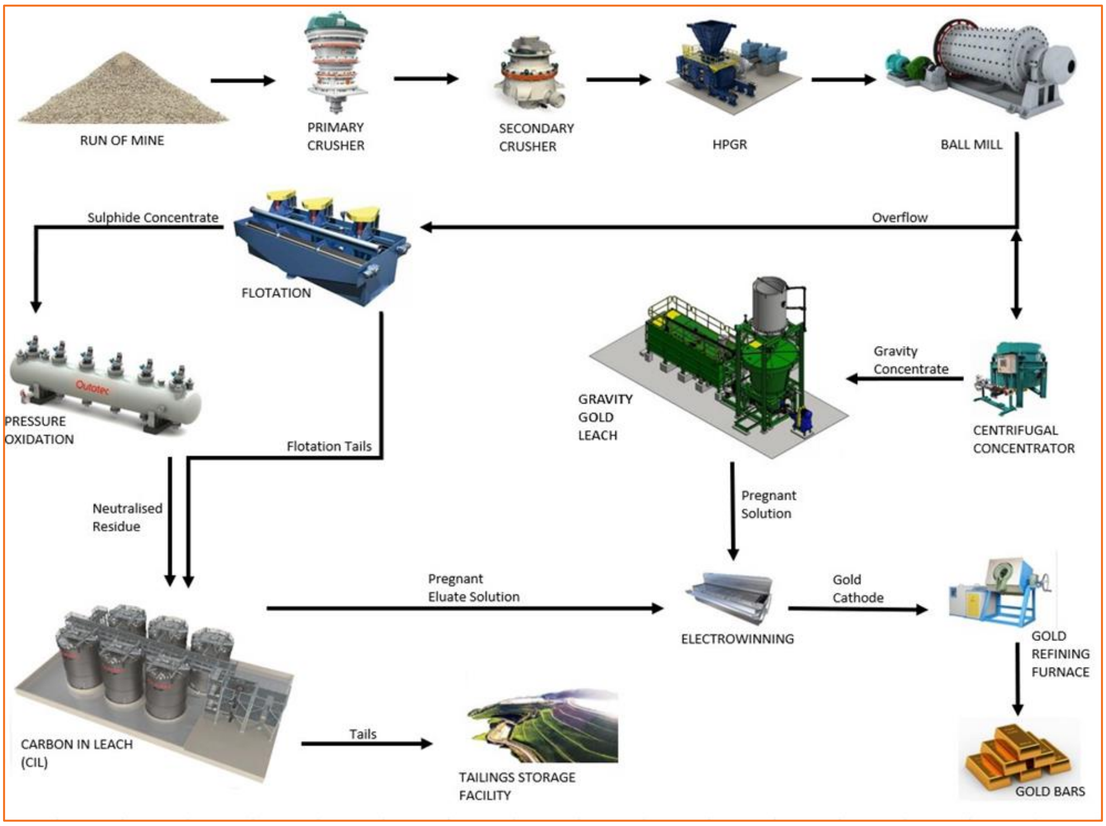

Figure 2-1: Process Flowsheet (RPMGlobal, 2022).

3 Assessment methodology

This section outlines the air quality study and assessment approach. It includes the methodology applied to define the meteorological characteristics of the Project area relevant to the assessment, the emission estimation, the dispersion, and the ambient assessment criteria selected for the purposes of determining the significance of the dispersion model results, and therefore the potential impact.

The simplified study structure is shown in Figure 2-1 and detailed in the following subsections.

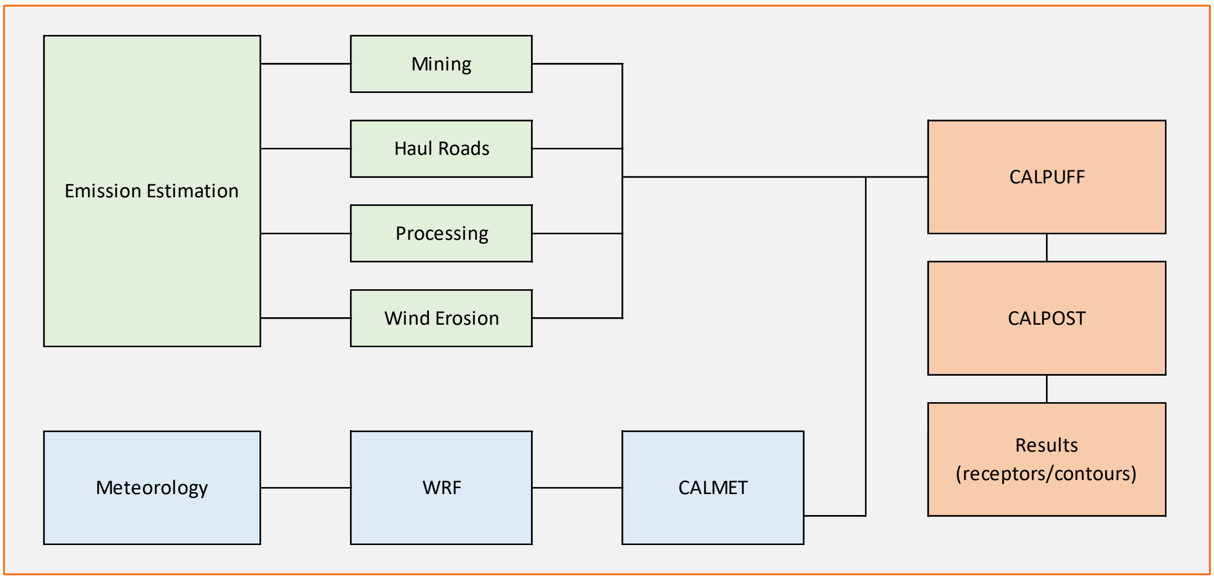

Figure 3-1: Air quality assessment – study approach.

3.1 Climate and Meteorology

This section outlines the key climate and meteorological characteristics of the region important for the dispersion, transformation and removal (or deposition) of pollutants from the atmosphere, and therefore ambient air quality.

The Project area is located approximately 85 km south of Port Hedland, in the inland Pilbara region of Western Australia. This region has a desert climate (arid), characterised by hot dry days and cold clear nights, with unreliable rainfall occurring during the year. The climate is classified according to the Köppen-Geiger climate classification system as BWh (Arid, Desert, Hot) (Kotteck et al, 2006). Two seasons are used to distinguish the general conditions:

- A hot summer period extending from October to April, and
- A mild winter from May to September.

A summary of the long term meteorological conditions as measured at the Bureau of Meteorology (BoM) station at the Marble Bar Airport is shown in Figure 3-2 to Figure 3-4. This site, which is located approximately 150 km to the east, has been chosen as it is the closest inland meteorological station with publicly available data. It is expected that the project area itself will experience some localised conditions due to topography however site specific measurements are not available at this stage.

3.1.1 Temperature

Recorded temperature in the Pilbara region is variable, and notably also at Marble Bar. The temperature range is characterised by high maxima, and the diurnal difference can be extreme. As shown in Figure 3-2 at Marble Bar the measured mean monthly maximum temperatures ranges from a high of 41.9 degrees Celsius (°C) in December to 27 °C in June. The mean monthly minimum temperatures range from 26.5 °C in January to 12.1 °C in July.

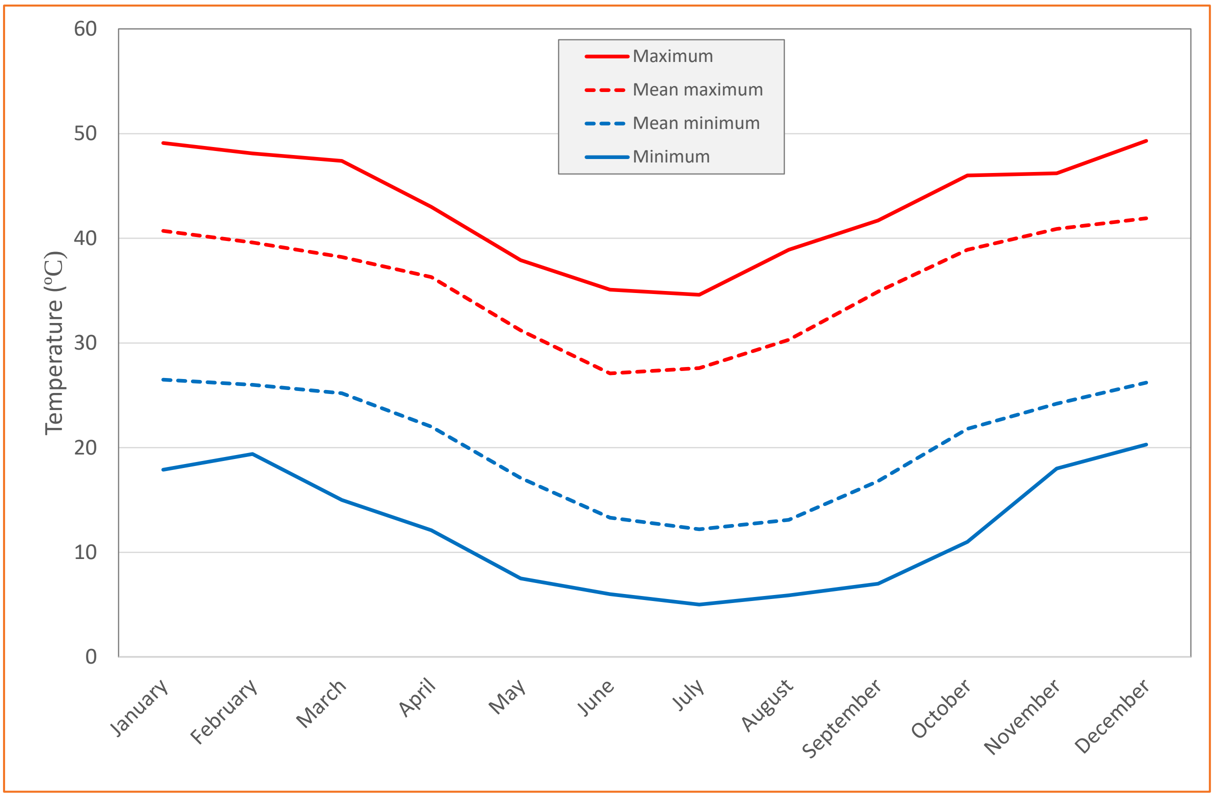

Figure 3-2: Mean Temperature 2000 to 2020 (BoM Marble Bar Airport).

3.1.2 Humidity

Humidity at the Marble Bar airport is also characterised by variability. Mean monthly humidity, recorded at 9am and 3pm, are shown in Figure 3-3. The higher humidity levels are associated with the summer months, however the monthly averages tend to be relatively low all year round.

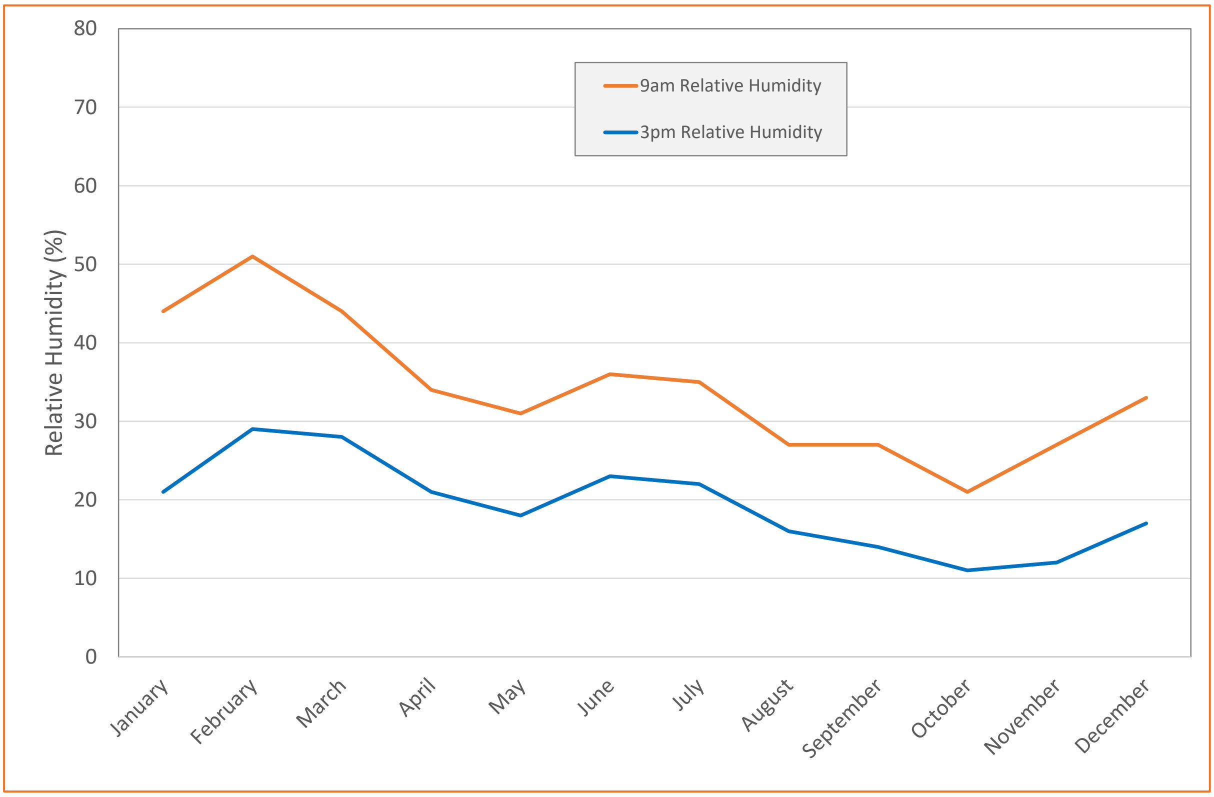

Figure 3-3: Relative Humidity 2000 to 2020 (BoM Marble Bar Airport).

3.1.3 Rainfall

There are two dominant rainfall systems that influence the Pilbara region:

- The northern rainfall systems of tropical origin, and
- The southern winter rainfall system.

This results in a bi-modal rainfall distribution, with the majority of rainfall occurring between December and March as a result of tropical cyclones originating from the north. A smaller peak in rainfall occurs between April and June, and is a result of extensive cold fronts moving across the south of Western Australia in an easterly direction, which on occasion may extend in the Pilbara.

The long term rainfall data measured at the BoM Marble Bar airport station is presented in Figure 3-4 and this data indicates that rainfall is unreliable, variable and occurring infrequently, with less than 30 days in the year receiving more than 1 millimetres (mm) of rain (long term average). This variability will influence the need or extent for dust management and mitigation.

The amount, and seasonality, of rainfall is important for understanding the periods in which natural dust suppression occurs from windblown sources associated with surface and open pit mining and material handling activities. It is also important to understand periods in which there is the potential for elevated windblown dust emissions to occur. This would primarily be periods with high evaporation and low rainfall. For the Pilbara region the period August to December is most conducive to high windblown dust emissions.

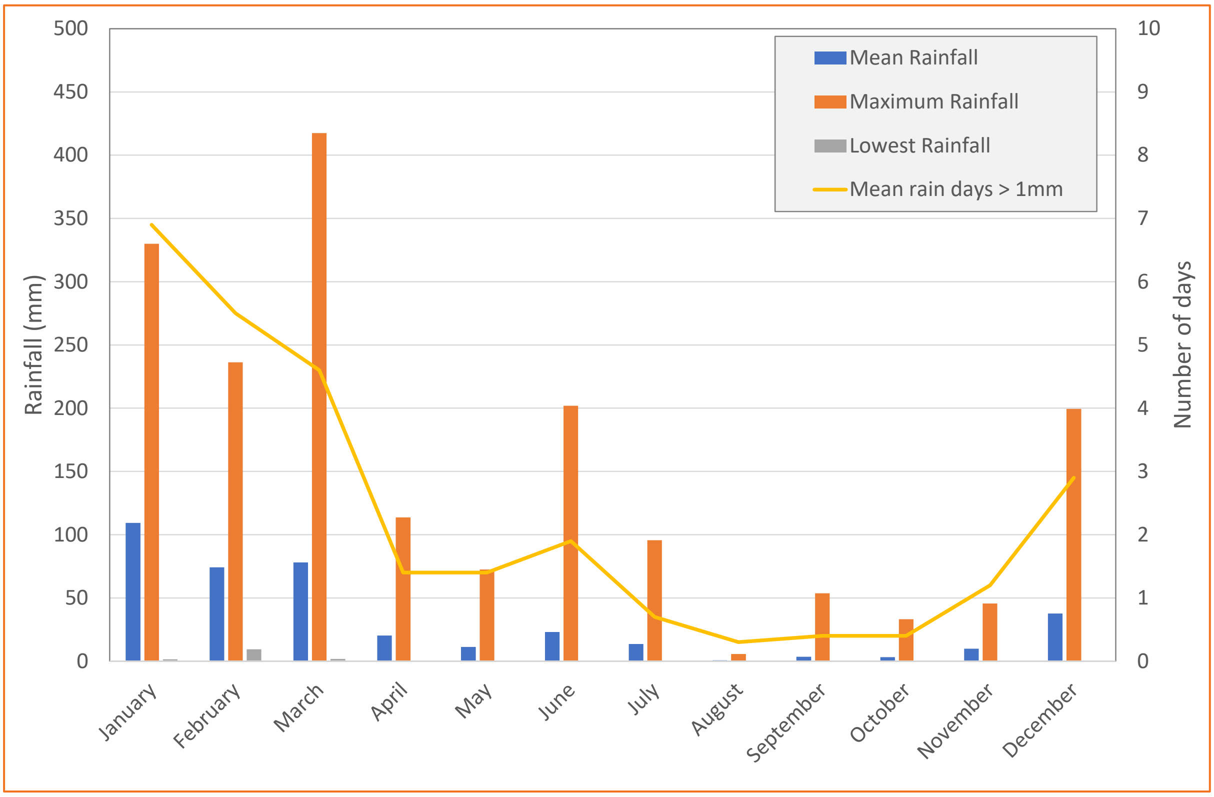

Figure 3-4: Rainfall 2000 to 2020 (BoM Marble Bar Airport).

3.1.4 Wind speed

The meteorology component of a dispersion model is a key element for the effectiveness or representativeness of the dispersion model outputs.

An analysis of 11 years (2011 to 2021) of historical surface observations obtained from the BoM Marble Bar airport weather station, as presented in Appendix A, concluded the 2015 calendar year as being the most representative against longer term climatic averages. The 2015 calendar year was selected for modelling on this basis. T

Both upper air and surface information are needed for modelling. In the absence of adequate onsite meteorological data, the Weather Research and Forecast (WRF V3.7) model (http://wrf-model.org/index.php) was used to generate hourly 3-dimensional data for the region. The 3-Dimensional meteorological data generated by WRF was input to CALMET for further processing to the finer resolution used in the dispersion modelling. This procedure will be referred to as the ‘WRF-CALMET methodology’. The output from the CALMET meteorological model is then used to drive the pollution dispersion in the CALPUFF model. Configuration of WRF is detailed in Appendix B, with the configuration of CALMET detailed in Appendix D.

3.2 Pollutants of Interest

Based on the description of the Project and key processes considered, the key pollutants of interest to be assessed are summarised in Table 3-1.

Table 3-1: Air pollutants of interest from the Project

Pollutant to be Assessed		
Particulate Matter	Airborne particles are a broad class of diverse substances that may be solid or liquid (liquid particles are often called aerosols) and are produced by a wide range of natural and human activities. Airborne particles are commonly classified by their size as total suspended particles (TSP), and inhalable particles (coarse fraction PM_{10} and fine fraction $PM_{2.5}$). **Project sources are principally from mining, handling of ore/waste, processing and wind generated surface erosion.**	
	PM_{10}	Inhalable particles are grouped into two size categories: those with a diameter of up to 10 µm (PM_{10}) and those with a diameter of up to 2.5 µm ($PM_{2.5}$). Inhalable particles are associated with increases in respiratory illnesses such as asthma, bronchitis and emphysema, with an increase in risk related to their size, chemical composition and concentration. Particles in the PM_{10} size fraction have been strongly associated with increases in the daily prevalence of respiratory symptoms, hospital admissions and mortality.
	$PM_{2.5}$	Particles in the $PM_{2.5}$ size fraction can be inhaled more deeply into the lungs than PM_{10}, and have been associated with health effects similar to those of PM_{10}. There is some evidence to suggest that $PM_{2.5}$ might be more deleterious to health than other size fractions. No lower limit for the onset of adverse health effects has yet been observed.
	TSP	Total suspended particulates (TSP) refers to the total amount of the PM suspended in air, typically up to 50 µm. These larger particles are primarily associated with amenity or visibility issues and are likely to be removed by gravitational settling within a short time of being emitted (i.e. they settle to the ground or other surfaces fairly quickly).
	Deposited Dust	Deposited matter refers to any dust that falls out of suspension in the atmosphere.

3.3 Existing | background air quality

The Pilbara region is a naturally dusty environment with wind-blown dust being a significant contributor to the particulate loading. Within the aggregated emission inventory for the Pilbara, undertaken by SKM in 2000 for the 1999/2000 financial year, it was calculated that approximately 170,000 tonnes was emitted as a result of wind erosion. Wildfires also account for a significant amount of the emissions with approximately 195,000 tonnes of particulates emitted. Note that these are calculated values and will vary on an annual basis depending on a range of factors including the extent of erodible areas, area burnt, rainfall and wind speed.

To determine the potential contribution of existing or background concentrations reference was made to the BHP Strategic Environmental Assessment (SEA) (BHP, 2015), noting that this study does not include any indication of potential background dust deposition rates. As part of this assessment BHP, through an analysis of their particulate monitoring network in the region, determined the following constant background concentrations:

- PM_{10}: 18 µg/m^3 (24-hour average)
- TSP: 33 µg/m^3 (24-hour average)
- $PM_{2.5}$: 3 µg/m^3 (24-hour average) (taken as 15% of the PM_{10} background)

These concentrations will be utilised in this assessment to represent background concentrations, maintaining consistency in assumptions.

3.4 Sensitive receptors and environmental values

This modelling assessment considers the potential air quality impacts on relevant environmental values and sensitive receptors, consistent with EPA (EPA, 2020), and DWER (DWER, 2019), noting that the current DWER guidelines excludes the consideration of on-site project related receptors as sensitive receptors. The key receptor locations considered are:

- Accommodation village and camp
- Heritage sites.
- Pools

The location of the nominated receptors in the region are presented in Figure 3-5 relative to the Project, and tabulated in Table 3-2.

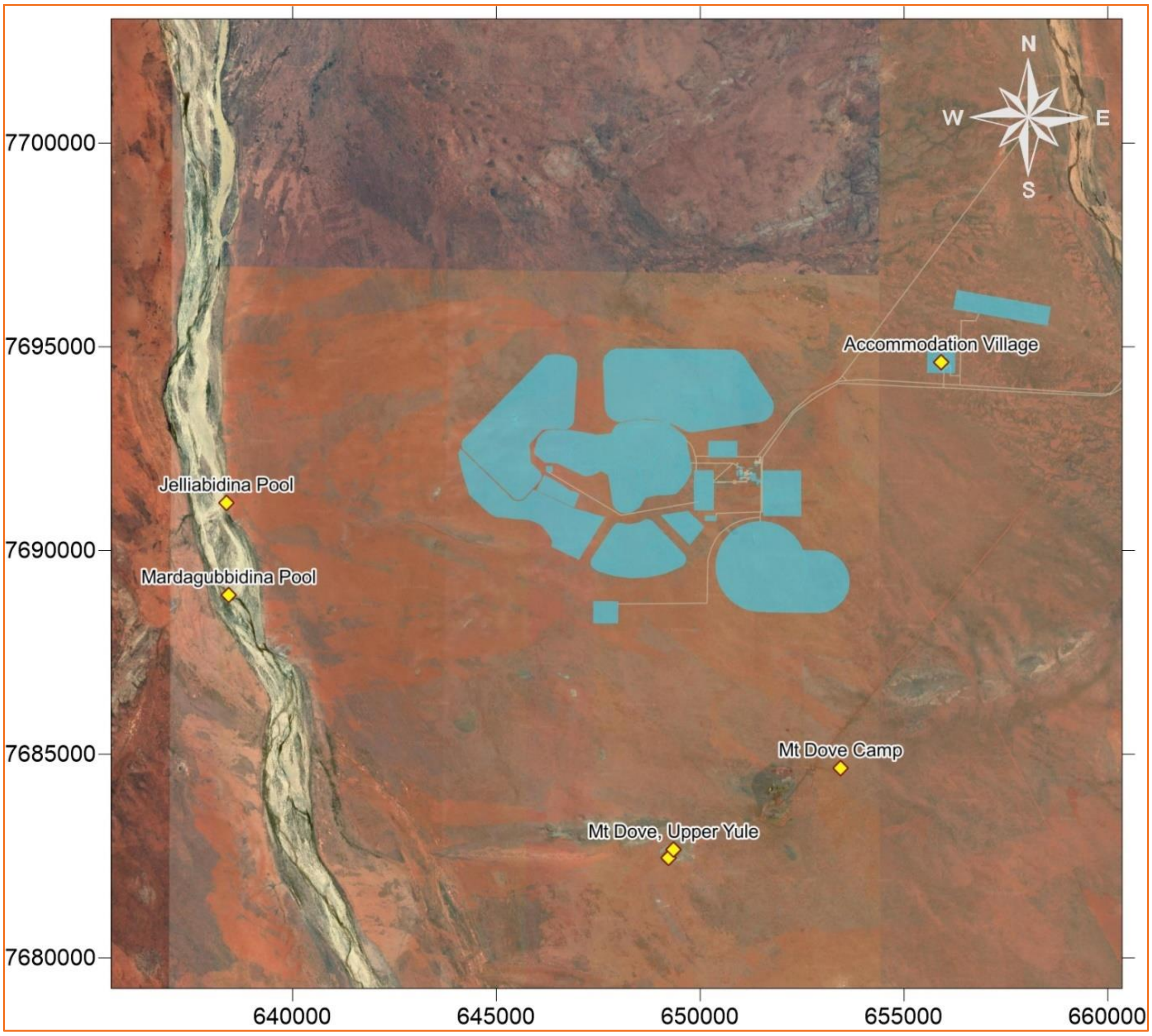

Figure 3-5: Receptor locations (GDA20, Zone 50).

Table 3-2: Receptors of interest for the Project

ID	Easting	Northing	Receptor	Assessment Criteria	Pollutant Impact Assessed			
					PM_{10}	$PM_{2.5}$	TSP	Dust deposition
1	653456	7684667	Mt Dove Camp	Human health | amenity | nuisance	✓	✓	✓	✓
2	655915	7694619	Accommodation Village		✓	✓	✓	✓
3	638383	7691162	Jelliabidina Pool	Amenity | Nuisance	-	-	✓	✓
4	638441	7688907	Mardagubbidina Pool		-	-	✓	✓
5	649241	7682457	Mt Dove, Portree		-	-	✓	✓
6	649341	7682657	Mt Dove, Upper Yule		-	-	✓	✓

3.5 Impact assessment

Ground-level concentrations of particulates (as Total Suspended Particulates (TSP), PM_{10} and $PM_{2.5}$) and dust deposition, predicted at nominated receptors and the surrounding environment were compared with the relevant air quality assessment criteria. This assessment has considered the potential impact attributable to the Project, as well as the cumulative (background) impact i.e. in conjunction with the existing emission sources in the area. The basis for this is summarised in Section 3.2.

Modelling results, at nominated receptors, are compared to the numerical value of the criteria, and assessed as being either above or below the numerical value. It is important to note that, as a risk based assessment approach is normally applied to the assessment of air quality, a modelled result above the numerical value is not an indicator of unacceptable impact, but is an indication that the potential risk for impact requires further consideration.

3.5.1 Assessment criteria

Modelled ground level concentrations for particulates have been compared to ambient air quality assessment criteria to determine the potential changes in impact resulting from the Project.

The assessment criteria adopted for this study (for particulates) are primarily based on the DWER (2019; 2021) guidelines, which also reference the numerical values from the ambient air quality standards specified in the Ambient Air Quality NEPM (NEPC, 2021).

In their current draft form, the DWER (2019) guidelines for TSP/PM_{10}/$PM_{2.5}$ (defined as *criteria pollutants* in the guideline) require the criteria to generally be '…met at all existing and future offsite sensitive receptors in the modelling domain'. DWER (2021) draft guidelines address the settling or deposition of dust, noting that at time of this assessment the guideline is draft and subject to public consultation.

There is no established criteria to represent the ecological impact of dust on the rockpools, and the dust (particulate) concentrations at which the rockpools may experience a noticeable or negative impact. In the absence of any documented criteria for assessing air quality impact on the rockpools, the ambient air quality assessment criteria intended to protect human amenity and nuisance values, are assumed to be conservatively protective of this environmental value, and are used in this assessment as a "proxy" value. A modelling result that is higher than the assessment criteria should not be interpreted as a predicted impact or loss of environmental value but is an indication that results may need further consideration for the sensitive receptor location, such as monitoring for determining baseline conditions and environmental change.

The ambient air quality assessment criteria adopted in this study are shown in Table 3-3.

Table 3-3: Summary of adopted assessment criteria.

Pollutant	Air quality assessment criteria					Reference
	Concentration [1]	Concentration [2]	Averaging Period	Allowable Exceedances	Environmental value protected	
PM_{10}	50 $\mu g/m^3$	46 $\mu g/m^3$	24-hour	exception event	Human health	DWER (2019) consistent with NEPM (NEPC, 2021)
	25 $\mu g/m^3$	23 $\mu g/m^3$	annual	none		
$PM_{2.5}$	25 $\mu g/m^3$	23 $\mu g/m^3$	24-hour	exception event		
	8 $\mu g/m^3$	8 $\mu g/m^3$	annual	none		
TSP	90 $\mu g/m^3$	82 $\mu g/m^3$	24-hour	none	Human health and amenity Proxy for protection of ecological values	DWER (2019)
Dust deposition	2 g/m^2/30 days		30-days	Maximum increase above background	Amenity | Nuisance Proxy for protection of ecological values	DWER (2021) referencing NZ MfE (2016)
	4 g/m^2/30 days		30-days	Maximum		DWER (2021) referencing NSW EPA (2016)

Notes:
1 Concentrations referenced to 0ºC (excluding reference to dust deposition)
2 Concentrations referenced to 25ºC (excluding reference to dust deposition)

4 Modelling

For this assessment, air dispersion modelling has been conducted using CALPUFF (Version 6.42, Level: 110325) with meteorological data produced from the WRF prognostic model due. Although simplistic steady state models, such as AERMOD, would be suitable to model particulate emissions from the proposed Project the CALMET/CALPUFF suite was chosen to ensure that the model is suitable for more complex assessments to take account of features such as power stations and additional processing.

The model has been used to predict ground level concentrations across the model domain. The potential air quality impacts associated with the Project have been considered in isolation of other emission sources, for particulates. The model was configured to predict the ground-level concentrations on a rectangular grid. The model domain was defined with the Southwest corner of the model domain at 635,550 m Easting and 7,679,250 m Northing (UTM Zone 50).

The 2015 calendar year was selected as having the most representative meteorological conditions based on the results of the statistical study presented in Appendix A.

Specifics for the modelling configuration are described further in this section.

4.1 Meteorological model (WRF and CALMET)

The meteorology component of a dispersion model is a key element for the effectiveness or representativeness of the dispersion model outputs. Both upper air and surface information are needed for modelling (or assumptions).

4.1.1 WRF model

In the absence of adequate onsite meteorological data, the Weather Research and Forecast (WRF V4.0) model (http://wrf-model.org/index.php) was used to generate hourly 3-dimensional data for the region. WRF is the next-generation mesoscale numerical weather prediction system. The model was primarily designed to serve both operational forecasting and atmospheric research. WRF features multiple dynamical cores, a 3-dimensional variational data assimilation system and a software architecture allowing for computational parallelism and system extensibility. Further details on WRF modelling are provided in Appendix B.

4.1.2 CALMET

The 3-Dimensional meteorological data generated by WRF was input to CALMET (Version 6.42 Level: 110325) for further processing to the finer resolution used in the dispersion modelling. This procedure will be referred to as the 'WRF-CALMET methodology'. The output from the CALMET meteorological model is then used to drive the pollution dispersion in the CALPUFF model.

CALMET is a three-dimensional 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, spatially and temporal-varying meteorological fields that are utilised in the CALPUFF dispersion model.

CALMET requires several datasets to resolve the surface and upper air meteorology occurring for each hour of the year:

- surface observations and upper air observations or gridded prognostic meteorological model data

- land use and topographical data.

CALMET was run for a 125 x 120 grid domain at a spatial resolution of 200 m. Vertically, the model consisted of 10 levels extending to 3,000 m. The southwest corner coordinates of the domain were Easting of 635.550 m and a false Northing of 7679.250 m.

The 90 m resolution Shuttle Radar Topography Mission (SRTM) dataset was used as input into the CALMET model to indicate terrain heights within the model domain (Figure 4-1). CALMET also requires geophysical data including gridded fields of land use categories. The CALMET land use is sourced from the 100 m spatial resolution Copernicus Global Land ”CGLOPS-1” dataset (Buchhorn et al, 2020), and converted to the 52-category United States Geological Service land use and land cover classification system required by CALMET.

The CALMET results are provided in Appendix D.

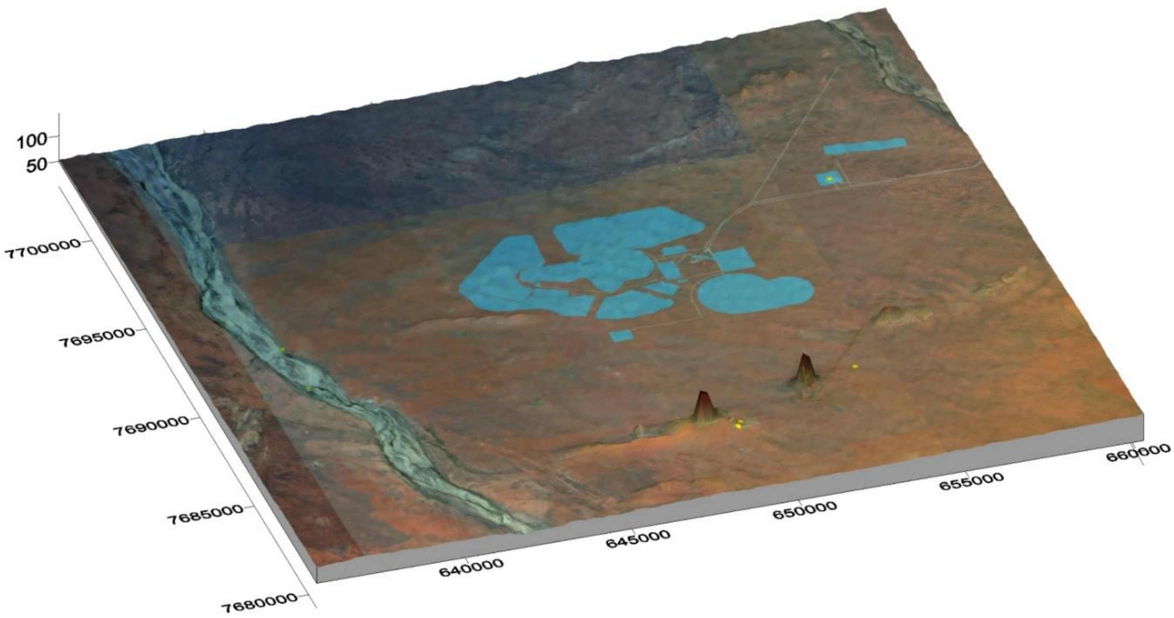

Figure 4-1: Image of SRTM terrain elevation[1] used in CALMET (GDA20, Zone 50).

4.2 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

[1] Vertical height is exaggerated.

across released puffs and considers the complex arrangement of emissions from point, area, volume and line sources (Scire et al., 2000).

The CALPUFF model was set to calculate concentrations on a set grid (gridded receptors). The model domain was defined as 24.8 km in the east–west and 23.8 km north-south direction at a spacing of 200 m x 200 m.

4.3 Particle sizing | gravitational settling

Since particulate matter is subject to gravitational settling, assumptions need to be made regarding particle sizes. Source specific particle size distribution information is required to define the relative PM_{10} and $PM_{2.5}$ component of total emitted PM and to simulate gravitational settling of particles present in emissions. Project specific particle size distribution information was not available for the emission sources.

A particle size distribution for modelling PM/dust dispersion was therefore estimated using composite data from the USEPA for dust emissions from "unpaved roads (USEPA, 2006)", "aggregate handling and storage piles (USEPA, 2006b)", and "industrial wind erosion (USEPA, 2006c)". These categories are considered the most appropriate for mining sources and are relevant to the Project sources. The resulting distributions are shown as percentages for each size range in Table 4-1.

Table 4-1: Particle size distribution (%).

Size range (µm)	Representative size	TSP	PM_{10}	$PM_{2.5}$
<2.5	1.3	6	15	100
2.5 – 5.0	3.5	14	36	-
5.0 – 10.0	7.5	19	48	-
10.0 – 15.0	12.5	14	-	-
15.0 – 30.0	22.5	29	-	-
30.0 – 50.0	37.5	18	-	-

5 Emissions to air estimation

This section outlines the emission estimation process for the Project. Emission estimates are sourced from this inventory for inclusion in the dispersion model. Emissions from all key sources associated with the Project have been identified according to accepted methods. The emphasis of the emission estimation and modelling is on the potential impact from the operating phase of the Project. Emission estimation of construction activities is excluded from the assessment due to their intermittent nature over the life of the Project.

The following sections outline the emission estimation process used to develop the hourly variable emission file for the project.

5.1 Emission Source Inventory

The key emission sources for the operating phase of the Project are associated with:

- drilling and blasting
- material handling from loading and unloading activities involving
  - loading trucks
  - unloading trucks
  - bulldozing
- processing
  - crushing
  - material transfer including conveyors and transfer stations
- wheel generated dust from roads and haul roads
- wind erosion from stockpiles and open areas.

The location of these sources, as modelled, are presented in Figure 5-1.

A summary of the estimated annual mining tonnages for the life of the mines within the Project are presented in Table 5-1. For this assessment the forecast mining Year 3 was chosen for emission estimation sand modelling as it represents one of the years with the highest mining tonnage.

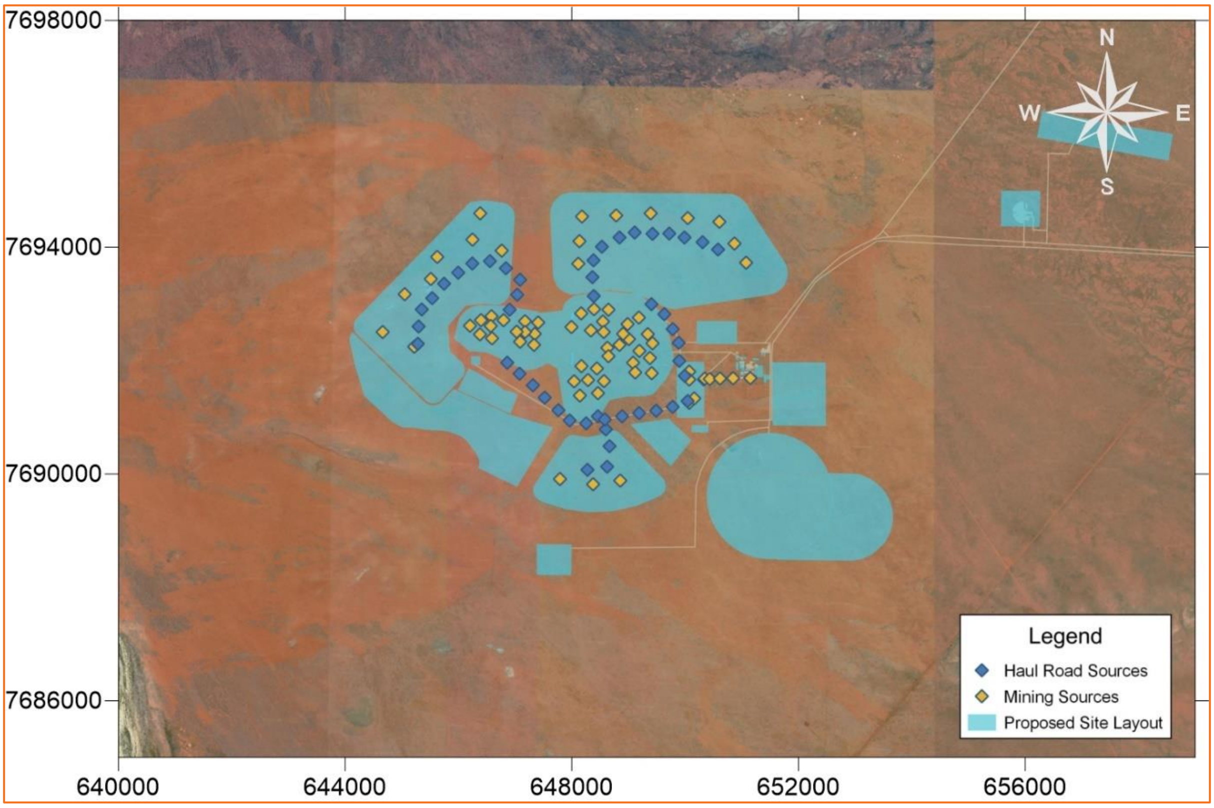

Figure 5-1: Location of volume sources for the proposed operations.

Table 5-1: Forecast mining tonnages (Mtpa)

Type	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Ore	0.30	10.12	11.81	10.09	10.91	12.74	10.73	9.97	10.94	11.36
Waste	20.05	60.59	80.32	82.03	79.85	79.11	83.14	76.33	68.50	39.67
TOTAL	20.36	70.71	92.12	92.12	90.76	91.85	93.87	86.30	79.44	51.03
Processed	0.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

5.2 Emission Estimation

5.2.1 Drilling

Emissions for drilling have been calculated using the default emissions contained within the EETM for Mining (EA, 2012a). The default values are:

- TSP: 0.59 kg/hole
- PM_{10}: 0.31 kg/hole
- $PM_{2.5}$: 30% of PM_{10} emissions

The statistics of the annual PM_{10} emissions from drilling are contained in Appendix F.

5.2.2 Blasting

Emissions for drilling have been calculated using Equation 19 outlined in Appendix A of the EETM for Mining. This is represented by Equation 1:

Equation 1: $$EF_{TSP\,(kg/blast)} = 0.00022 \times A^{1.5}$$

Where A = blast area (m^2)

The emission factor for PM_{10} is taken as 52% of the TSP emission and the $PM_{2.5}$ emissions are taken as 15% of the PM_{10} emissions. The statistics of the annual PM_{10} emissions for blasting are contained in Appendix F.

Within the model blasting was assumed to occur approximately once per week with blasting times at 11am.

5.2.3 Loading ore/waste

Emissions for loading ore and waste have been calculated using the default value for excavators and front end loaders on overburden of:

- TSP: 0.025 kg/t
- PM_{10}: 0.012 kg/t

The emission factor for $PM_{2.5}$ emissions is taken as 15% of the PM_{10} emissions. The statistics of the annual emissions for loading for PM_{10} are contained in Appendix F.

5.2.4 Unloading ore/waste

Emissions for unloading ore and waste have been calculated using the default values of:

- TSP: 0.012 kg/t
- PM_{10}: 0.0043 kg/t

The emission factor for $PM_{2.5}$ emissions is taken as 15% of the PM_{10} emissions. The statistics of the annual PM_{10} emissions for loading are contained in Appendix F.

5.2.5 Bulldozing

Emissions for the operation of bulldozers on both ore and waste have been determined using Equation 16 and Equation 17 outlined in Appendix A of the EETM for Mining (EA, 2012) and presented below as Equation 2 for TSP and Equation 3 for PM_{10}. The silt and moisture contents used were the defaults listed in the manual (2% moisture, 10% silt).

Equation 2: $$EF_{TSP\,(kg/hr)} = 2.6 \times \frac{s^{1.2}{}_{(\%)}}{M^{1.3}{}_{(\%)}}$$

Equation 3: $$EF_{PM_{10}\,(kg/hr)} = 0.34 \times \frac{s^{1.5}{}_{(\%)}}{M^{1.4}{}_{(\%)}}$$

Where: s = silt content (%)
M = moisture (%)

The emission factor for $PM_{2.5}$ emissions is taken as 15% of the PM_{10} emissions. The statistics of the annual PM_{10} emissions for bulldozing are contained in Appendix F.

5.2.6 Primary Crusher

The emissions for the primary crusher were determined using the default emission factors for high moisture content ores from Table 3 of the EETM for Mining (EA, 2012). These factors are:

- TSP: 0.01 kg/tonne
- PM_{10}: 0.004 kg/tonne

The emission factor for $PM_{2.5}$ emissions is taken as 15% of the PM_{10} emissions. The statistics of the annual emissions for loading for PM_{10} are contained in Appendix F.

5.2.7 Secondary crusher

The emissions for the secondary crusher were determined using the default emission factors for high moisture content ores from Table 3 of the EETM for Mining (EA, 2012). These factors are:

- TSP: 0.03 kg/tonne
- PM_{10}: 0.012 kg/tonne

The emission factor for $PM_{2.5}$ emissions is taken as 15% of the PM_{10} emissions. The statistics of the annual emissions for loading for PM_{10} are contained in Appendix F.

5.2.8 Stacking

The emissions for stacking were determined using the default emission factors for high moisture content ores from Table 3 of the EETM for Mining (EA, 2012). These factors are:

- TSP: 0.005 kg/tonne
- PM_{10}: 0.002 kg/tonne

The emission factor for $PM_{2.5}$ emissions is taken as 15% of the PM_{10} emissions. The statistics of the annual emissions for loading for PM_{10} are contained in Appendix F.

5.2.9 Haul Roads

To determine emissions from wheel generated dust along the haul roads the default equation for 'unpaved roads from wheels' was utilised (Equation 2). The weight of the haul trucks was taken as 273 tonnes – being the average of an empty and fully laden CAT793E haul truck and the default silt content of 10% was utilised.

Equation 4:

$$EF_{(kg/VKT)} = \frac{0.4536}{1.6093} \times k \times \left(\frac{s_{(\%)}}{12}\right)^{a} \times \left(\frac{W_{(t)}}{3}\right)^{b}$$

Where: k = constant (TSP = 4.9, PM_{10} = 1.5)
$s_{(\%)}$ = silt content (%)
$W_{(t)}$ = vehicle mass (t)
a = constant (TSP = 0.7, PM_{10} = 0.9)
b = constant (0.45)

The emission factor for $PM_{2.5}$ emissions is taken as 15% of the PM_{10} emissions. The statistics of the annual emissions for loading for PM_{10} are contained in Appendix F.

5.2.10 Wind erosion – Mines and open areas

The default emission factor for wind erosion in the EETM for Mining is a constant emission of 0.2 kg/ha/hr which, while potentially suitable for the calculation of annual emissions, is not suitable for inclusion in atmospheric modelling. This assessment used the modified Shao equation outlined in SKM (2005) which is represented as Equation 5:

Equation 5:

$$PM_{10(g/m^2/s)} = k \times \left\{WS^3 \times \left(1 - \left(WS_0{}^2/WS^2\right)\right)\right\} \qquad WS > WS_0$$

$$PM_{10(g/m^2/s)} = 0 \qquad WS < WS_0$$

Where: WS = wind speed (m/s)
WS_0 = threshold for particulate matter lift off (m/s)
k is a constant

For this assessment the wind speed threshold (WS_0) was set at 5.5 m/s and the k constant was set at 4.6 x 10^{-6}. This results in an overall emission rate of 0.4 kg/ha/hr for PM_{10} from open areas, which is higher than the emission rate of 0.2 kg/ha/hr specified in the EETM for Mining but, as outlined in SKM (2005) is applicable to the Pilbara region.

The emission factor for TSP is taken as twice that of the PM_{10} emissions while $PM_{2.5}$ emissions are taken as 15% of the PM_{10} emissions.

5.3 Emission controls

Emissions controls (for dust abatement) were included in the emissions estimation, and the default control factors outlined in Table 4 in the EETM for Mining (EA, 2012). These controls are summarised in Table 5-2, along with the percentage reduction applied to each source type.

Table 5-2: Project dust abatement in place (included in model).

	Equipment	Dust abatement description	Emission reduction
Mining	Drilling	In pit reduction	5% (PM_{10}) 50% (TSP)
	Blasting	In pit reduction	5% (PM_{10}) 50% (TSP)
	Loading ore and waste	In pit reduction	5% (PM_{10}) 50% (TSP)
	Unloading waste	None	0%
	Unloading ore at ROM pad	None	0%
	Bulldozing	None	0%
	Wind erosion (pits)	In pit reduction	5% (PM_{10}) 50% (TSP)
	Wind erosion (waste landforms, ROM pad, processing area)	Watering	50%
Haul road	Hauling	Level 1 watering	50%
Processing Facility	Unloading ore into primary crusher	Watering	50%
	Primary crushing of ore	Underground	90%

	Equipment	Dust abatement description	Emission reduction
	Secondary crusher	Enclosed with extraction	80%
	Screening	Enclosed with extraction	95%
	Stacking	Water	20%

5.4 Emission summary

A summary of the estimated annual emissions, for each particle size fraction, is shown in Table 5-3 for mining Year 3.

Table 5-3: Estimates of the emissions from Project for 2023 (kg/year).

Source	TSP	PM_{10}	$PM_{2.5}$
Drilling	84,139	83,996	12,599
Blasting	40,150	39,668	5,950
Load (pit)	1,151,665	1,050,319	157,548
Unload Waste	964,195	345,503	51,825
Unload Ore	119,914	42,969	6,445
Bulldozers	58,026	12,154	1,823
Loading Ore (ROM)	250,196	120,094	18,014
Unload into Crusher	60,047	21,517	3,228
Crushing (all)	40,031	16,013	2,402
Screening	40,031	36,028	5,404
Stacking	40,031	16,013	2,402
Haul Trucks	8,687,016	2,564,068	384,610
Wind erosion	418,724	223,377	33,507
TOTAL	11,954,165	4,571,719	685,757

6 Predicted air quality impact

This assessment has used the WRF/CALMET/CALPUFF modelling suite to estimate the air quality impacts associated with the Project. The results are presented for the Project with close to the maximum ore tonnage being mined and handled as an estimate of the likely worst-case operating conditions. The emissions are modelled for Mining Year 3.

To assess the potential air quality impact, modelled concentrations of particulates (as TSP, PM_{10}, $PM_{2.5}$ and deposition) are compared to the assessment criteria outlined in Table 3-3.

Note that the comparison of the modelling results to nominated ambient air quality assessment criteria has been done as an indicator for potential changes in conditions at the nominated receptor locations. It should be noted that the nominated receptors are locations of interest for the Project and are not all consistent with the DWER definition of a "sensitive receptor". The assessment criteria applicable to a sensitive receptor has been applied at all receptor locations as a conservative comparison approach.

6.1 Mining Year 3

6.1.1 Particulates as PM_{10}

As outlined in Table 3-3 the PM_{10} results are used to evaluate the potential impact on human health. The statistics of the predicted ground level concentrations of PM_{10}, at all nominated receptor locations are presented in Table 6-1 for both standalone (project only) and cumulatively (i.e. including background concentrations) for information purposes. The results at the nominated receptors for assessing impact (i.e. Mt Dove and Accommodation Camp) (see Section 3.4 for receptor description) indicate that:

- The predicted concentration at the Accommodation Camp receptor is above the PM_{10} assessment criterion for the mine operating in isolation on 18 occasions, and approximately 48 times when the background concentration is included.
- The predicted annual average concentration from the mine (i.e. without background) is below the assessment criterion at all receptors, but is above the criterion at the Accommodation Camp receptor when the background concentration is included for the predicted cumulative impact.

The predicted isopleths (contours) for ground level concentrations of particulates (as PM_{10}) are presented as follows:

- Annual average PM_{10} concentrations for the proposed facility in isolation (Figure 6-1) and cumulatively with background concentrations (Figure 6-2).
    - Dispersion pattern reflects the prevailing south-easterly and north-westerly winds.
- Maximum predicted 24-hour PM_{10} concentrations for the proposed facility in isolation (Figure 6-3) and cumulatively with background concentrations (Figure 6-4).

The red lines in these figures represent the criteria (Section 3.5.1) for each of the averaging periods.

Table 6-1: Predicted PM_{10} concentrations at receptor locations (µg/m³).

Receptor	Receptor Type	Standalone						Cumulative					
		Maximum	6th Highest	10th Highest	90th Percentile	70th Percentile	Average	Maximum	6th Highest	10th Highest	90th Percentile	70th Percentile	Average
Mardagubbidina Pool	Amenity | Nuisance	62	44	33	7	1	3	80	62	51	25	19	21
Mt Dove, Portree	Amenity | Nuisance	62	45	39	15	1	5	80	63	57	33	19	23
Mt Dove, Upper Yule	Amenity | Nuisance	66	48	41	16	1	5	84	66	59	34	19	23
Mt Dove Camp	Human health | amenity | nuisance	126	87	69	38	9	11	144	105	87	56	27	29
Jelliabidina Pool	Amenity | Nuisance	50	40	30	8	1	3	68	58	48	26	19	21
Accommodation Village	Human health | amenity | nuisance	90	73	59	38	19	14	108	91	77	56	37	32

Note:

Assessment criteria: 46 µg/m³ 24-hour average and 23 µg/m³ annual average (based on DWER (2019), at 25 degrees Celsius), consistent with NEPM (NEPC (2021)). Results above the assessment criteria are highlighted for information purposes.

Shading depicts predicted results above the relevant criteria.

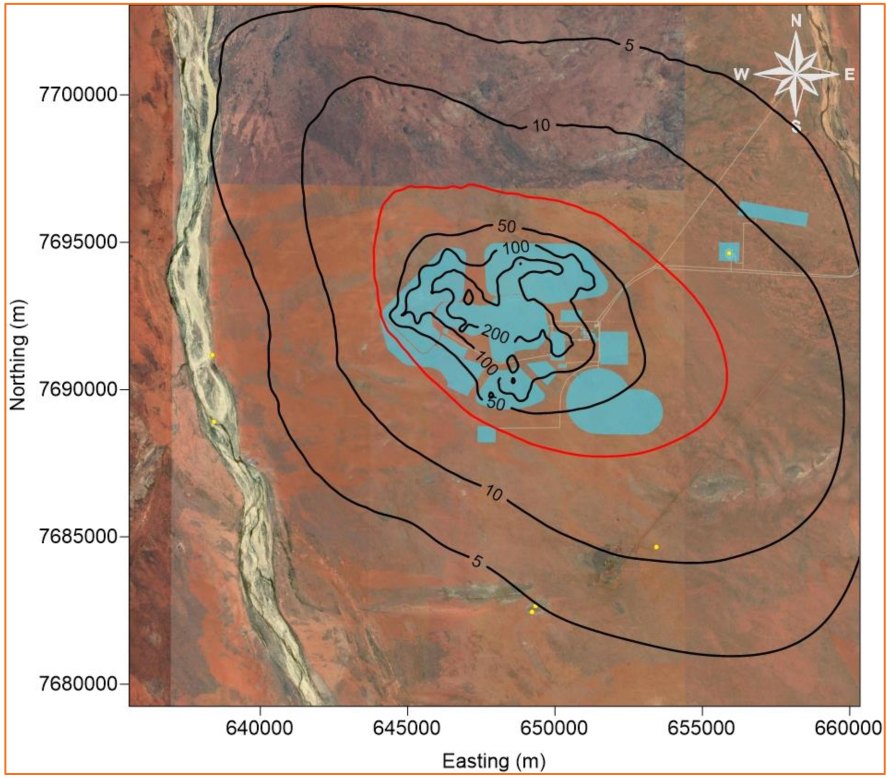

Figure 6-1: 2023: Annual average PM_{10} concentration – Project only (excluding background).

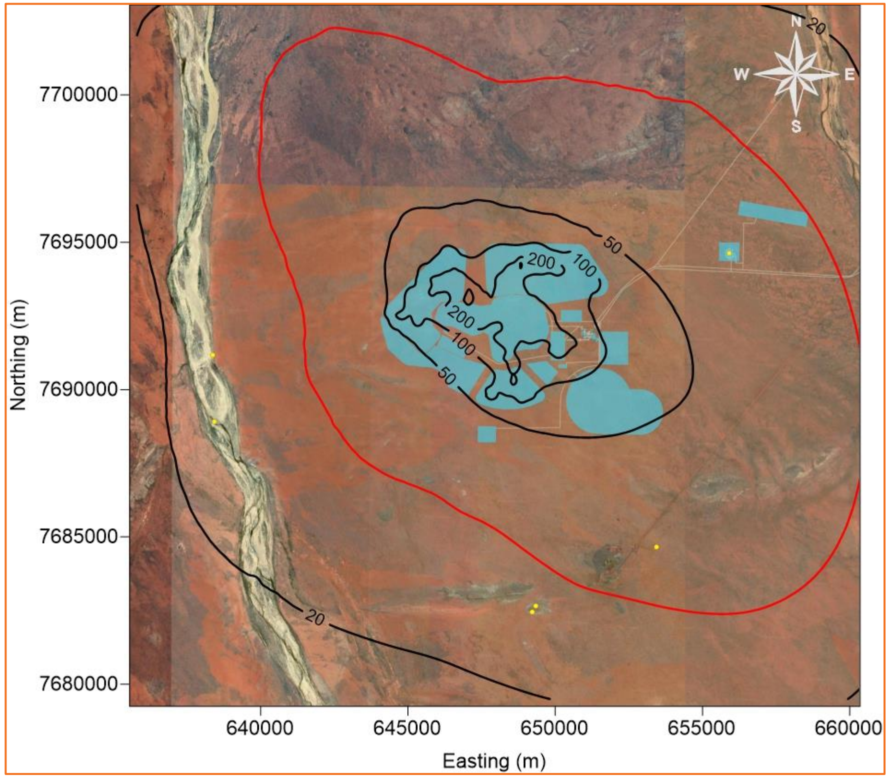

Figure 6-2: 2023: Annual average PM_{10} concentration – Cumulative (including background).

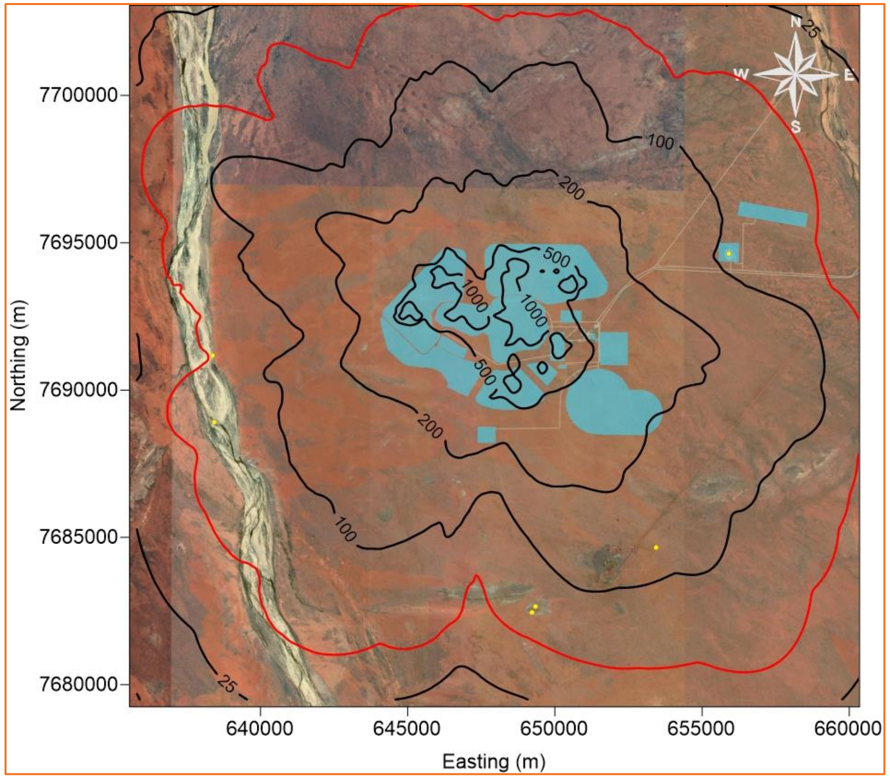

Figure 6-3: 2023: Maximum 24-hour PM_{10} concentration – Project only (excluding background).

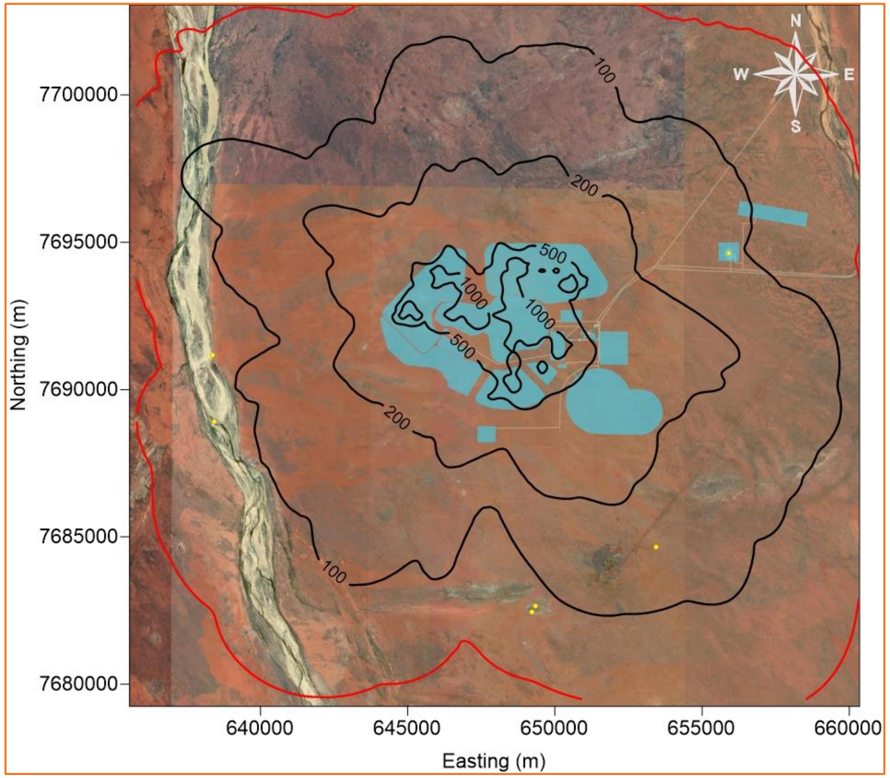

Figure 6-4: 2023: Maximum 24-hour PM_{10} concentration – Cumulative (including background).

6.1.2 Particulates as $PM_{2.5}$

As outlined in Table 3-3 the $PM_{2.5}$ results are used to evaluate the potential impact on human health. The statistics of the predicted ground level concentrations of $PM_{2.5}$, at all nominated receptors, are presented in Table 6-2 for both standalone impacts (Project only) and cumulatively (including background concentrations, for information purposes). The results at the nominated receptors for assessing impact (i.e. Mt Dove and Accommodation Camp) indicate that:

- The predicted concentration at the Mt Dove and accommodation Camp receptors is above the 24-hour average assessment criterion for $PM_{2.5}$ both with and without the inclusion of background concentration.

The predicted isopleths (contours) for ground level concentrations of particulates (as $PM_{2.5}$) are presented as follows:

- Annual average $PM_{2.5}$ concentrations for the proposed facility in isolation (Figure 6-5) and cumulatively with background concentrations (Figure 6-6).
    - Results above the annual average criterion area largely limited to the mine area.
- Maximum predicted 24-hour PM_{10} concentrations for the mine in isolation (Figure 6-7) and cumulatively with background concentrations (Figure 6-8).

Table 6-2: Predicted $PM_{2.5}$ concentrations at receptors (µg/m³).

Receptor	Receptor Type	Standalone						Cumulative					
		Maximum	6th Highest	10th Highest	90th Percentile	70th Percentile	Average	Maximum	6th Highest	10th Highest	90th Percentile	70th Percentile	Average
Mardagubbidina Pool	Amenity | Nuisance	19	13	10	2	0	1	21	16	13	5	3	4
Mt Dove, Portree	Amenity | Nuisance	19	13	12	5	0	1	21	16	14	7	3	4
Mt Dove, Upper Yule	Amenity | Nuisance	20	14	12	5	0	1	23	17	15	8	3	4
Mt Dove Camp	Human health | amenity | nuisance	38	26	21	12	3	3	40	29	23	14	5	6
Jelliabidina Pool	Amenity | Nuisance	15	12	9	2	0	1	18	15	12	5	3	4
Accommodation Village	Human health | amenity | nuisance	27	22	18	11	6	4	30	25	20	14	8	7

Note:

Assessment criteria: 23 µg/m³ 24-hour average and 7 µg/m³ annual average (based on DWER (2019), at 25 degrees Celsius), consistent with NEPM (NEPC (2021)).

Shading indicates predicted result higher than the assessment criteria.

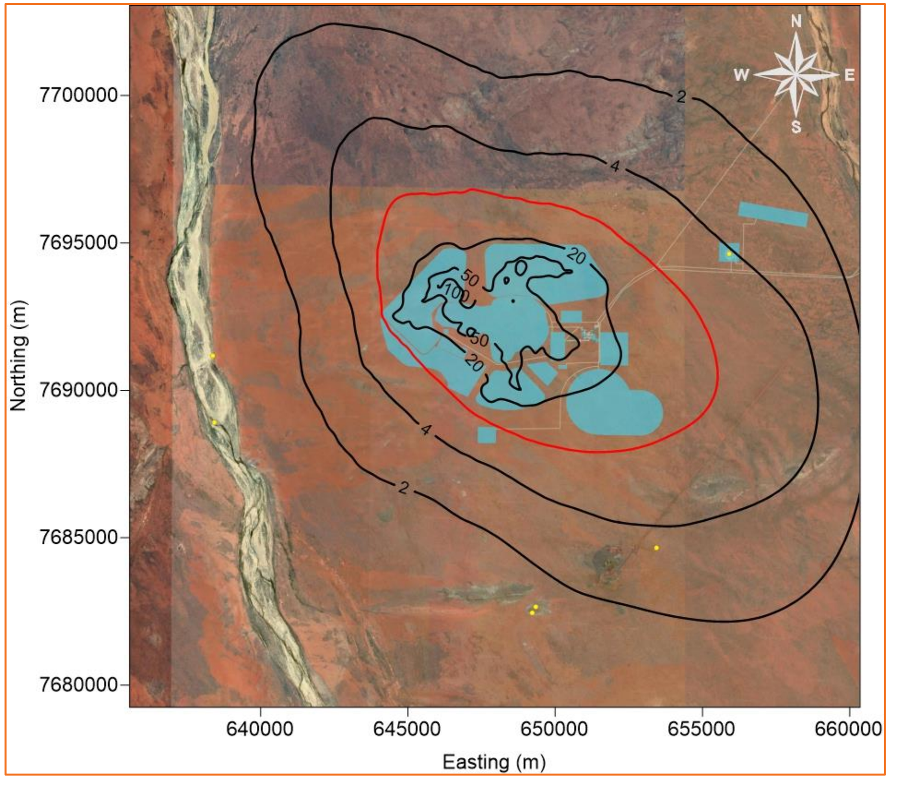

Figure 6-5: 2023: Annual average $PM_{2.5}$ concentration – Project only (excluding background).

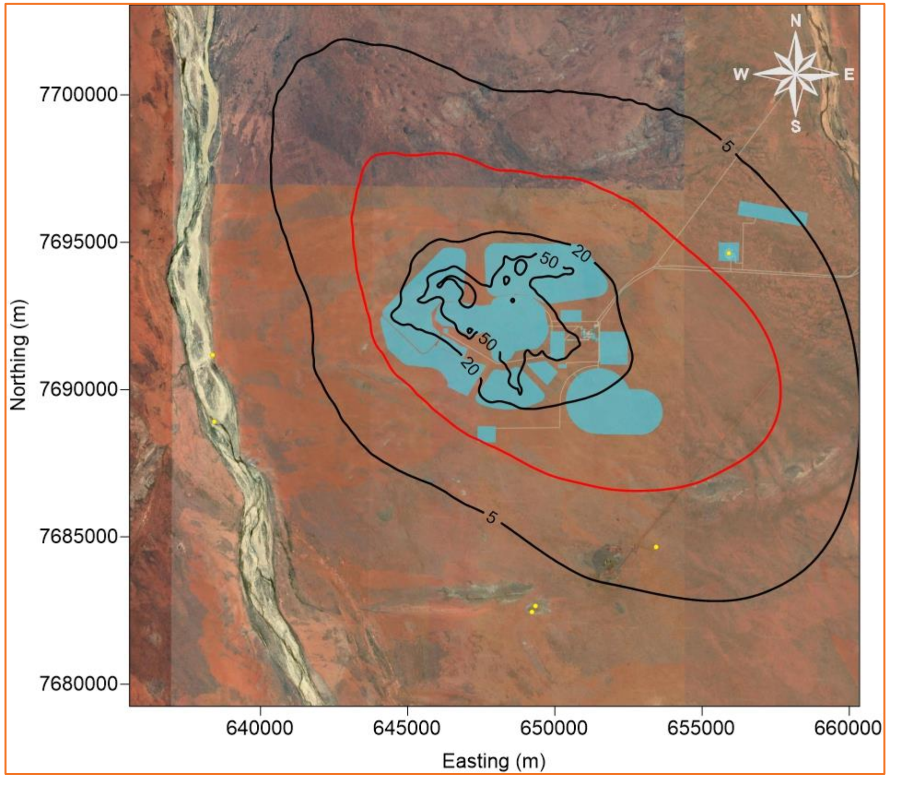

Figure 6-6: 2023: Annual average $PM_{2.5}$ concentration – Cumulative (including background).

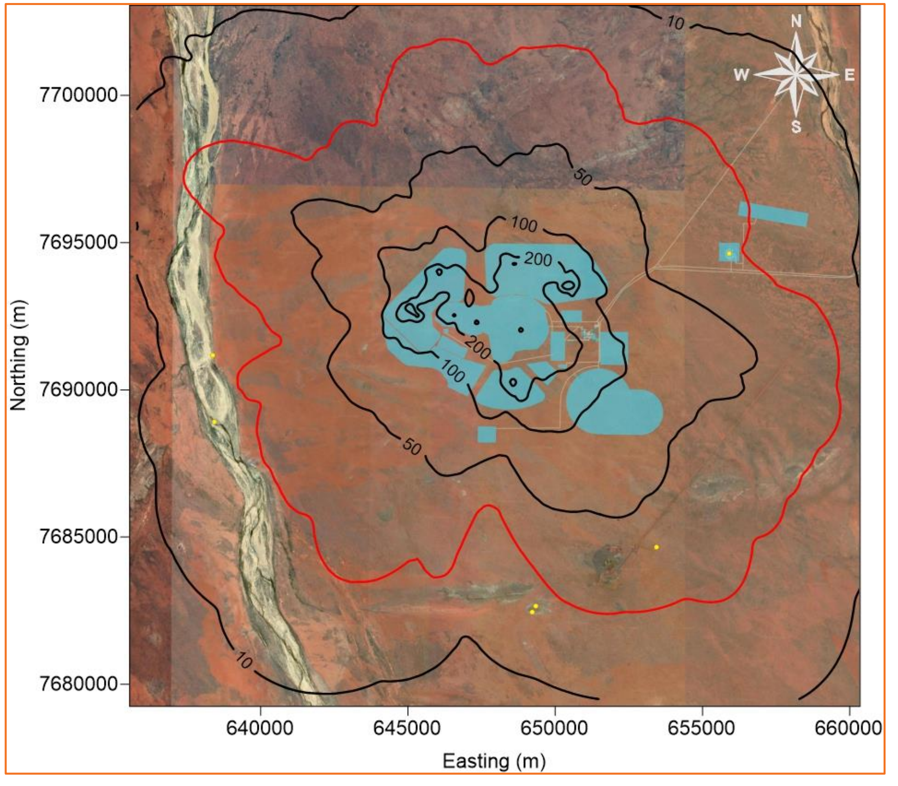

Figure 6-7: 2023: Maximum 24-hour $PM_{2.5}$ concentration – Project only (excluding background).

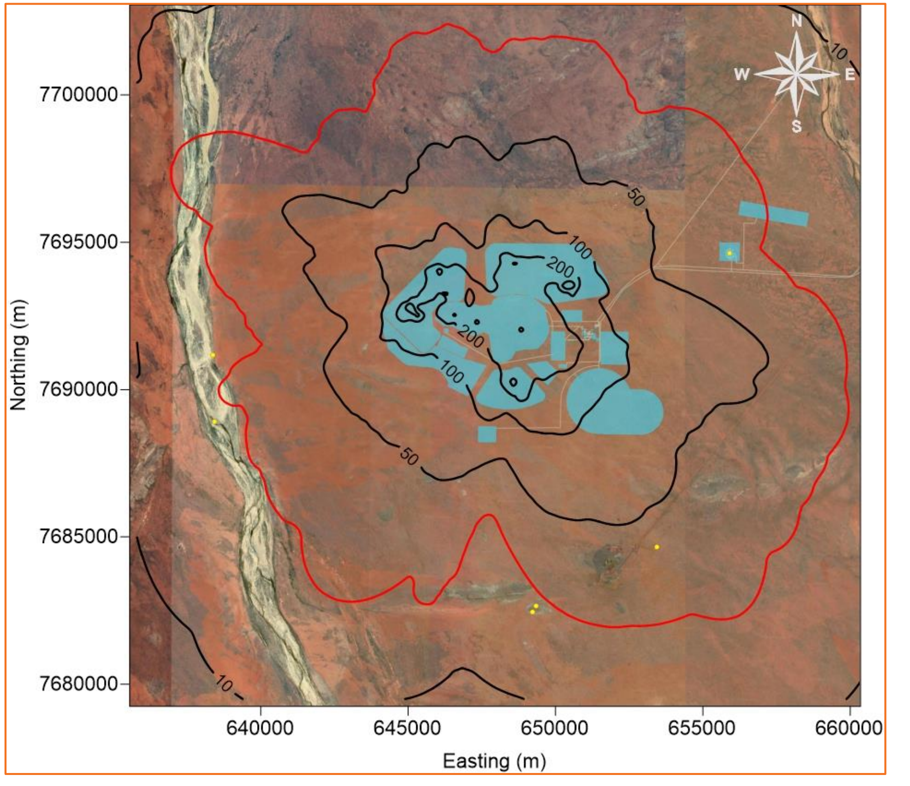

Figure 6-8: 2023: Maximum 24-hour $PM_{2.5}$ concentration – Cumulative (including background).

6.1.3 Total Suspended Particulates

As outlined in Table 3-3 the TSP results are used to evaluate the potential impact on human health and amenity. The statistics of the predicted ground level concentrations of TSP at all the nominated receptors are presented in Table 6-3 as standalone impacts (Project only) and cumulatively (including background concentrations). The results at these selected receptors indicate that:

- The highest predicted 24-hour TSP concentration of approximately 330 µg/m^3 (363 µg/m^3 including background) occurs at the Mt Dove Camp receptor.
- The Accommodation Village receptor has a predicted maximum 24-hour TSP concentration of 251 µg/m^3 (as standalone).
- There are predicted to be 48 (91 including background) exceedances of the assessment criterion for human health and amenity impact at the Accommodation Village (Section 3.5.1).

The maximum predicted 24-hour ground level concentrations of TSP concentrations for the proposed facility are presented Figure 6-9 (standalone) and cumulatively with background concentrations in Figure 6-10.

Table 6-3: Predicted TSP concentrations at receptors (µg/m³).

Receptor	Receptor Type	Standalone						Cumulative					
		Maximum	6th Highest	10th Highest	90th Percentile	70th Percentile	Average	Maximum	6th Highest	10th Highest	90th Percentile	70th Percentile	Average
Mardagubbidina Pool	Amenity | Nuisance	156	121	90	17	2	8	189	154	123	50	35	41
Mt Dove, Portree	Amenity | Nuisance	166	118	102	40	3	12	199	151	135	73	36	45
Mt Dove, Upper Yule	Amenity | Nuisance	177	125	107	43	4	13	210	158	140	76	37	46
Mt Dove Camp	Human health | amenity | nuisance	330	222	182	97	23	29	363	255	215	130	56	62
Jelliabidina Pool	Amenity | Nuisance	140	105	80	21	3	8	173	138	113	54	36	41
Accommodation Village	Human health | amenity | nuisance	251	205	162	103	50	38	284	238	195	136	83	71

Note:

Assessment criteria: 82 µg/m³ 24-hour average (based on DWER (2019), at 25 degrees Celsius). Shading indicates predicted result higher than the assessment criteria.

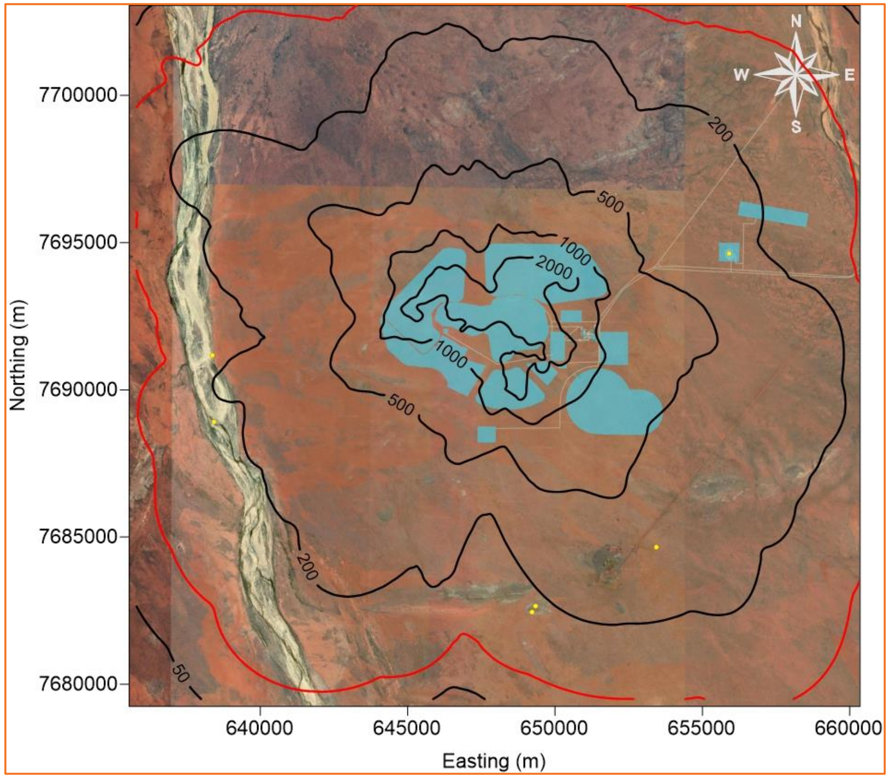

Figure 6-9: 2023: Maximum 24-hour TSP concentration – Project only (excluding background).

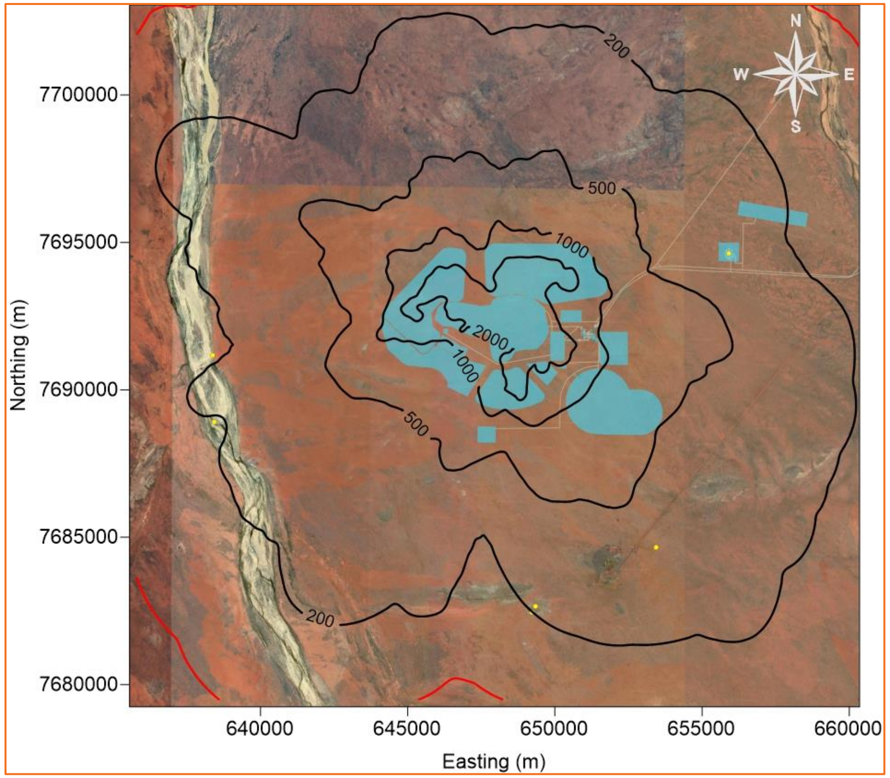

Figure 6-10: 2023: Maximum 24-hour TSP concentration – Cumulative (including background).

6.1.4 Dust deposition

The predicted monthly dust deposition (based on annual average predicted flux rates) is presented in Figure 6-11. The contour plot shows that monthly deposition is largely limited to the proposed mine footprint.

The modelling predicts that the deposition rates will be below the criteria (4 g/m^2/month) at all the receptor locations (Table 6-4).

Table 6-4: Predicted dust deposition at receptors (g/m^2/month).

Receptor	Receptor Type	Maximum
Mardagubbidina Pool	Amenity | Nuisance	0.1
Mt Dove, Portree	Amenity | Nuisance	0.1
Mt Dove, Upper Yule	Amenity | Nuisance	0.1
Mt Dove Camp	Human health | amenity | nuisance	0.1
Jelliabidina Pool	Amenity | Nuisance	0.1
Accommodation Village	Human health | amenity | nuisance	0.2

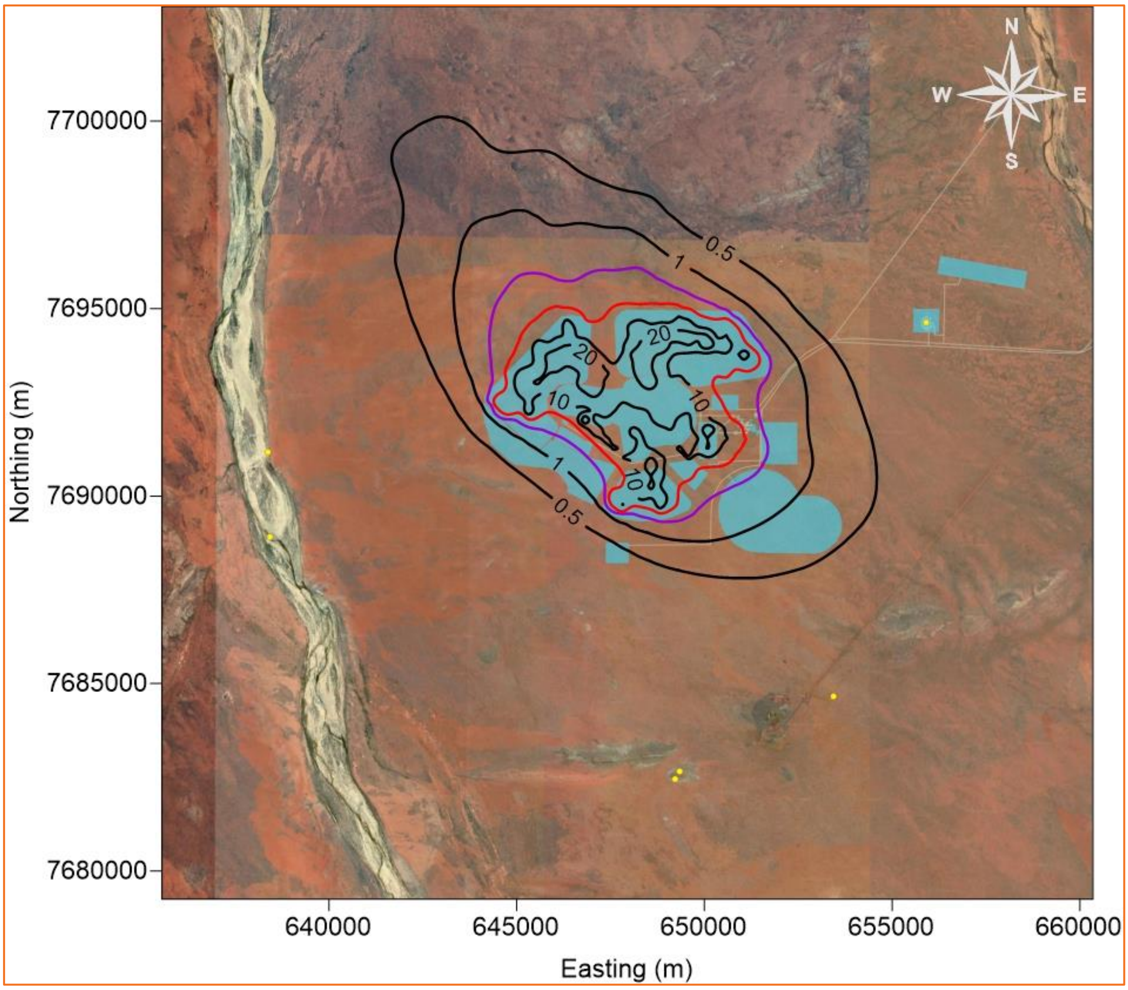

Figure 6-11: 2023: Total monthly dust deposition – Project only.

7 Conclusions

The proposed Hemi Gold Project, located approximately 85 km south of Port Hedland, is owned by De Grey Mining Limited. The Project area is predominately located on the Indee Station Pastoral Lease with the northern miscellaneous licences partially covering the Mundabullandgana Station Pastoral Lease. The Project is located within the Native Title Determination (NTD) area of the Kariyarra people.

The objectives for this assessment were to undertake an air quality assessment to determine the potential air quality impacts of the Project on nearby receptors.

This modelling assessment determined the potential air quality impacts of particulates (as TSP, PM_{10}, $PM_{2.5}$ and deposition) using the CALMET/CALPUFF modelling suite for determining predicted ground level concentrations from a worst case Project scenario, as well as cumulatively with background air quality. Meteorological fields in the region of the mine were created, in the absence of weather station data, from 3-dimensional data generated by the WRF prognostic meteorological model. Fine resolution terrain elevation (SRTM) data with 90 m resolution was used in conjunction with CGLOPS-1 land-use data to characterise the geophysical environment.

Emissions were estimated using methodologies outlined in the NPI EET for Mining manual and input into the CALPUFF dispersion model as volume sources to simulate mining and haulage emissions, and area sources to simulate wind-blown dust emissions.

Modelled ground level concentrations for the key pollutants as particulates (as TSP, PM_{10}, $PM_{2.5}$ and dust deposition) have been compared to ambient air quality assessment criteria, derived from DWER's draft Air Emissions Guideline (DWER, 2019), and draft Dust Emissions Guideline (DWER, 2021) to determine the potential impacts. Receptor types considered in the assessment include the project related accommodation camp, and environmental receptors with important ecological value and heritage value. In the absence of criteria specific to these ecological and heritage receptors, the criteria for human health, amenity and nuisance have been presented as a proxy. Therefore, it is important to consider that modelled predictions that are higher than the assessment criteria should not be interpreted as a predicted impact or loss of environmental value but is an indication that results may need further consideration for the receptor at the specified location.

7.1 Modelling results – comparison to air quality assessment criteria

At the Accommodation Village and Mt Dove Camp, assessed for potential impact on human health and amenity, and nuisance:

- The model results indicate that at the Accommodation Village the PM_{10} is above the 24-hour assessment criterion on 18 occasions in isolation and potentially up to 48 times with the background concentration included.
- The predicted annual average concentration (in isolation) is below the assessment criterion at the Accommodation Camp but is above the criterion when background concentration is included.
- The predicted concentration at the Accommodation Village and Mt Dove Camp receptors is above the 24-hour average assessment criterion for $PM_{2.5}$ both with and without the inclusion of background concentration.
- The modelling indicates that all sensitive receptors will be well below the deposition criteria

As outlined in Section 3.5 that modelled result above the numerical value is not an indicator of unacceptable impact, but is an indication that the potential risk for impact requires further consideration. For the accommodation village this may necessitate the installation of an ambient monitor for the first 2 – 3 years of mining to verify the actual PM_{10} concentrations at this receptor.

The Pools and Mt Dove locations (Portree and Upper Yule) were assessed for potential impact using the amenity and nuisance assessment criteria (i.e. TSP and dust deposition) as a proxy in the absence of specific impact criteria for protecting ecological and heritage values:

- TSP is predicted to be higher than the proxy assessment criterion at the receptor.
- Dust deposition rate is predicted to be below the proxy assessment criterion.
- As noted in Section 3.5.1, there is no established criteria at which the rockpools may experience a noticeable or negative impact from particles settling or dust deposition, and that the results should not be interpreted as a predicted impact or loss of environmental value but is an indication that results may need further consideration for the receptor location, such as monitoring for potential impact or change.

8 References

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9 Acronyms and Glossary

Acronym	Description
AFWA	Air Force Weather Agency
BoM	Bureau of Meteorology
BWh	Koppen-Geiger classification - hot desert climate, with no distinct rainy season
C	Degrees Celsius (temperature)
COS	Coarse ore stockpile
CV	Conveyor
DSD	Department of State Development
DWER	Department of Water and Environmental Regulation
EA	Environment Australia
EE	Emissions estimation
EET	Emissions Estimation Technique
EET	Emissions Estimation Technique Manual
EF	Emission factor
EPAV	Environmental Protection Authority Victoria, Australia
EPP	Environmental Protection Policy
ESACCI	European Space Agency Climate Change Initiative
ETA	Environmental Technologies& Analytics Pty Ltd
FAA	Federal Aviation Administration
FEL	Front end loader
FSL	Forecast Systems Laboratory
FY	Financial Year
GDA94	Geocentric Datum of Australia 1994
GLC	Ground Level Concentration
g/m^2/month	Grams per square metre per month
g/s	Grams per second
h/yr	Hours per year
kg	Kilogram

Acronym	Description
kg/t	Kilogram per tonne
kg/yr	Kilograms per year
kPa	KiloPascals
km	Kilometre
LSM	Land Surface Model
m	Metre
m^2	Metres squared
m/s	Metres per second
mm	Millimetre
MOST	Monin-Obukhov Similarity Theory
Mt	Million tonnes
Mtpa	Million tonnes per annum
NCAR	National Center for Environmental Prediction
NEPC	National Environment Protection Council
NEPM	National Environmental Protection Measure
NOAA	National Oceanic and Atmospheric Administration
NPI	National Pollutant Inventory
NSW	New South Wales, Australia
PBL	Planetary Boundary Layer
PEM	The Victorian Protocol for Environmental Management
PM	Particulate matter, small particles and liquid droplets that can remain suspended in air.
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of 10 µm or less.
PM_{10}	Particulate matter with an aerodynamic diameter of 2.5 µm or less.
Qld	Queensland, Australia

Acronym	Description
ROM	Run of mine
SEA	Strategic Environmental Assessment
SRTM	Shuttle Radar Topography Mission
t	Tonnes
t/h	Tonnes per hour
tpa	Tonnes per annum
TSP	Total suspended particulates
µg/m^3	Micro grams (one millionth of a gram) per cubic metre

Acronym	Description
µm	Micrometre
USEPA	United States Environment Protection Agency
USGS	United State Geological Services
WA	Western Australia, Australia
WHO	World Health Organisation
WRF	Weather Research Forecast Model

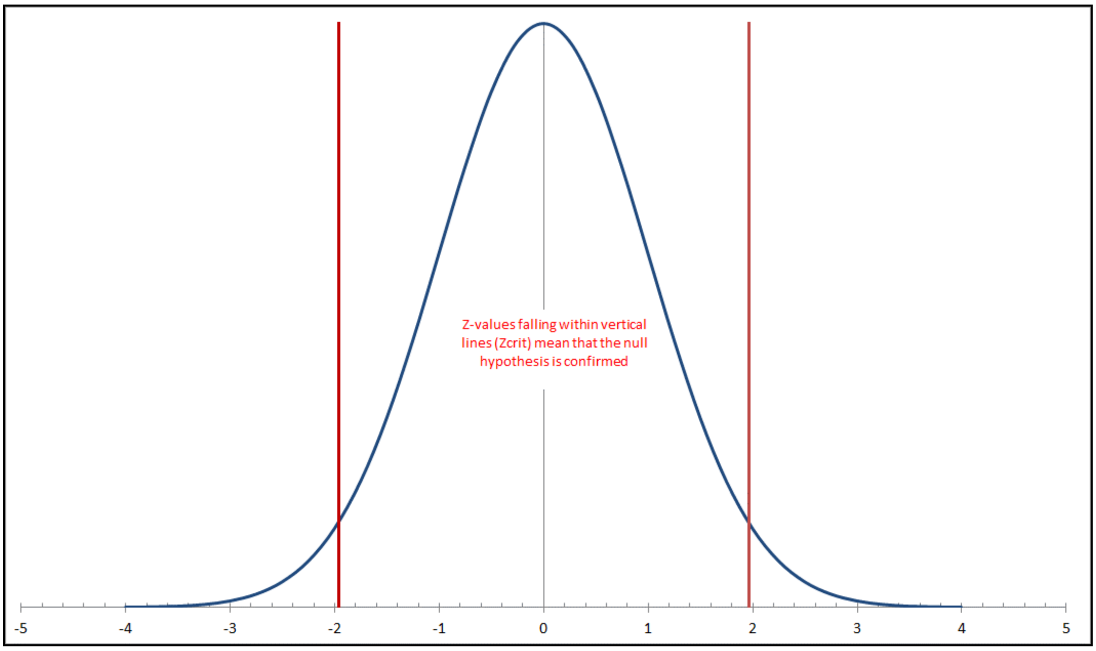
10 Appendices

Appendix A – Selection of Representative Meteorological Year for Modelling

Generally, a minimum of one year of meteorological data is acceptable for dispersion modelling in Australia and New Zealand. 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 hourly [2] surface observations from the nearest BoM station at Marble Bar (2011 to 2020 inclusive) were reviewed. The Mann-Whitney U and Pearson's Chi^2 tests were used to statistically identify the representative modelling year based on recorded scalar meteorological parameters including wind speed, wind direction, temperature, and rainfall.

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). 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. The graph below shows that if values fall within the vertical lines (at 5% confidence interval, two tailed), then accept the null hypothesis. Note that only scalars were assessed (i.e. temperature and wind speed). Wind direction was assessed through radar plots.

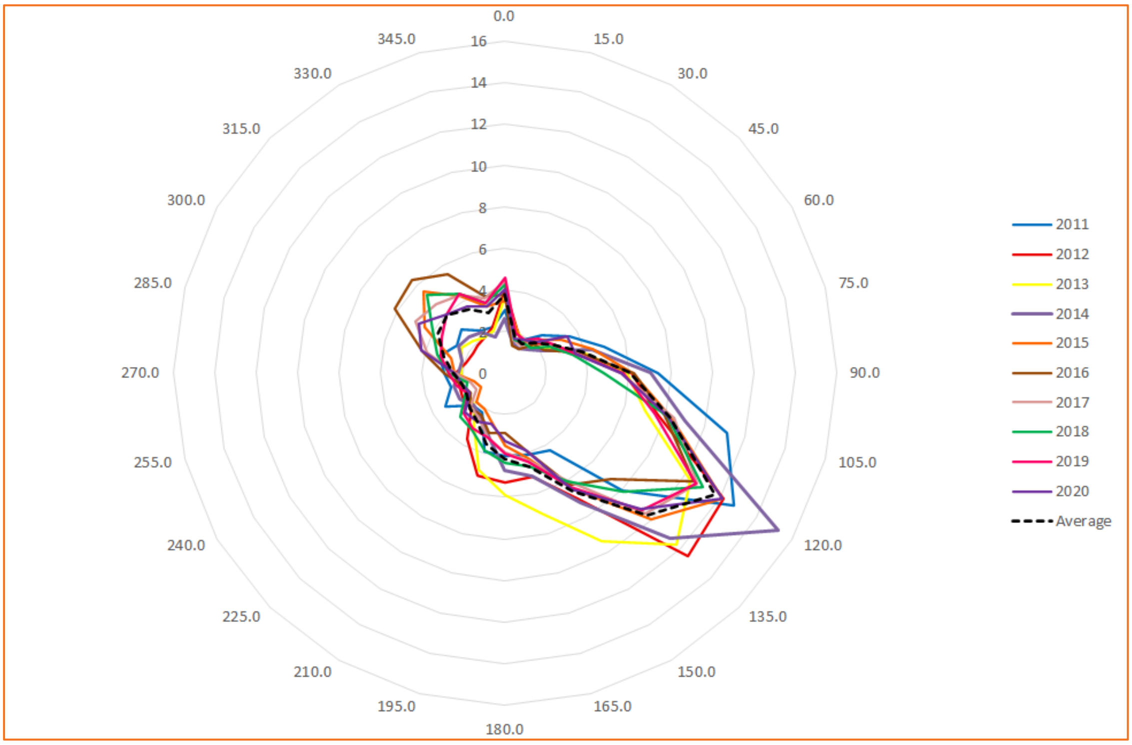


Appendix Figure 1: Null Hypothesis for Mann-Whitney U test.

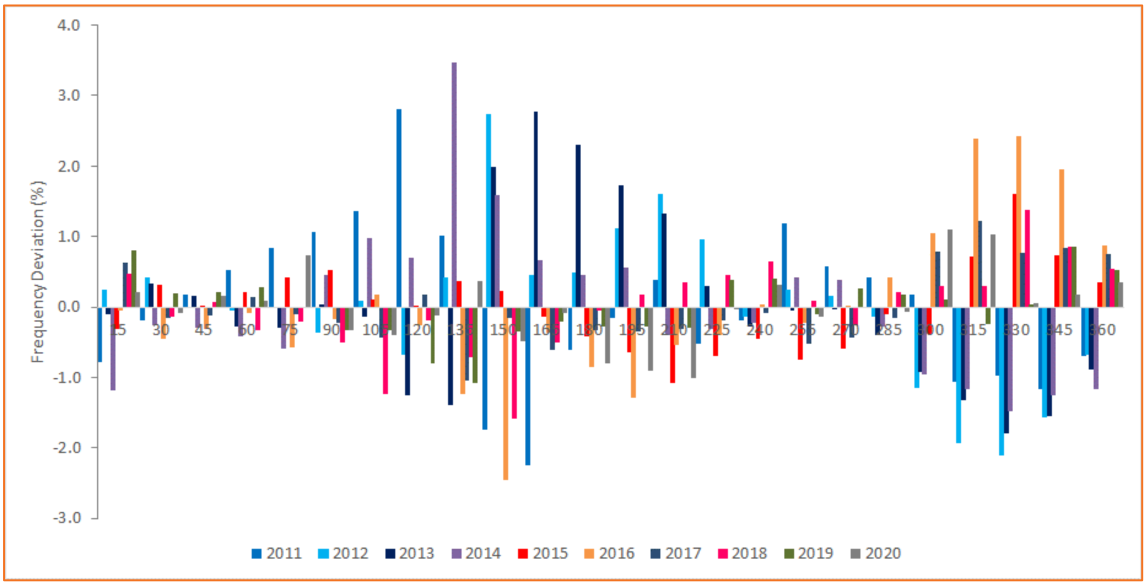
[2] Calculated from 1-minute data

Wind Direction

The average wind direction radar plots for 2011 to 2020 at BoM Marble Bar are compared in Appendix Figure 2. Generally, the wind direction pattern is consistent across all years. There are minor differences apparent, especially during (2012) 2016, where there is a slight (decrease) increase in northwesterly winds compared to average conditions and in 2012 and 2014 with an increase (2-3%) in southeasterly winds compared to average (Appendix Figure 3).



Appendix Figure 2: Wind direction radar plot for BoM Marble Bar Airport (2011-2020).



Appendix Figure 3: Wind direction radar plot (upper) and frequency deviation from the 10-year mean (lower) for BoM Marble Bar Airport (2011-2020).

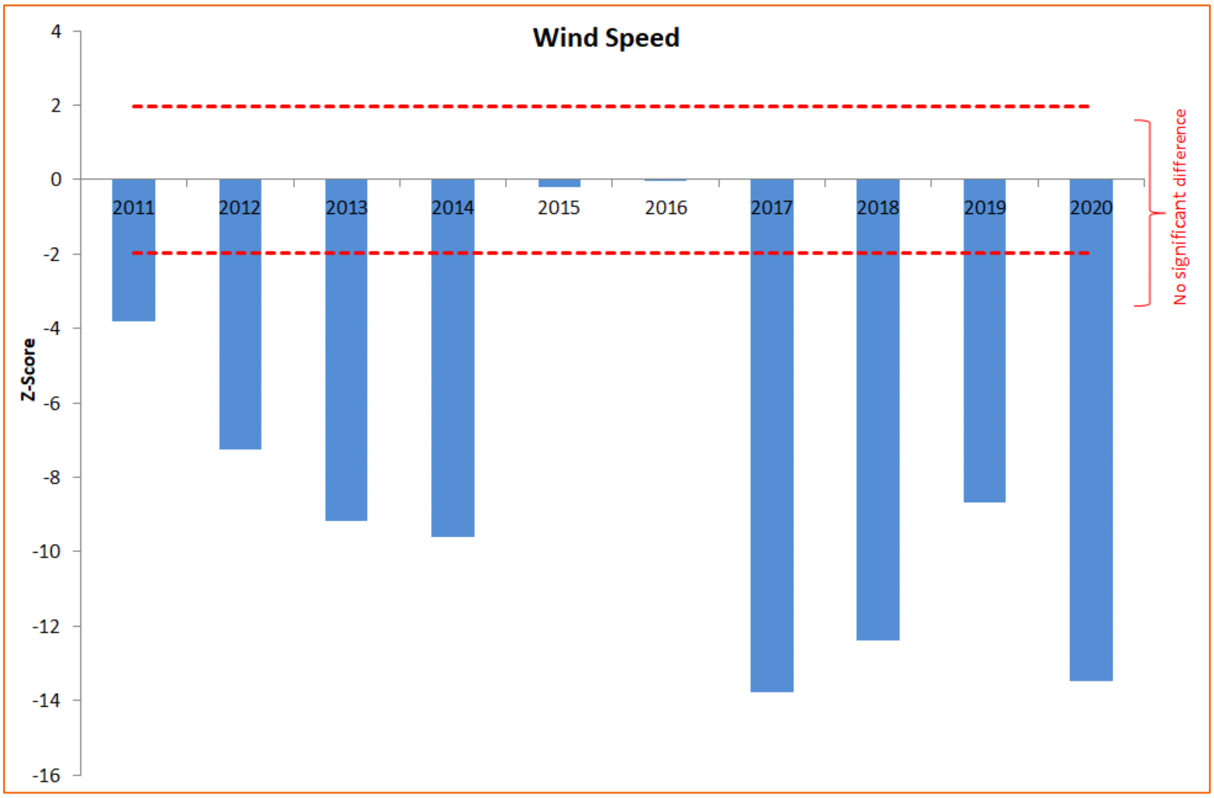
Wind Speed

The basic statistics for average wind speed for the 10-year period and individual years are shown in Appendix Table 1. Overall, there is minimal difference between the chosen years though the average and standard deviations during 2012, 2015, 2018 and 2019 are closest to long term averages. The frequency of stronger (>8 m/s) and lighter (<1 m/s) winds during those years are close to long term average values.

Appendix Table 1: Annual wind speed statistics for BoM Marble Bar Airport (2011-2020).

Year	Mean	Standard Deviation	% >6 m/s	% <1 m/s
10-yr average	2.9	1.9	17.4	6.7
2011	3.2	2.0	15.5	9.5
2012	2.9	1.9	17.5	6.9
2013	2.9	2.1	17.4	7.6
2014	2.8	1.8	18.1	5.7
2015	3.0	1.8	16.3	6.4
2016	3.0	1.8	15.3	6.6
2017	2.7	1.9	19.4	5.5
2018	2.8	1.9	19.7	7.2
2019	2.8	1.9	18.0	6.4
2020	2.7	1.8	18.5	5.2

The Mann-Whitney U test results for wind speed are presented in Appendix Figure 4. This figure indicates that 2015 and 2016 were representative of 10-year average conditions at the 5% confidence interval. Wind speed data for 2013, 2014, 2017, 2018, 2019 and 2020 show significant difference from the 10-year average conditions according to the two-tailed Mann-Whitney test.



Appendix Figure 4: Mann-Whitney U test result for wind speed at BoM Marble Bar Airport (2011-2020).

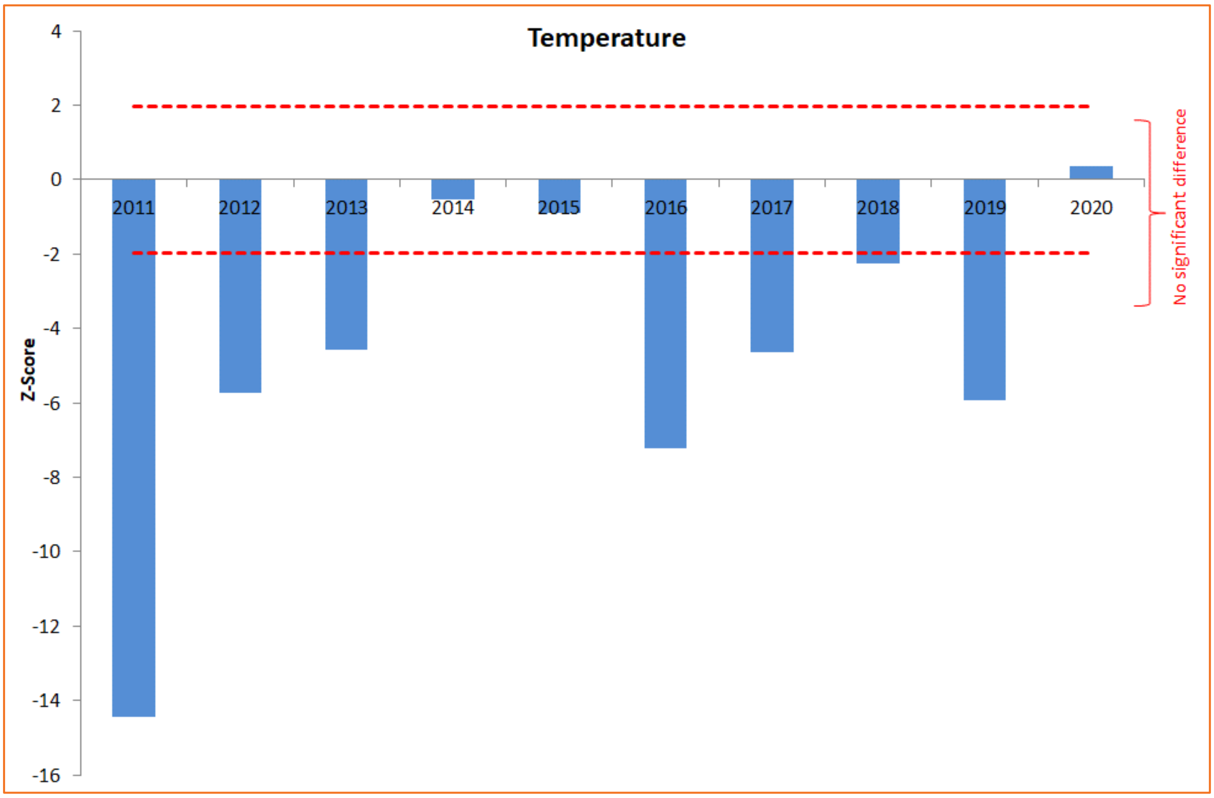
Temperature

The basic statistics for average temperature for the 10-year period and individual years are shown in Appendix Table 2. Except for 2011 and 2016 the average temperature for the years 2011 to 2020 are within 1°C of the 10-year average. These 2 years also had a lowest and highest percentage of temperatures above 35°C.

Appendix Table 2: Annual temperature statistics for BoM Marble Bar Airport (2011-2020).

Year	Mean	Standard Deviation	% >35°C	% <10°C
10-yr average	28.0	7.0	18.7	0.4
2011	26.3	7.2	11.7	0.4
2012	27.1	7.2	15.0	0.6
2013	27.4	7.4	17.7	0.2
2014	27.9	7.9	20.5	0.9
2015	28.1	7.9	21.1	0.2
2016	29.0	7.3	22.4	0.1
2017	27.4	7.2	15.2	0.5
2018	27.7	7.7	19.4	0.7
2019	28.6	8.1	23.2	0.3
2020	28.0	7.3	19.6	0.2

The Mann-Whitney U test results for temperature is presented in Appendix Figure 5. From this figure it is apparent that the hourly temperature values during 2014, 2015, 2018 and 2020 were not significantly different to the hourly long term average values.

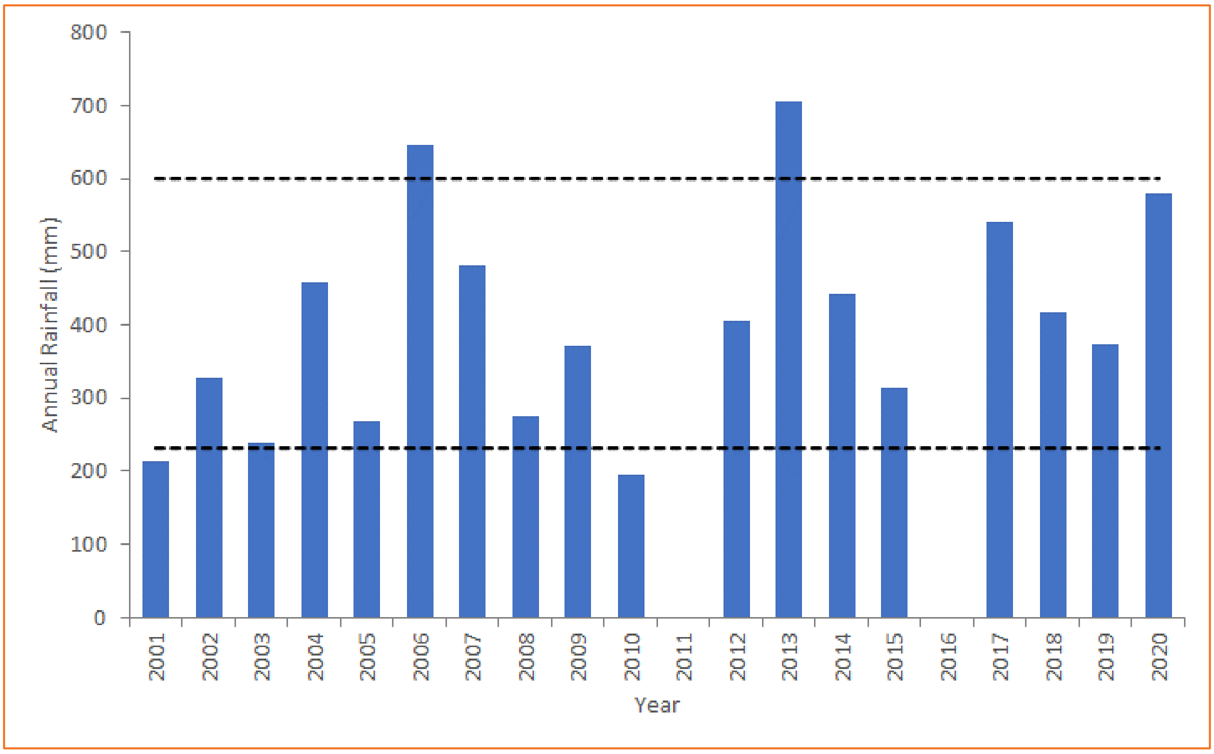


Appendix Figure 5: Mann-Whitney U test result for temperature at BoM Marble Bar Airport (2011-2020).

Rainfall

The annual rainfall at BoM Marble Bar Airport for the period 2001-2020 is displayed in Appendix Figure 6, noting that there is no available data for 2011. There is a significant variation in rainfall between each year which is to be expected for the region. The years 2001, 2006, 2010 and 2013 have total rainfalls that fall outside the 10th and 90th percentile[3] long-term (20 year) rainfall totals.

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



Appendix Figure 6: Annual rainfall at BoM Marble Bar Airport (2001 and 2020)[4].

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:

- Wind direction displayed little interannual variability but 2012, 2014 and 2016 displayed wind directions that varied from the other years.
- For wind speed, 2015 and 2016 were not statistically different to longer term conditions.
- For temperature, 2014, 2015 and 2020 were not significantly different to longer term average values.
- Rainfall, although highly variable, showed that with the exception of 2013 all years between 2012 and 2020 fell within the 10^{th} and 90^{th} percentile of 24-year rainfall totals.

This analysis shows that 2015 can be considered largely representative of longer-term average conditions. The meteorological variables affecting dispersion, namely wind speed, temperature and direction compare favourably to the long-term average conditions.

[4] Dotted lines indicate the 20 year 10^{th} percentile (lower line) and 90^{th} percentile (upper line) rainfall values.

Appendix B – Weather Research and Forecast (WRF) 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 (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, 2012).

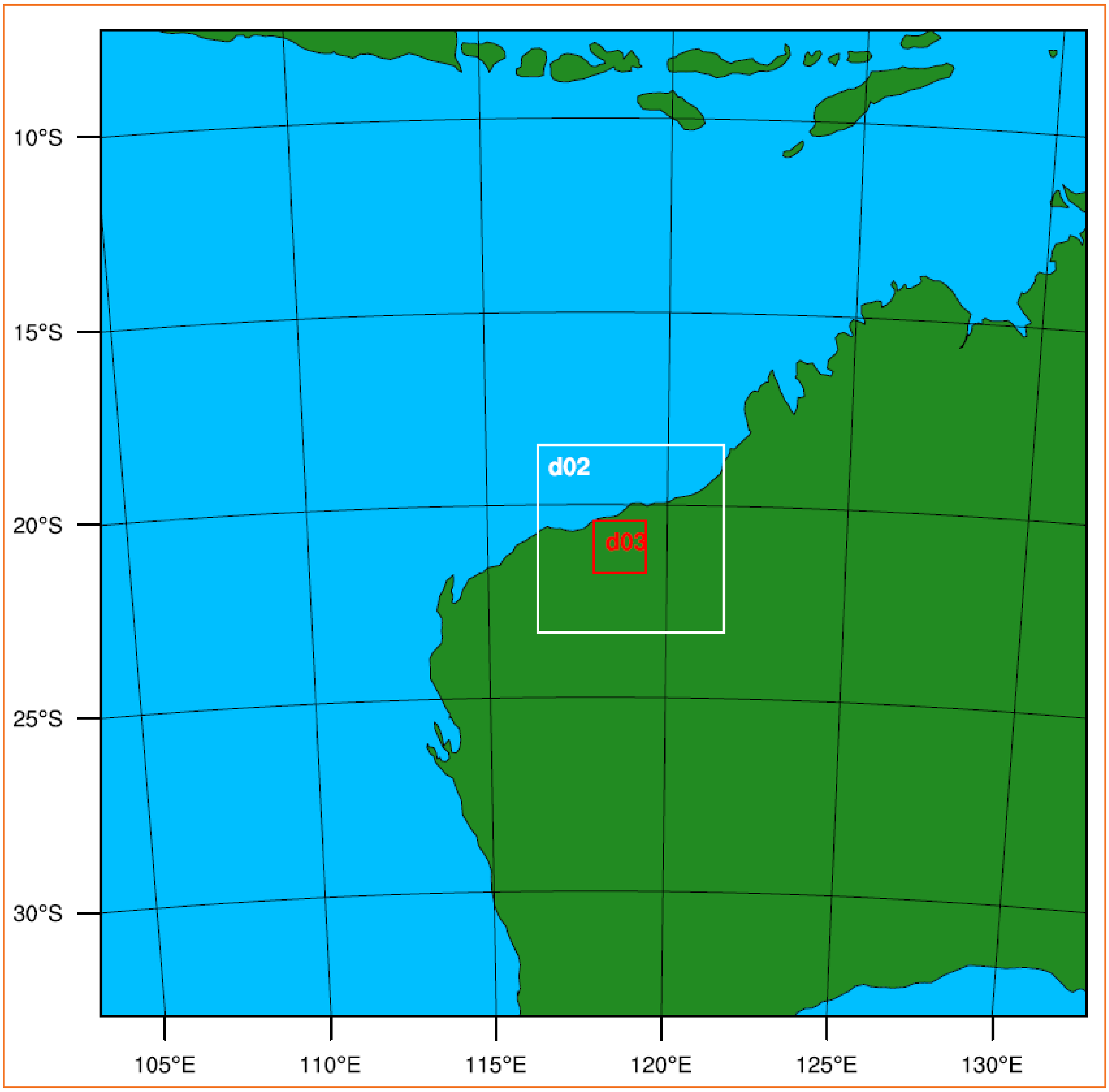
WRF is a fully compressible, Eulerian, non-hydrostatic meso-scale numerical model developed by the National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA) in the United States. WRF is suitable for a broad spectrum of applications across scales ranging from metres to thousands of kilometres. The model utilises global reanalysis[5] data to produce fine-scale 3-dimensional meteorological fields that considers local terrain and land-use effects.

WRF was run with a three-nest structure (30 km, 7.5 km, and 1.87 km horizontal grid space resolution) centred on 21.0203°S and 118.54677°E. This is shown in Appendix Figure 6. The model vertical resolution consists of 38 hybrid-eta levels[6].

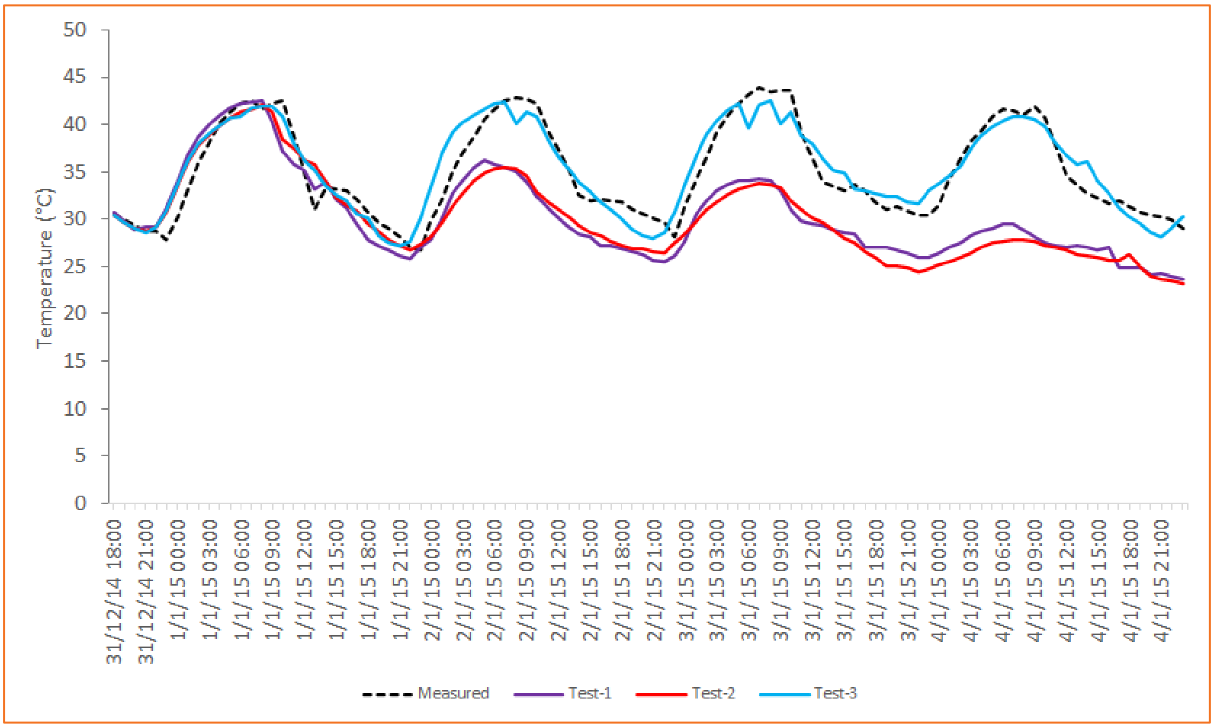
WRF can be run with a variety of model physics options which can lead to varying results and hence it is crucial to test for the most appropriate model setup for a particular purpose over a given region/domain. The choice of radiation, cumulus, planetary boundary layer (PBL) schemes and land surface model (LSM) can strongly influence near surface temperature, moisture and winds. Therefore, in order to determine the optimal physics options, a sensitivity study was conducted whereby WRF outputs (with various physics settings) are compared to measured temperature, wind speed and direction at the closest interior Bureau of Meteorology station, Marble Bar. Appendix Figure 6 shows that "Test-3" produced temperatures that best reflected measurements. Similarly, for wind speed, "Test-3" also produced results that best approximated corresponding measurements (Appendix Figure 6). For wind direction, no one sensitivity run outperformed the others (Appendix Figure 6).

Based on the above sensitivity tests, it was decided that the physics options suite for "Test-3" be used for generating the full year of meteorological data for the dispersion modelling. These physics options are summarised in Appendix Table 3.

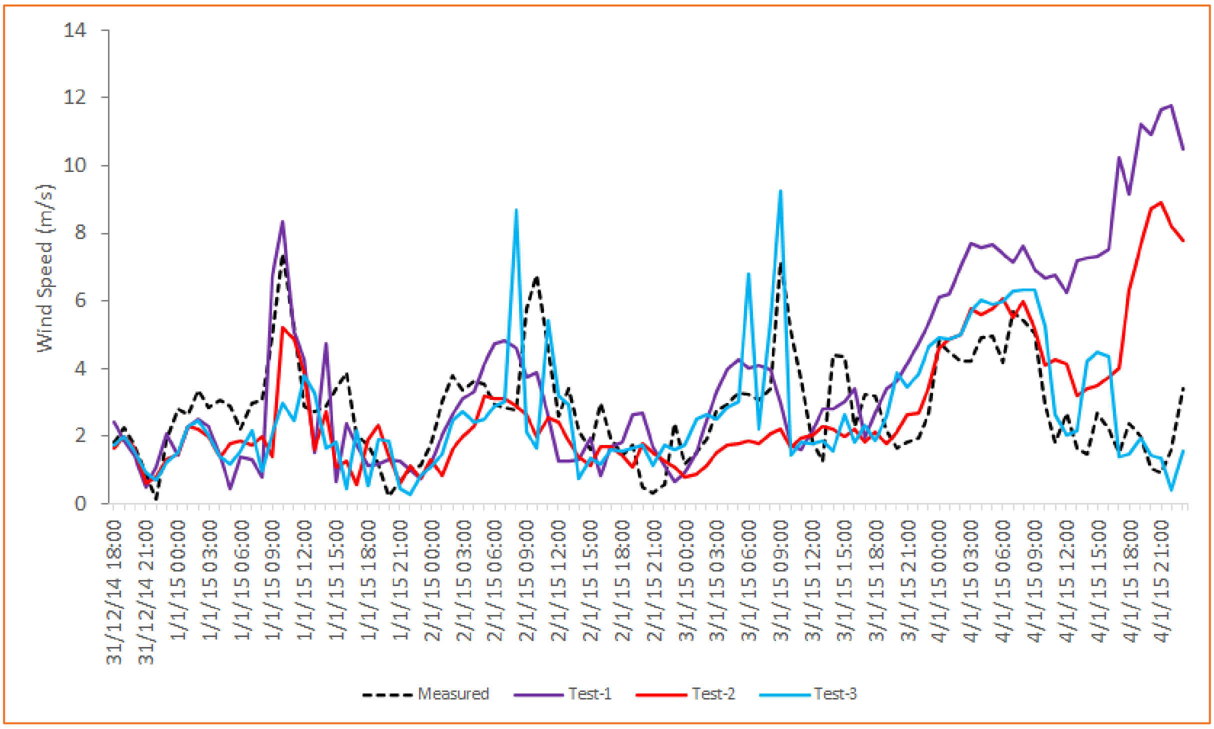
[5] Global modelling using observed climate data for temperature, wind speed, and pressure. The observations are analysed; interpolated onto a system of grids and the model initialised with this data.
[6] Terrain-following close to the earth's surface and pressure levels higher in the atmosphere.



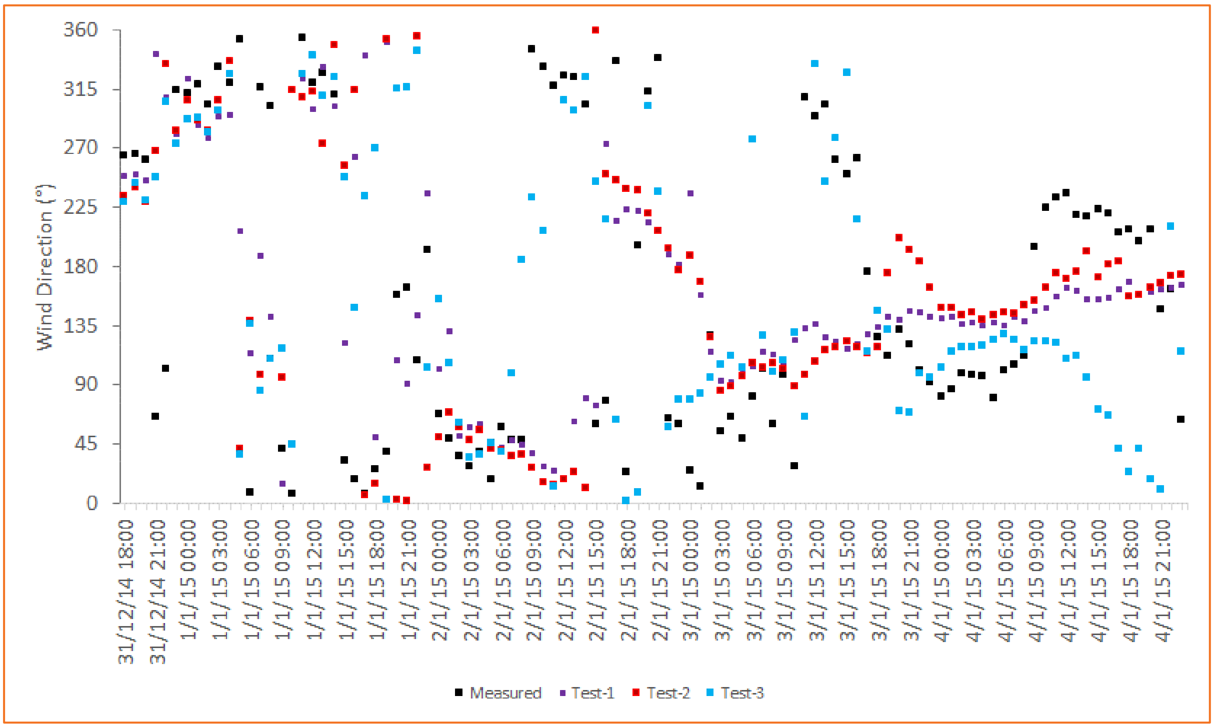
Appendix Figure 7: Three nest structure, WRF model.



Appendix Figure 8: WRF sensitivity results for temperature.



Appendix Figure 9: WRF sensitivity results for wind speed.



Appendix Figure 10: WRF sensitivity results for wind direction.

Appendix Table 3: WRF Physics Options Selected for Model.

	Domain 1	Domain 2	Domain 3	Explanatory Notes
mp_physics	4	4	4	WRF Single–moment 5–class Scheme
ra_lw_physics	1	1	1	Rapid radiative transfer model scheme
ra_sw_physics	1	1	1	Dudhia scheme for cloud and clear sky absorption and scattering
Radt	15	15	5	Time step for radiation schemes
sf_sfclay_physics	1	1	1	MM5 based on MOST
sf_surface_physics	2	2	2	Noah land surface model with 6 soil layers
bl_pbl_physics	1	1	1	Non-local K-scheme with entrainment layer
bldt	0	0	0	Boundary layer time step (0=every time step)
cu_physics	1	1	1	Kain-Fritch scheme using mass flux approach for domain 1 only.
cudt	5	5	5	Cumulus physics time step (minutes)

Six-hourly global final analysis[7] 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 was 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. A review of the Vegparm.tbl[8] reveals that these are based on North American parameterisations, with marked seasonal differences to allow for winter snow cover. These are clearly inappropriate for Australia. A non-seasonally varying roughness length value of 0.4 m was assigned to the shrub land category based on a study by Peel *et al*. (2005) for Spinifex vegetation. Albedo was also set to 0.2 based on values cited in Peel *et al*. (2005). Other parameters such as Bowen ratio were adjusted to allow for the drier climate of the region.

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 4 quantities to the parent atmospheric model (WRF), namely:

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

The performance of WRF was assessed for a winter and summer month against corresponding measurements at Marble Bar (Appendix C).

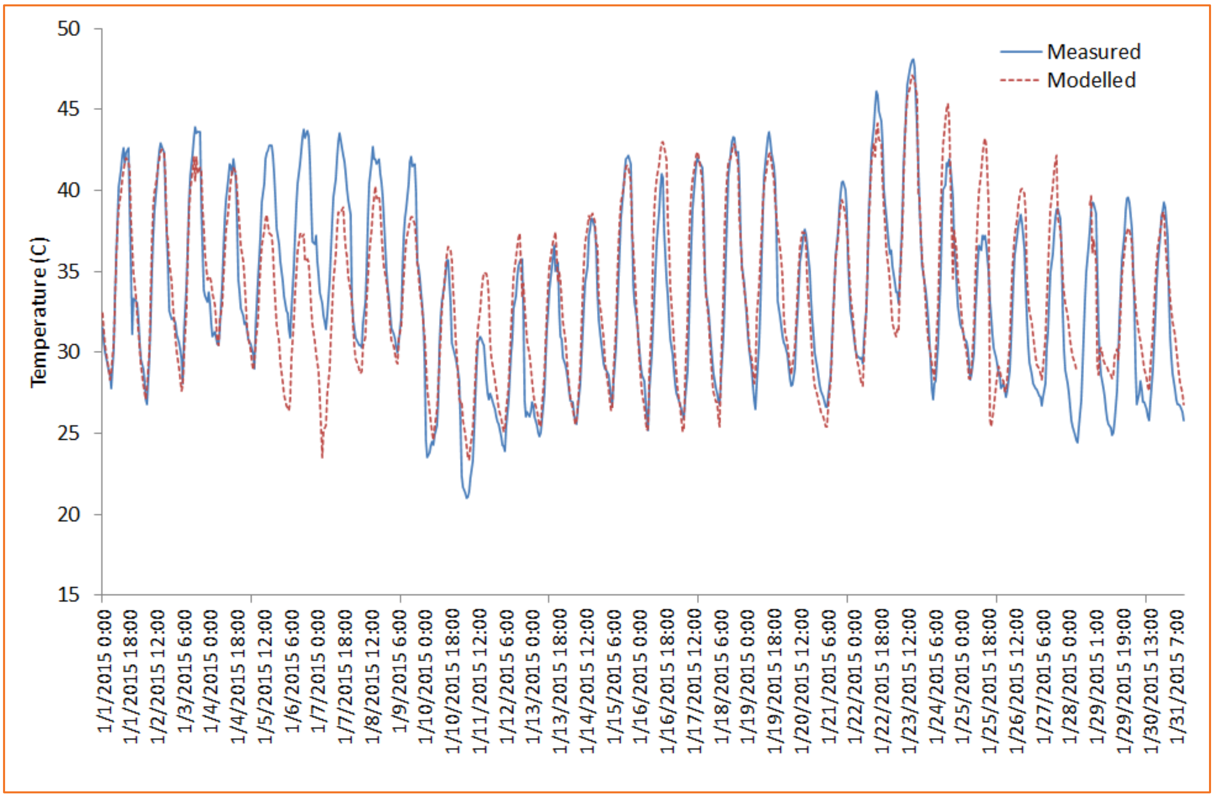
[7] Final analysis data is global modelled data that has been retrospectively corrected using surface, upper air and satellite measurements.
[8] A table consisting of land-use specific surface roughness, albedo and Bowen ratio.

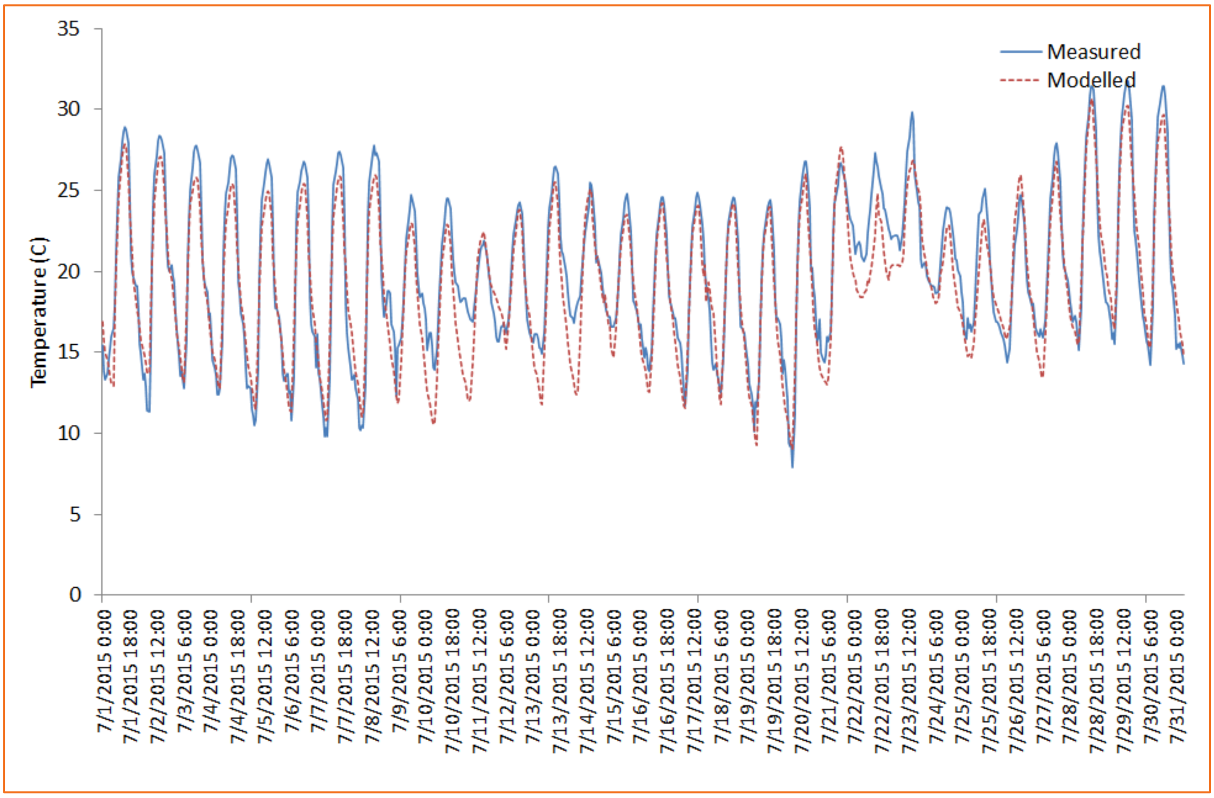
Appendix C – Model Configuration Performance

The performance of the weather forecast model (WRF) was assessed by comparing model output against the Bureau of Meteorology weather station at Marble Bar Airport. It is important to note that as Marble Bar was beyond the boundary of the inner-most WRF domain, the WRF extract for Marble Bar Airport was taken from the outer WRF domain (7.5 km resolution).

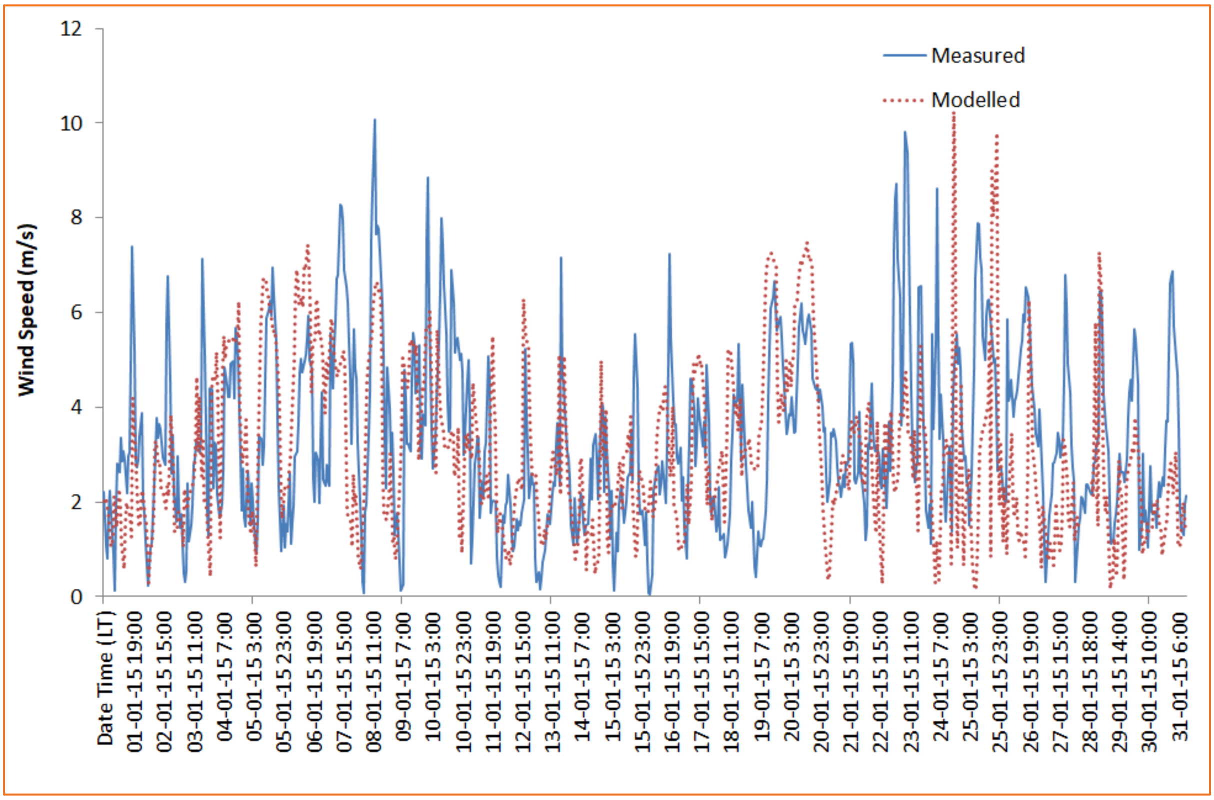
At an initial level of validation, the model output is visually compared against measured temperature, wind speed and wind direction from the Marble Bar Airport weather station. Time series of measured and modelled temperatures show that modelled approximated measurements satisfactorily, especially with respect to trends (Appendix Figure 6). For wind speed, modelled trends reflect measurements well, although the model does tend to underpredict magnitude (Appendix Figure 6).

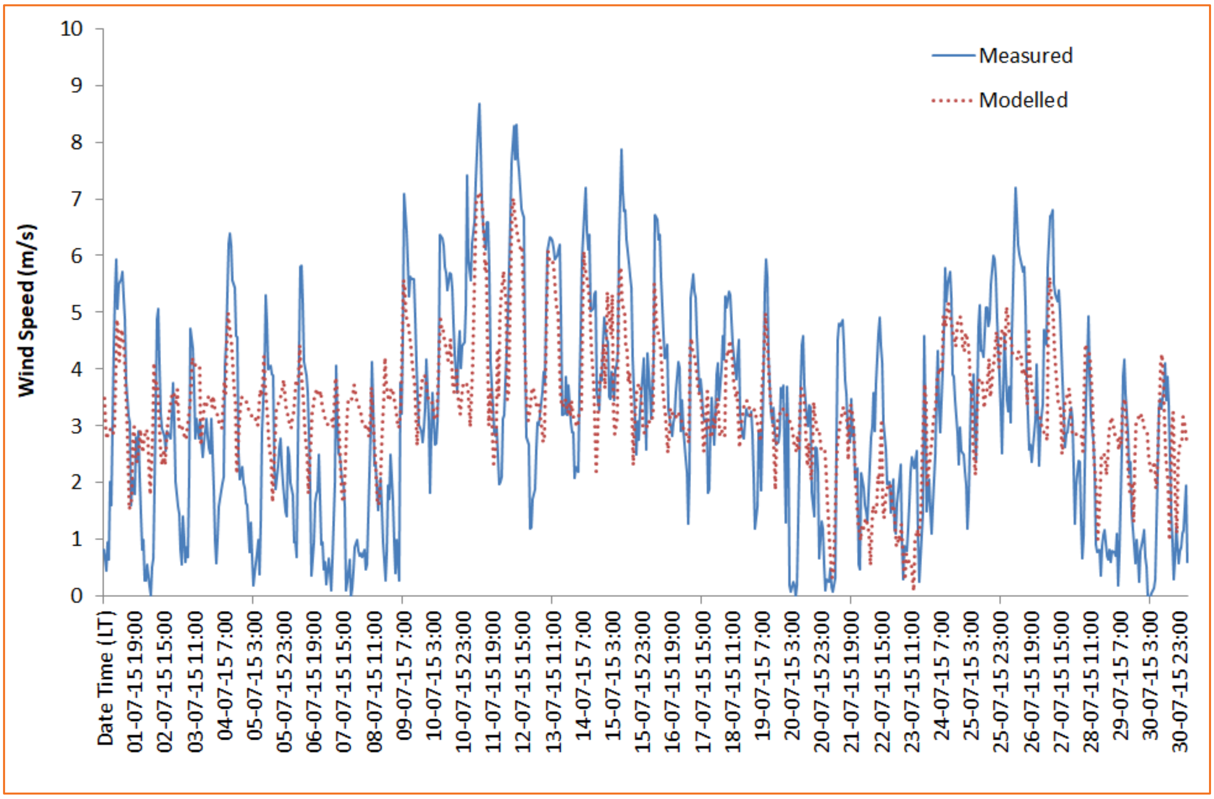
Wind roses show that modelled wind directions generally reflect measured wind directions during January and July (Appendix Figure 6).



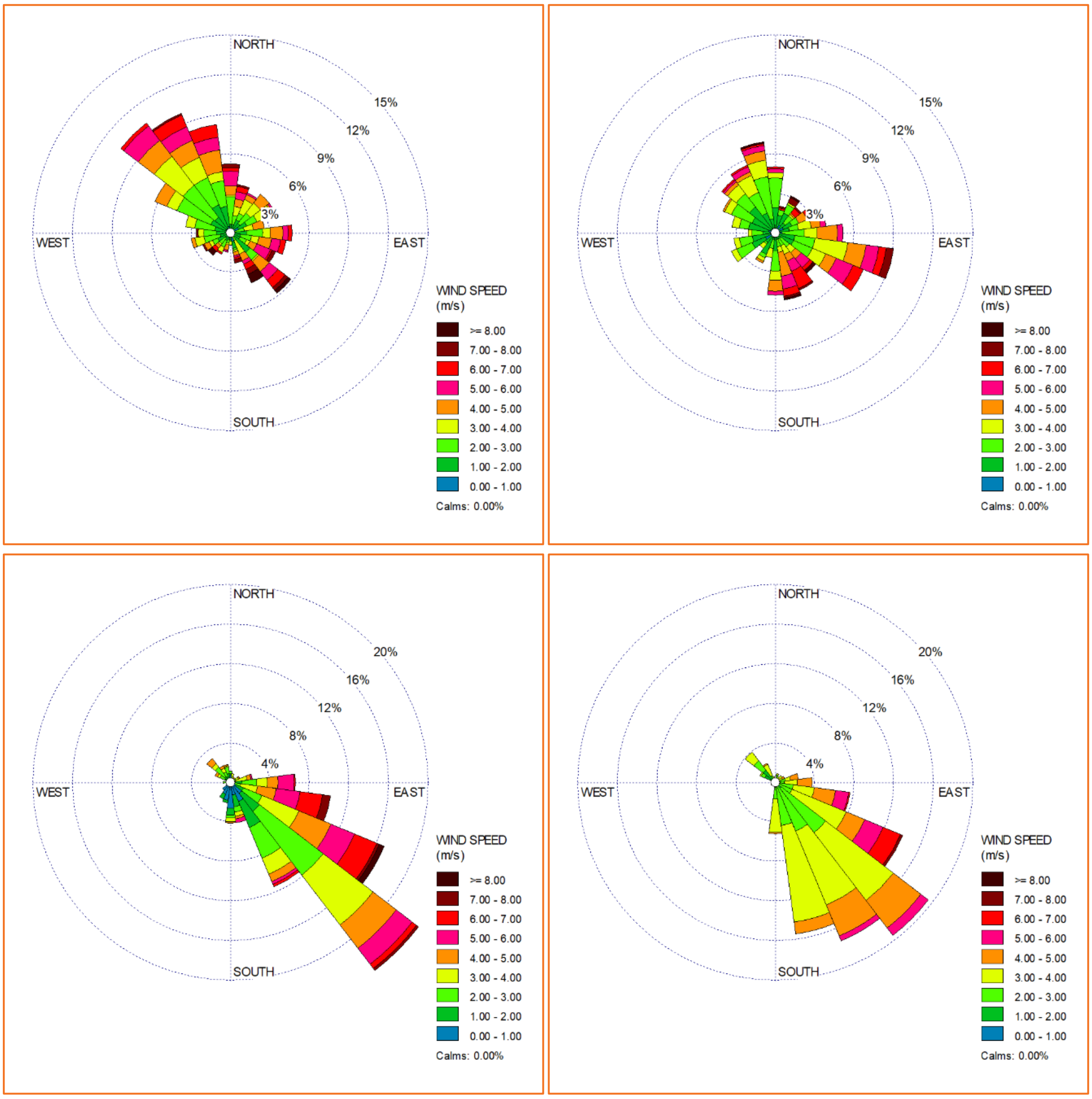


Appendix Figure 11: Time series of hourly modelled and measured temperature for January (upper) and July (lower).





Appendix Figure 12: Time series of hourly modelled and measured wind speed for January (upper) and July (lower).



Appendix Figure 13: Measured (left) and modelled (right) wind roses for January (upper) and July (lower).

More objective methods to evaluate model performance are applied using statistical tests that have been 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.

$$IOA = 1 - \left[\frac{N(RMSE)^2}{\sum_{i=1}^{n} \left\{ \left| \left(P_i - \bar{O} \right) \right| + \left| \left(O_i - \bar{O} \right) \right| \right\}^2} \right]$$

where:

n	=	the number of pairs of observed data
O_i	=	the observed value for the i-th hour
$\bar{O}_i$	=	the mean observed value

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

Validation Benchmarks

A set of benchmarks were set for mesoscale model evaluation by Emery *et al.* (2001) and Teschke *et al.* (2001) and were adopted by the US EPA in 2002 (Teschke, 2002). They are listed in Appendix Table 4.

Appendix Table 4: Mesoscale model benchmarks (after Emery et al, 2001; Teschke et al, 2002).

Parameter	Test	Benchmark
Wind Speed	RMSE	≤2 m/s
	BIAS	≤± 0.5 m/s
	IOA	≥0.6
Temp	Gross Error	≤2 K
	BIAS	≤± 0.5 K
	IOA	≥0.8
Wind Direction	Gross Error	≤30°
	BIAS	≤10°

Statistical Analysis

Statistical model verification provides a more objective test of model accuracy than the visual inspection performed above. The results of these tests are shown in Appendix Table 5.

Temperature meets all but one of the listed validation benchmarks across the two months. The wind speed evaluation meets all the listed validation benchmarks across the two months. Wind direction falls outside the Bias benchmark for January.

Overall, the analysis of WRF performance shows acceptable model performance when compared against measurements at Marble Bar, despite the relatively coarse spatial resolution of the model.

Appendix Table 5: Results of statistical validation test for January and July. Red font indicates values exceeding the benchmark.

January	Model Bias	Gross Error	IOA	RMSE
Ideal Score	**0**	**0**	**1**	**0**
Temperature	-0.13	2.00	0.94	
(benchmark)	≤± 0.5 K	≤± 2 K	≥ 0.8	-
Wind Speed	0.32	-	0.66	1.97
(benchmark)	≤± 0.5 m/s	-	≥0.6	≤2 m/s
Wind Direction	17.16	29.56	-	-
(benchmark)	≤10 °	≤30 °	-	-
July	**Model Bias**	**Gross Error**	**IOA**	**RMSE**
Ideal Score	**0**	**0**	**1**	**0**
Temperature	0.70	1.39	0.97	-
(benchmark)	≤± 0.5 K	≤± 2 K	≥ 0.8	-
Wind Speed	-0.22	-	0.73	1.46
(benchmark)	≤± 0.5 m/s	-	≥0.6	≤2 m/s
Wind Direction	2.7	11.38	-	-
(benchmark)	≤10 °	≤30 °	-	-

Appendix D – CALMET Configuration

Wind Direction and Speed

The general features of the 10 m winds illustrated in the annual and seasonal wind rose diagrams for the 12-month period from January 2015 – December 2015[9] are shown in Appendix Figure 14. 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 roses are as follows:

- Wind direction is predominantly from the southeast with a secondary maximum from the northwest.
- The highest frequency of stronger (> 7 m/s) and lighter (< 3 m/s) wind is from the northwest.
- North-westerly winds are relatively common during summer.
- South-easterly winds dominate during Autumn and Winter.
- Spring is characterised by a high frequency of south-easterly and north-westerly winds.
- Average wind speeds are 3.1 m/s with strongest hourly wind speed of 11.5 m/s.
- Light winds (< 1 m/s) occur for approximately 5% (~418 hours) during the year.

The time-date [10] diagrams for wind direction and wind speed are shown in Appendix Figure 15. The diagrams depict wind direction and speed by hour of the day on the x-axis and day of the year on the y-axis. The figures show that winds are generally from the southeast. During the wet season, south-easterly winds are interspersed with periods of westerly to north-westerly monsoon-influenced winds. Wind speeds are generally highest at night and early morning hours during the dry season whereas during the wet season, highest wind speeds occur during the afternoon.

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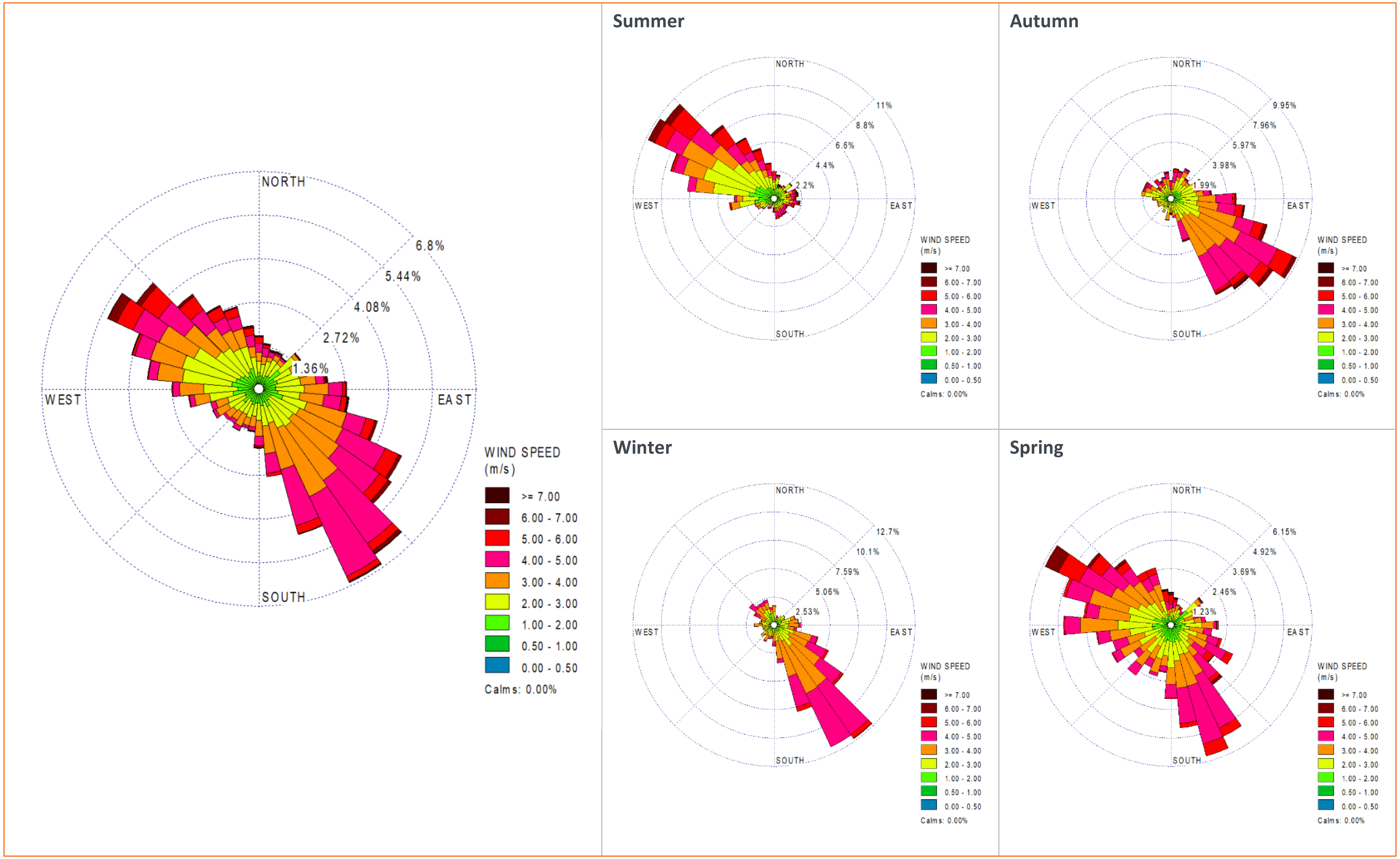
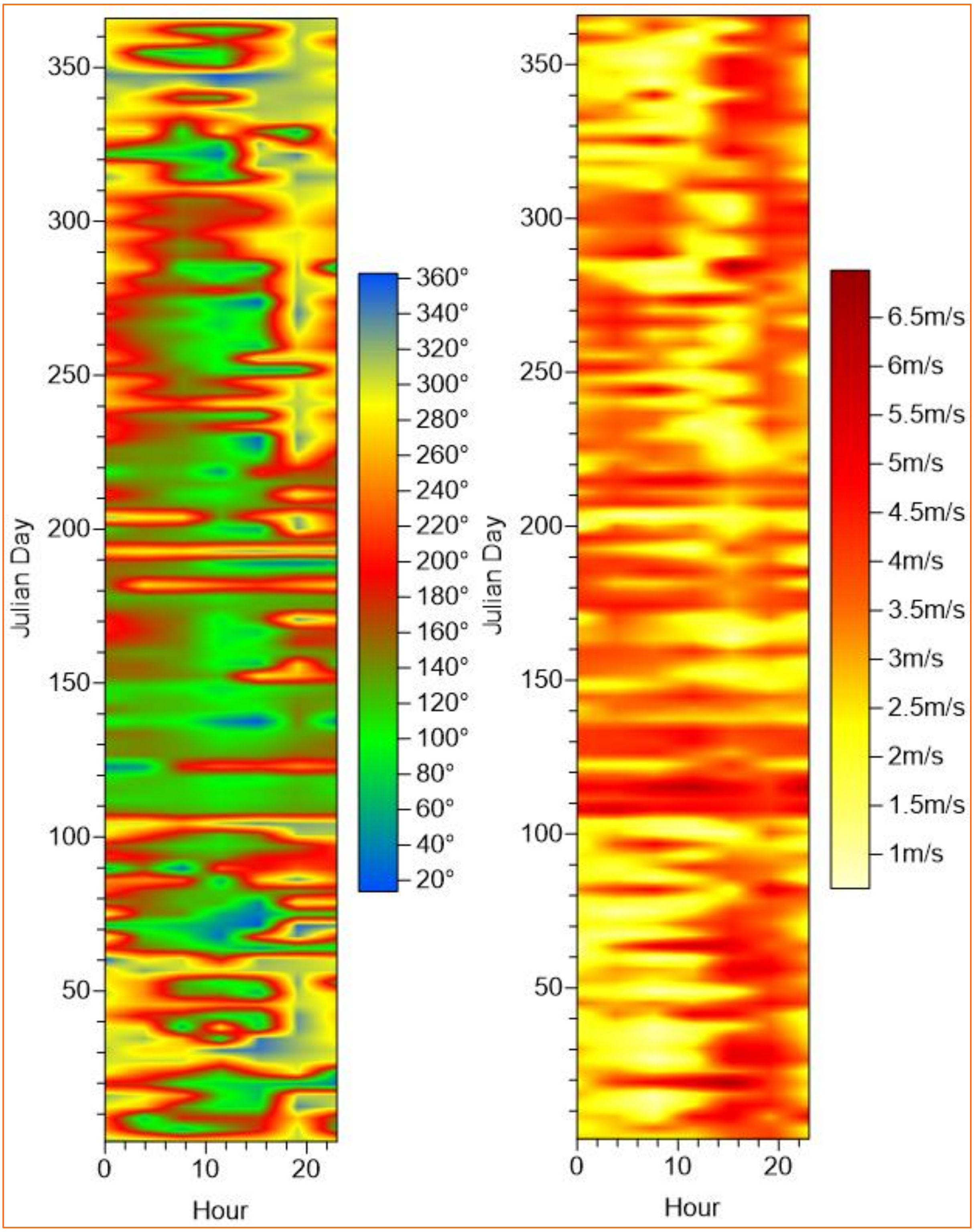
[9] The selected representative meteorological year (as determined in Appendix A).
[10] These diagrams are useful for displaying large amounts of data in a meaningful and understandable form.



Appendix Figure 14: Wind roses generated from WRF/CALMET for Hemi Gold Mine.

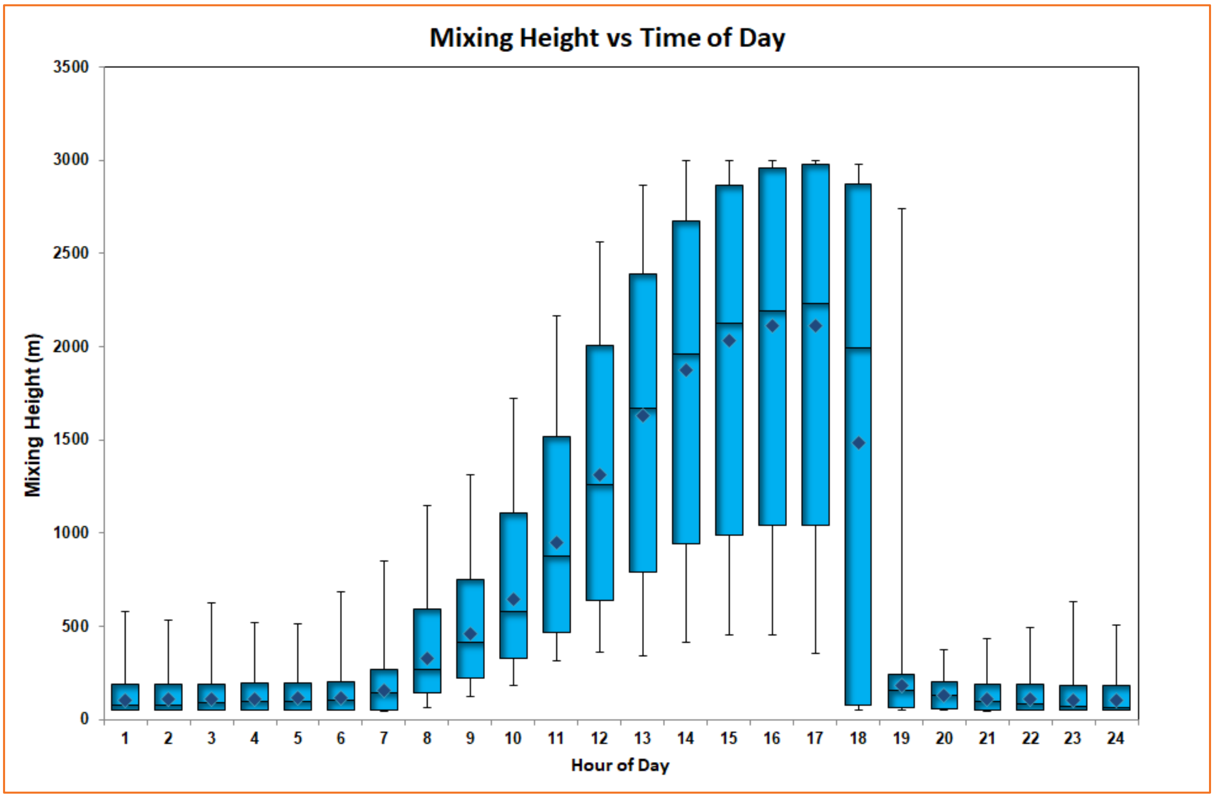


Appendix Figure 15: Date-time plot of wind direction (left) and wind speed (right) generated from WRF/CALMET.

Mixing Height

Mixing height is the depth of the atmospheric surface layer beneath an elevated temperature inversion. It is an important parameter within air pollution meteorology. Vertical diffusion or mixing of a plume is limited by the mixing height, as the air above this layer tends to be stable, with restricted vertical motion.

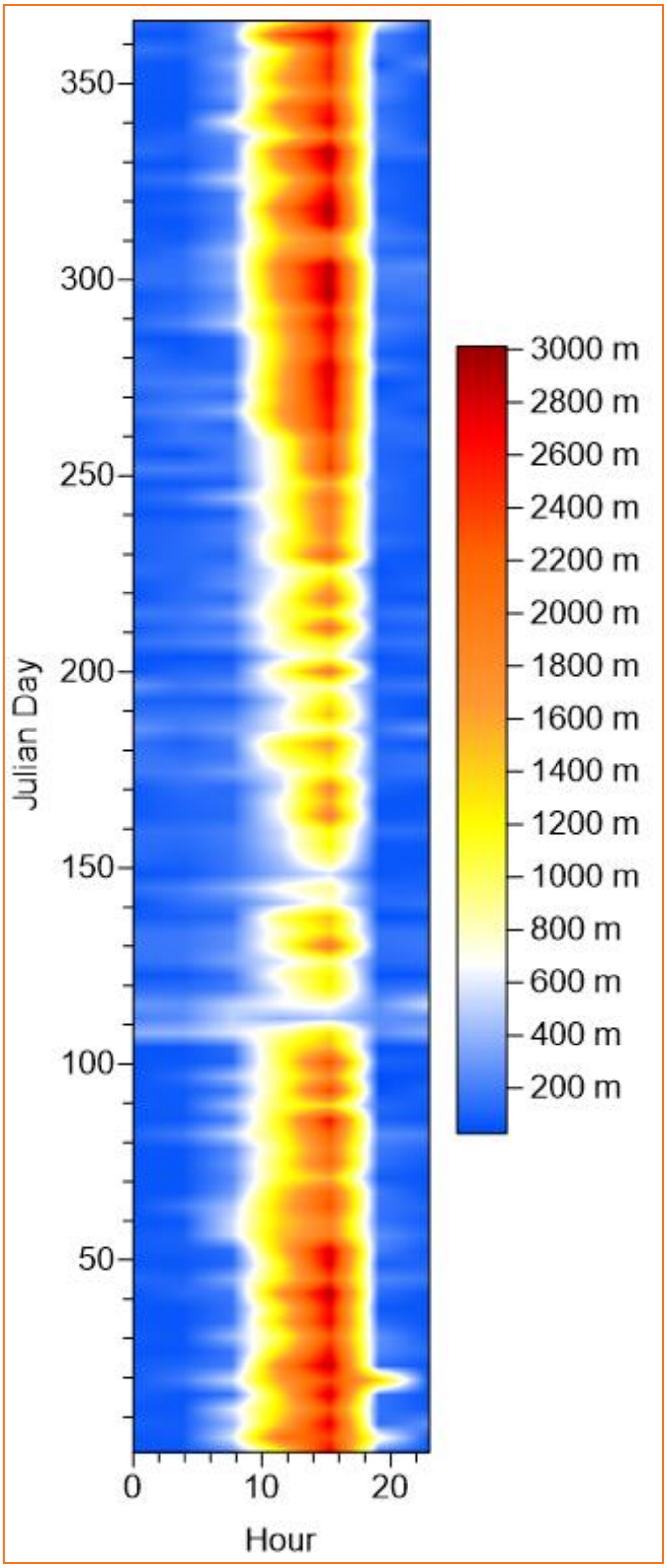
A series of internal algorithms within CALMET is used to calculate mixing heights for the subject site where it is assumed that mixing height is formed through mechanical means (wind speed) at night and through a mixture of mechanical and convective means (wind speed and solar radiation) during the day (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 hourly variation of mixing height at the Hemi Gold Mine is summarised in Appendix Figure 16[11] with the diurnal cycle clearly evident. At night, mixing height is normally low and after sunrise it typically increases to between 1,000 m and 3,000 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.



Appendix Figure 16: Simulated annual statistics of hourly mixing heights, Hemi Gold Mine

[11] The blue bars depicts the 10th and 90th percentile values while the diamond shape show the average conditions. The whiskers indicate minimum and maximum values of the data, and the line within the blue bar indicates the median.

The date-time plot of mixing height shows that, as expected, mixing heights are greatest during spring and summer when solar radiation and resulting convection is greatest (Appendix Figure 17).



Appendix Figure 17: Date-time plot of mixing height generated from WRF/CALMET.

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.

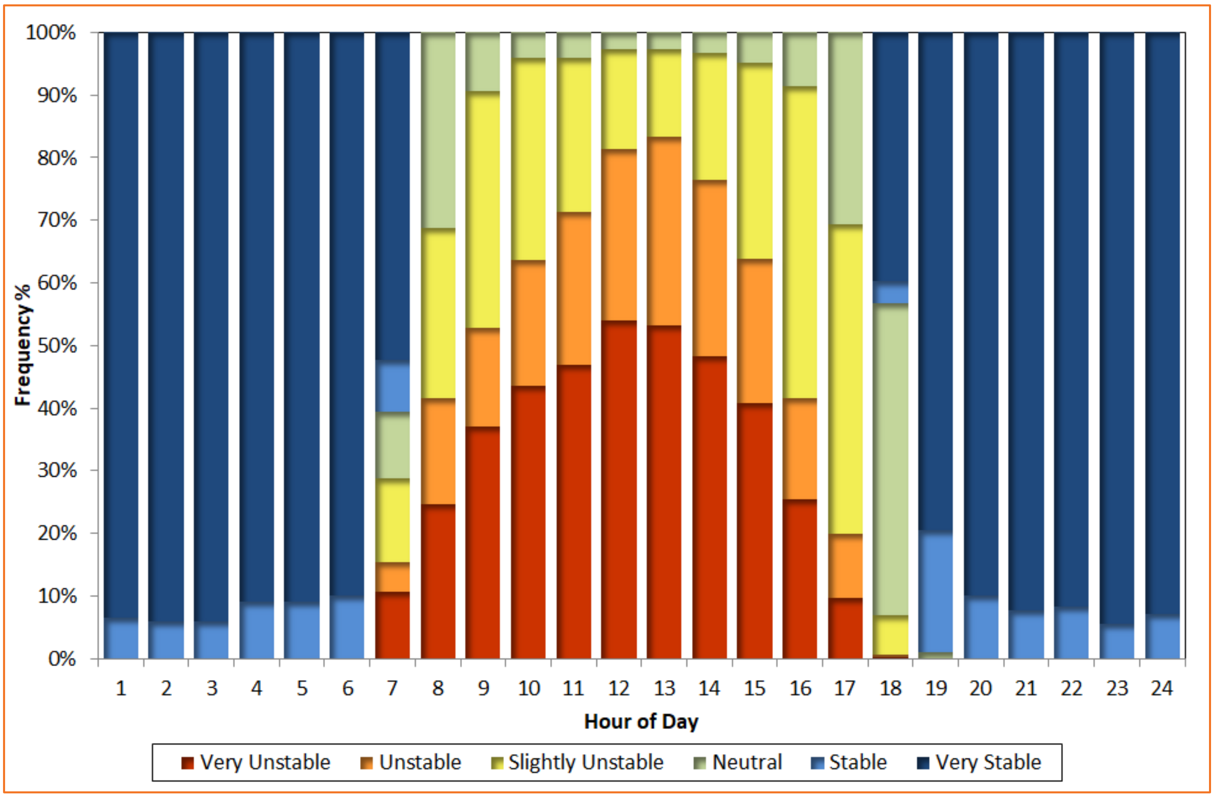
Turbulence in the boundary layer is influenced by the vertical temperature gradient, which is one of several indicators of stability. Plume models use indicators of atmospheric stability in conjunction with other meteorological data to estimate the dispersion conditions in the atmosphere.

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. One of the measures of the PBL is the Monin-Obukhov length (L), which approximates the height at which turbulence is generated equally by thermal and mechanical effects (Seinfeld and Pandis 2006). It is a measure of the relative importance of mechanical and thermal forcing on atmospheric turbulence.

Because values of L diverge to + and - infinity as stability approaches neutral from the stable and unstable sides, respectively, it is often more convenient to use the inverse of L (i.e. 1/L) when describing stability.

The hourly averaged 1/L for Hemi Gold computed from all data in the CALMET surface file is presented in Appendix Figure 18. This plot indicates that the PBL is stable to very stable overnight becoming unstable (reaching maximum instability between 12:00 pm and 1:00 pm) as radiation from the sun heats the surface layer of the atmosphere and drives convection.

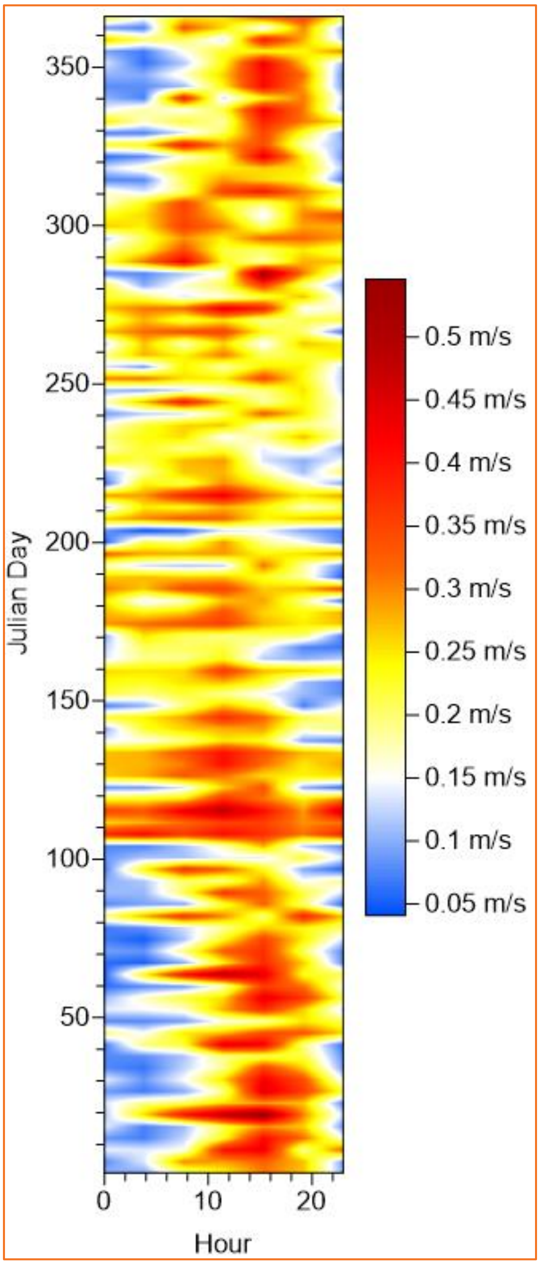


Appendix Figure 18: Simulated annual statistics of hourly stability at the Hemi Gold Mine.

Friction Velocity

An important quantity in wind erosion studies is threshold friction velocity u_{*t}, which describes the capacity of the surface to resist wind erosion. u_{*t} is the minimum friction velocity (u_*) required for the initiation of mobilization of sand particles from the ground into the atmosphere. Friction velocity is affected by a range of factors, such as wind speed, vegetation cover, and other roughness elements.

The Hovmöller diagram of CALMET-generated friction velocity shows that the highest friction velocity (and therefore dust lift-off potential) occurs during the early- to mid-morning hours during the dry season. During the west season (summer), highest friction velocity occurs during the afternoon hours (Appendix Figure 19).



Appendix Figure 19: Hour-Date-time plot of friction velocity generated from WRF/CALMET.

Appendix E – Emission Parameters

A summary of the volume sources (statistical characteristics for emission rates) input into the model are shown in:

- Appendix Table 4 for mining and processing emissions,
- Appendix Table 5 for haul road sources

Appendix Table 4: Emission parameters for mining sources.

Source Id	Easting	Northing	Effective Height	Sigma Y	Sigma Z
Drill1	646206	7692607	1.5	100	0.70
Drill2	646585	7692774	1.5	100	0.70
Drill3	646595	7692385	1.5	100	0.70
Drill4	647177	7692686	1.5	100	0.70
Drill5	647090	7692325	1.5	100	0.70
Drill6	647349	7692464	1.5	100	0.70
Drill7	648167	7692824	1.5	100	0.70
Drill8	648648	7692889	1.5	100	0.70
Drill9	648338	7692524	1.5	100	0.70
Drill10	648986	7692635	1.5	100	0.70
Drill11	649009	7692371	1.5	100	0.70
Drill12	648630	7692218	1.5	100	0.70
Drill13	649425	7692297	1.5	100	0.70
Drill14	649083	7691955	1.5	100	0.70
Drill15	649412	7691770	1.5	100	0.70
Drill16	648172	7691895	1.5	100	0.70
Drill17	648570	7691631	1.5	100	0.70
Drill18	648144	7691377	1.5	100	0.70
Blast1	646572	7692602	20	25.00	9.30
Blast2	647177	7692496	20	25.00	9.30
Blast3	648551	7692681	20	25.00	9.30
Blast4	648843	7692269	20	25.00	9.30
Blast5	649379	7692038	20	25.00	9.30
Blast6	648288	7691650	20	25.00	9.30
Load1	646400	7692704	6	100	2.79
Load2	646798	7692704	6	100	2.79
Load3	646382	7692454	6	100	2.79
Load4	647029	7692501	6	100	2.79
Load5	647409	7692663	6	100	2.79
Load6	647335	7692269	6	100	2.79
Load7	647996	7692584	6	100	2.79
Load8	648394	7692898	6	100	2.79
Load9	648565	7692496	6	100	2.79
Load10	649185	7692750	6	100	2.79
Load11	648907	7692464	6	100	2.79
Load12	648648	7692070	6	100	2.79

Source Id	Easting	Northing	Effective Height	Sigma Y	Sigma Z
Load13	649342	7692459	6	100	2.79
Load14	649194	7692163	6	100	2.79
Load15	649120	7691784	6	100	2.79
Load16	648445	7691853	6	100	2.79
Load17	648463	7691418	6	100	2.79
Load18	648042	7691626	6	100	2.79
UnWaste1	651077	7693717	2	125	0.93
UnWaste2	650605	7694439	2	125	0.93
UnWaste3	649393	7694587	2	125	0.93
UnWaste4	648181	7694531	2	125	0.93
UnWaste5	648116	7693699	2	125	0.93
UnWaste6	646766	7693930	2	125	0.93
UnWaste7	646387	7694587	2	125	0.93
UnWaste8	645628	7693819	2	125	0.93
UnWaste9	645054	7693162	2	125	0.93
UnWaste10	644666	7692496	2	125	0.93
UnWaste11	647793	7689906	2	125	0.93
UnWaste12	648857	7689878	2	125	0.93
UnOre1	650073	7691798	2	100	0.93
UnOre2	650073	7691247	2	100	0.93
LoadOre1	650161	7691326	6	100	2.79
LoadOre2	650073	7691659	6	100	2.79
UnCrush	650332	7691659	2	25	0.93
Bull1	650871	7694055	2	150	0.93
Bull2	650048	7694503	2	150	0.93
Bull3	648785	7694550	2	150	0.93
Bull4	648137	7694096	2	150	0.93
Bull5	646250	7694124	2	150	0.93
Bull6	645515	7693430	2	150	0.93
Bull7	645223	7692237	2	150	0.93
Bull8	648378	7689813	2	150	0.93
PriCrush	650346	7691675	3	3.8	1.40
SecondCrush	650436	7691668	5	12.5	2.33
Screen	650617	7691677	6	17.5	2.79
Stk	650848	7691682	10	2.5	4.65

Appendix Table 5: Emission parameters for haul road sources.

Source Id	Easting	Northing	Effective Height	Sigma Y	Sigma Z
HR1	646905	7692889	5.3	16.7	4.9
HR2	647039	7693153	5.3	16.7	4.9
HR3	647090	7693416	5.3	16.7	4.9
HR4	646840	7693620	5.3	16.7	4.9
HR5	646558	7693745	5.3	16.7	4.9
HR6	646248	7693703	5.3	16.7	4.9

Source Id	Easting	Northing	Effective Height	Sigma Y	Sigma Z
HR7	645998	7693541	5.3	16.7	4.9
HR8	645748	7693347	5.3	16.7	4.9
HR9	645540	7693093	5.3	16.7	4.9
HR10	645355	7692894	5.3	16.7	4.9
HR11	645300	7692593	5.3	16.7	4.9
HR12	645286	7692288	5.3	16.7	4.9
HR13	648389	7693130	5.3	16.7	4.9
HR14	648366	7693463	5.3	16.7	4.9
HR15	648385	7693759	5.3	16.7	4.9
HR16	648533	7693999	5.3	16.7	4.9
HR17	648843	7694161	5.3	16.7	4.9
HR18	649111	7694249	5.3	16.7	4.9
HR19	649425	7694226	5.3	16.7	4.9
HR20	649721	7694231	5.3	16.7	4.9
HR21	649990	7694161	5.3	16.7	4.9
HR22	650309	7694078	5.3	16.7	4.9
HR23	650582	7693948	5.3	16.7	4.9
HR24	648463	7691011	5.3	16.7	4.9
HR25	648602	7690780	5.3	16.7	4.9
HR26	648667	7690484	5.3	16.7	4.9
HR27	648625	7690123	5.3	16.7	4.9
HR28	648278	7690068	5.3	16.7	4.9
HR29	646863	7691955	5.3	16.7	4.9
HR30	647080	7691761	5.3	16.7	4.9
HR31	647316	7691557	5.3	16.7	4.9
HR32	647524	7691340	5.3	16.7	4.9
HR33	647765	7691118	5.3	16.7	4.9
HR34	647964	7690937	5.3	16.7	4.9
HR35	648255	7690886	5.3	16.7	4.9
HR36	648584	7690956	5.3	16.7	4.9
HR37	648889	7691011	5.3	16.7	4.9
HR38	649190	7691067	5.3	16.7	4.9
HR39	649490	7691108	5.3	16.7	4.9
HR40	649782	7691178	5.3	16.7	4.9
HR41	650045	7691280	5.3	16.7	4.9
HR42	649407	7692986	5.3	16.7	4.9
HR43	649634	7692811	5.3	16.7	4.9
HR44	649782	7692547	5.3	16.7	4.9
HR45	649888	7692306	5.3	16.7	4.9
HR46	649897	7691987	5.3	16.7	4.9
HR47	649994	7691724	5.3	16.7	4.9

Appendix F – Emission Rates

A summary of the PM_{10} emission rates for the Project sources, used as input into the model is shown in:

- Appendix Table 6 for mining sources.
- Appendix Table 7 for haul roads.

Appendix Table 6: PM_{10} emission rates for mining sources.

Source Id	Maximum (g/s)	99th Percentile (g/s)	95th Percentile (g/s)	90th Percentile (g/s)	70th Percentile (g/s)	Average (g/s)
Drill1	0.19	0.19	0.19	0.19	0.19	0.15
Drill2	0.19	0.19	0.19	0.19	0.19	0.15
Drill3	0.19	0.19	0.19	0.19	0.19	0.15
Drill4	0.19	0.19	0.19	0.19	0.19	0.15
Drill5	0.19	0.19	0.19	0.19	0.19	0.15
Drill6	0.19	0.19	0.19	0.19	0.19	0.15
Drill7	0.19	0.19	0.19	0.19	0.19	0.15
Drill8	0.19	0.19	0.19	0.19	0.19	0.15
Drill9	0.19	0.19	0.19	0.19	0.19	0.15
Drill10	0.19	0.19	0.19	0.19	0.19	0.15
Drill11	0.19	0.19	0.19	0.19	0.19	0.15
Drill12	0.19	0.19	0.19	0.19	0.19	0.15
Drill13	0.19	0.19	0.19	0.19	0.19	0.15
Drill14	0.19	0.19	0.19	0.19	0.19	0.15
Drill15	0.19	0.19	0.19	0.19	0.19	0.15
Drill16	0.19	0.19	0.19	0.19	0.19	0.15
Drill17	0.19	0.19	0.19	0.19	0.19	0.15
Drill18	0.19	0.19	0.19	0.19	0.19	0.15
Blast1	30.19	0.00	0.00	0.00	0.00	0.21
Blast2	30.19	0.00	0.00	0.00	0.00	0.21
Blast3	30.19	0.00	0.00	0.00	0.00	0.21
Blast4	30.19	0.00	0.00	0.00	0.00	0.21
Blast5	30.19	0.00	0.00	0.00	0.00	0.21
Blast6	30.19	0.00	0.00	0.00	0.00	0.21
Load1	2.31	2.31	2.31	2.31	2.31	1.86
Load2	2.31	2.31	2.31	2.31	2.31	1.85
Load3	2.31	2.31	2.31	2.31	2.31	1.84
Load4	2.31	2.31	2.31	2.31	2.31	1.87
Load5	2.31	2.31	2.31	2.31	2.31	1.83
Load6	2.31	2.31	2.31	2.31	2.31	1.86
Load7	2.31	2.31	2.31	2.31	2.31	1.85
Load8	2.31	2.31	2.31	2.31	2.31	1.85
Load9	2.31	2.31	2.31	2.31	2.31	1.86
Load10	2.31	2.31	2.31	2.31	2.31	1.85
Load11	2.31	2.31	2.31	2.31	2.31	1.86
Load12	2.31	2.31	2.31	2.31	2.31	1.85

Source Id	Maximum (g/s)	99th Percentile (g/s)	95th Percentile (g/s)	90th Percentile (g/s)	70th Percentile (g/s)	Average (g/s)
Load13	2.31	2.31	2.31	2.31	2.31	1.83
Load14	2.31	2.31	2.31	2.31	2.31	1.86
Load15	2.31	2.31	2.31	2.31	2.31	1.85
Load16	2.31	2.31	2.31	2.31	2.31	1.84
Load17	2.31	2.31	2.31	2.31	2.31	1.87
Load18	2.31	2.31	2.31	2.31	2.31	1.85
UnWaste1	1.14	1.14	1.14	1.14	1.14	0.92
UnWaste2	1.14	1.14	1.14	1.14	1.14	0.91
UnWaste3	1.14	1.14	1.14	1.14	1.14	0.91
UnWaste4	1.14	1.14	1.14	1.14	1.14	0.92
UnWaste5	1.14	1.14	1.14	1.14	1.14	0.90
UnWaste6	1.14	1.14	1.14	1.14	1.14	0.92
UnWaste7	1.14	1.14	1.14	1.14	1.14	0.91
UnWaste8	1.14	1.14	1.14	1.14	1.14	0.91
UnWaste9	1.14	1.14	1.14	1.14	1.14	0.92
UnWaste10	1.14	1.14	1.14	1.14	1.14	0.91
UnWaste11	1.14	1.14	1.14	1.14	1.14	0.92
UnWaste12	1.14	1.14	1.14	1.14	1.14	0.91
UnOre1	0.85	0.85	0.85	0.85	0.85	0.69
UnOre2	0.85	0.85	0.85	0.85	0.85	0.68
LoadOre1	2.38	2.38	2.38	2.38	2.38	1.90
LoadOre2	2.38	2.38	2.38	2.38	2.38	1.91
UnCrush	0.85	0.85	0.85	0.85	0.85	0.68
Bull1	0.14	0.14	0.14	0.14	0.14	0.05
Bull2	0.14	0.14	0.14	0.14	0.14	0.05
Bull3	0.14	0.14	0.14	0.14	0.14	0.05
Bull4	0.14	0.14	0.14	0.14	0.14	0.05
Bull5	0.14	0.14	0.14	0.14	0.14	0.05
Bull6	0.14	0.14	0.14	0.14	0.14	0.05
Bull7	0.14	0.14	0.14	0.14	0.14	0.05
Bull8	0.14	0.14	0.14	0.14	0.14	0.05
PriCrush	0.16	0.16	0.16	0.16	0.16	0.13
SecondCrush	0.48	0.48	0.48	0.48	0.48	0.38
Screen	1.43	1.43	1.43	1.43	1.43	1.14
Stk	0.63	0.63	0.63	0.63	0.63	0.51

Appendix Table 7: PM_{10} emission rates for haul roads.

Source Id	Maximum (g/s)	99th Percentile (g/s)	95th Percentile (g/s)	90th Percentile (g/s)	70th Percentile (g/s)	Average (g/s)
HR1	4.78	4.78	4.78	4.78	4.78	3.83
HR2	4.78	4.78	4.78	4.78	4.78	3.83
HR3	4.78	4.78	4.78	4.78	4.78	3.83
HR4	4.78	4.78	4.78	4.78	4.78	3.83

Source Id	Maximum (g/s)	99th Percentile (g/s)	95th Percentile (g/s)	90th Percentile (g/s)	70th Percentile (g/s)	Average (g/s)
HR5	4.78	4.78	4.78	4.78	4.78	3.83
HR6	3.83	3.83	3.83	3.83	3.83	3.06
HR7	3.83	3.83	3.83	3.83	3.83	3.06
HR8	2.87	2.87	2.87	2.87	2.87	2.30
HR9	2.87	2.87	2.87	2.87	2.87	2.30
HR10	2.87	2.87	2.87	2.87	2.87	2.30
HR11	0.96	0.96	0.96	0.96	0.96	0.76
HR12	0.96	0.96	0.96	0.96	0.96	0.76
HR13	4.78	4.78	4.78	4.78	4.78	3.83
HR14	4.78	4.78	4.78	4.78	4.78	3.83
HR15	4.78	4.78	4.78	4.78	4.78	3.83
HR16	3.83	3.83	3.83	3.83	3.83	3.07
HR17	3.83	3.83	3.83	3.83	3.83	3.07
HR18	3.83	3.83	3.83	3.83	3.83	3.07
HR19	2.87	2.87	2.87	2.87	2.87	2.29
HR20	2.87	2.87	2.87	2.87	2.87	2.29
HR21	2.87	2.87	2.87	2.87	2.87	2.29
HR22	0.96	0.96	0.96	0.96	0.96	0.77
HR23	0.96	0.96	0.96	0.96	0.96	0.77
HR24	1.91	1.91	1.91	1.91	1.91	1.53
HR25	1.91	1.91	1.91	1.91	1.91	1.53
HR26	1.91	1.91	1.91	1.91	1.91	1.53
HR27	1.91	1.91	1.91	1.91	1.91	1.53
HR28	1.91	1.91	1.91	1.91	1.91	1.53
HR29	0.71	0.71	0.71	0.71	0.71	0.57
HR30	0.71	0.71	0.71	0.71	0.71	0.57
HR31	0.71	0.71	0.71	0.71	0.71	0.57
HR32	0.71	0.71	0.71	0.71	0.71	0.57
HR33	0.71	0.71	0.71	0.71	0.71	0.57
HR34	0.71	0.71	0.71	0.71	0.71	0.57
HR35	0.71	0.71	0.71	0.71	0.71	0.57
HR36	0.71	0.71	0.71	0.71	0.71	0.57
HR37	0.71	0.71	0.71	0.71	0.71	0.57
HR38	0.71	0.71	0.71	0.71	0.71	0.57
HR39	0.71	0.71	0.71	0.71	0.71	0.57
HR40	0.71	0.71	0.71	0.71	0.71	0.57
HR41	0.71	0.71	0.71	0.71	0.71	0.57
HR42	0.71	0.71	0.71	0.71	0.71	0.58
HR43	0.71	0.71	0.71	0.71	0.71	0.58
HR44	0.71	0.71	0.71	0.71	0.71	0.58
HR45	0.71	0.71	0.71	0.71	0.71	0.58
HR46	0.71	0.71	0.71	0.71	0.71	0.58
HR47	0.71	0.71	0.71	0.71	0.71	0.58

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