Ministers North – Dust Modelling

Assessment | Study

Final Report

Version 2

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Ministers North – Dust Modelling

Final Report

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Signature		

Executive Summary

BHP commissioned Environmental Technologies & Analytics Pty Ltd (ETA) to undertake an air quality assessment for the Ministers North Project (the Project). The purpose of this air quality assessment is to assess the potential air quality impacts associated with these operations.

This report presents the assessment of the potential air quality impacts associated with the Project.

Study Overview

The potential air quality impacts of the existing operations were determined through a review of ambient air quality monitoring data, and a dispersion modelling study, which incorporated prognostic meteorological data, and emissions information estimates for the project based on equipment design specifications supplied by BHP. The scope of the modelling assessment is summarised below.

Modelled meteorological period	1 January to 31 December 2016
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 for the operations utilised forecast emissions for FY30 as these represent the maximum material handling assumptions for the life of the Project.
Sensitive Receptors	Discrete receptor locations were nominated to represent: • Human health receptors • Heritage receptors • Sites of Significance receptors.
Model Scenarios	The model scenarios that have been included in the assessment consider the operations in isolation, as well as cumulatively (with background air quality)

Key findings

The key findings of the atmospheric dispersion modelling are:

- For TSP:
  - The highest 24-hour TSP concentration of 136 µg/m^3 (including background) is predicted to occur at the Yandicoogina Gorge receptor.

  - It is predicted that there will be 14 excursions of the TSP criteria at the Yandicoogina Gorge receptor.
  - The modelling is predicting two excursions of TSP criteria at Yandi Camp 1.
- For PM_{10}:
  - The predicted annual average PM_{10} concentration at any discrete receptor (including background) is not predicted to exceed the NEPM criteria of 25 µg/m^3.
  - The highest 24-hour PM_{10} concentration of 68µg/m^3 (including background) is predicted to occur at the Heritage 2 receptor.
  - The Yandicoogina Gorge receptor is predicted to have up to 11 excursions of the NEPM criteria.
  - The KCHA1 receptor is predicted to have up to 2 excursions of the NEPM criteria.
  - All other receptors are not predicted to have any excursion of the NEPM criteria.
- For $PM_{2.5}$:
  - The maximum predicted annual average $PM_{2.5}$ concentration of 3.6 µg/m^3 (including background) occurs at the Yandicoogina Gorge receptor.
  - The maximum predicted annual average $PM_{2.5}$ concentration of 10.2 µg/m^3 (including background) occurs at the Yandicoogina Gorge receptor.
  - Yandi Camp 1 and Yandi Camp 2, the Rio Yandi Camp and Weeli Wolli Spring are not predicted to have any excursion of the NEPM criterion.
- For deposition:
  - the model is predicting deposition rates, without background, that are well below the relevant criteria.

It should be noted that a modelling result that is higher than the assessment criteria is interpreted as an indication that results may need further consideration for the sensitive receptor, and is not necessarily a predicted impact or loss of environmental value.

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1 Introduction

1.1 Background

BHP is proposing to mine the iron ore deposit 'Ministers North' approximately 80 kilometres (km) northwest of Newman in the Pilbara region of Western Australia (Figure 1-1). The processing facilities for the proposed operations will be located at the existing Yandi mining operations, approximately 15 kilometres (km) north-west of Ministers North. The proposed operations will include the following:

- At Ministers North:
  - drilling/blasting
  - loading and unloading of ore/waste
- Transport of material via:
  - Haulage
- At existing Yandi operations:
  - crushing/screening
  - stacking/reclaiming
  - rail load out.

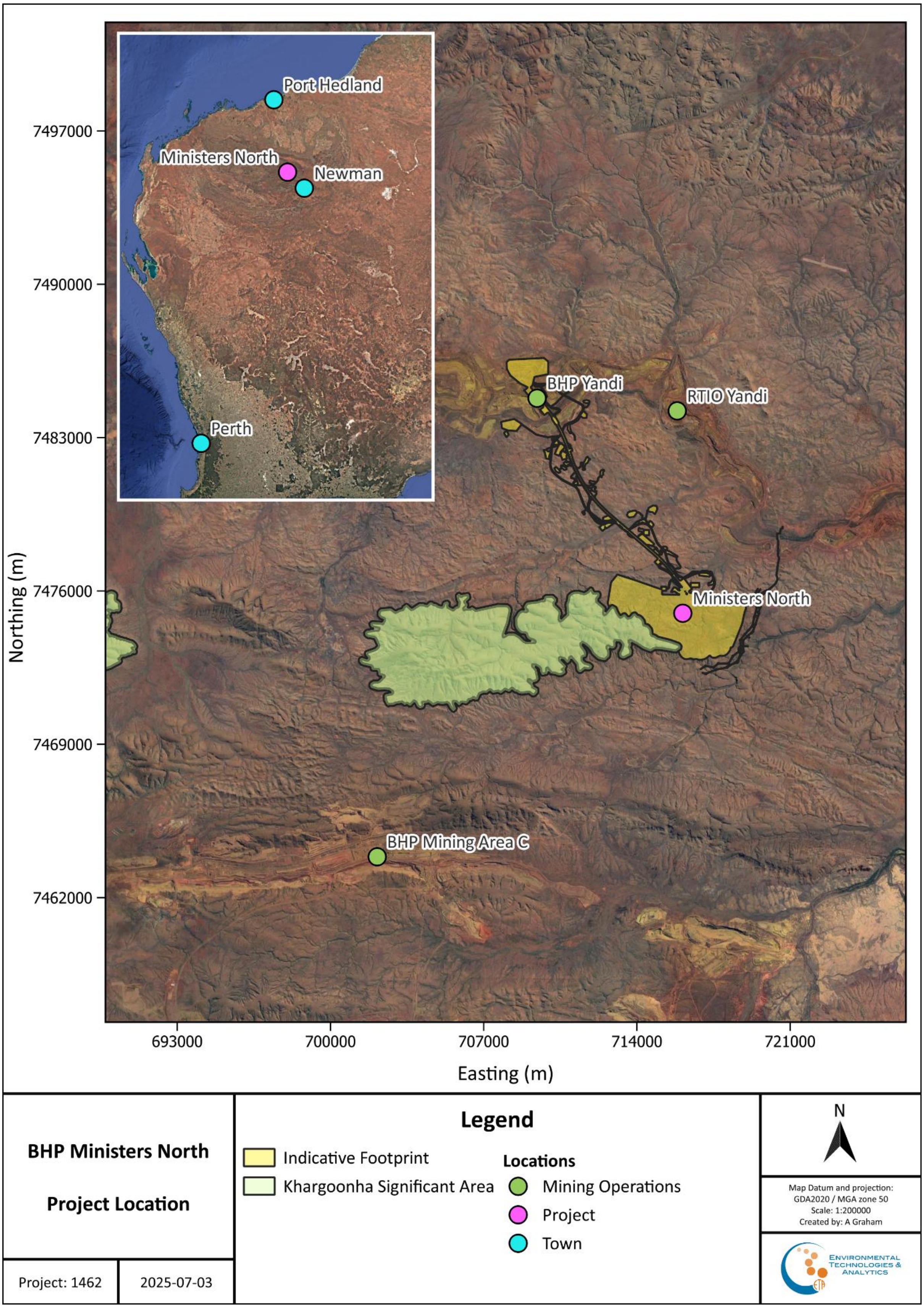

Figure 1-1: Project location and setting.

1.2 Scope of Work

The aim of this study was to assess the potential impact on nearby sensitive receptors from the proposed Ministers North Project ('Project').

The scope of this report covers the air quality modelling assessment of the Project. For the purposes of the air quality assessment, the Project comprises:

- mining operations,
- processing operations,
- haulage operations.

Ambient air quality and potential impacts are assessed in terms of the following:

- particulates as PM_{10}, $PM_{2.5}$ and TSP including deposition.

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 operations. The assessment includes:

- The study approach and methodology, including the regional climate, pollutants of interest and sensitive receptors in the immediate region, in Section 2.
- Impact assessment criteria for human health and amenity, ecological/biological, and heritage (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 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 study structure is shown in Figure 2-1 and detailed in the following subsections.

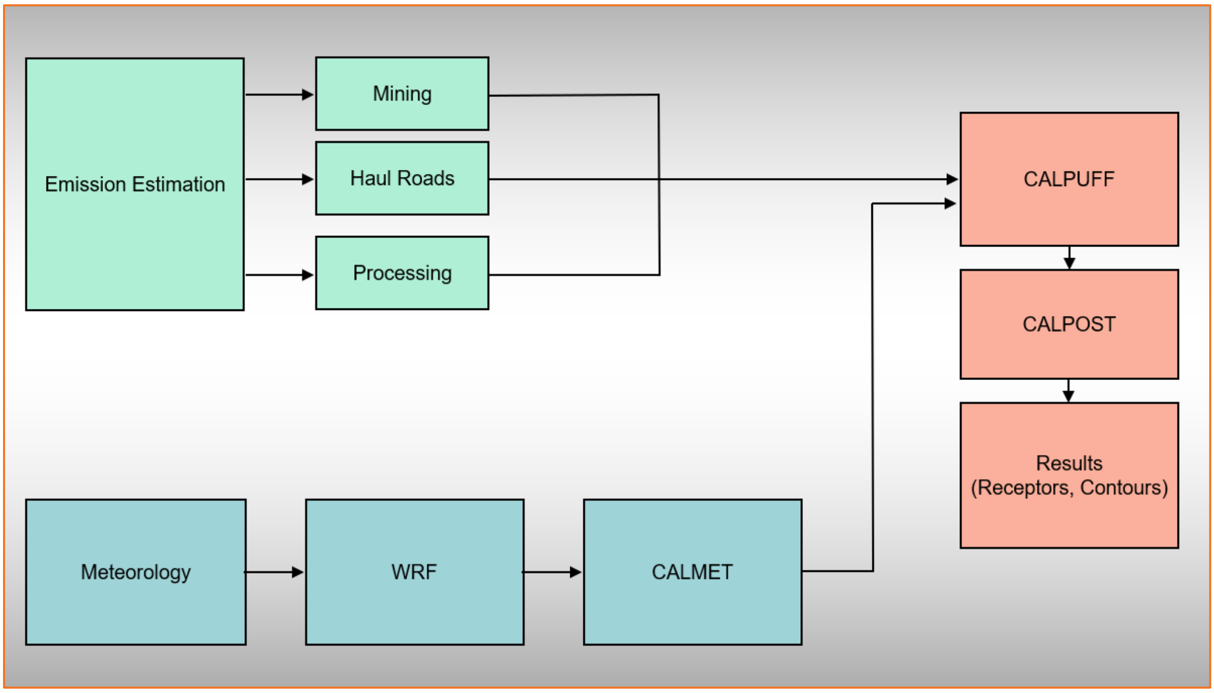

Figure 2-1: Air quality assessment – study approach.

2.1 Climate and Meteorology

The climate and meteorological characteristics of the region control the dispersion, transformation and removal (or deposition) of pollutants from the atmosphere, and therefore ambient air quality.

The 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 Pilbara region of Western Australia is characterised as semi-arid and has two primary seasons – wet and dry. The wet season, from October to April, is dominated by high temperatures and evaporation rates with isolated intense rainfall and cyclonic activity. The dry season, from May to September, is relatively dry with mild temperatures.

2.1.1 Temperature

The long-term temperature statistics from the BoM AWS in Newman are presented in Figure 2-2. From this figure it is apparent that the wet season (summer) period has very warm to hot days and warm nights while the dry season (winter) has warm days with cool, and occasionally cold, nights. Mean monthly maximum temperatures ranging from a high of 43.0°C in January to 27.6°C in July. The mean monthly minimum temperatures range from 20.6°C in January down to 2.0°C in July.

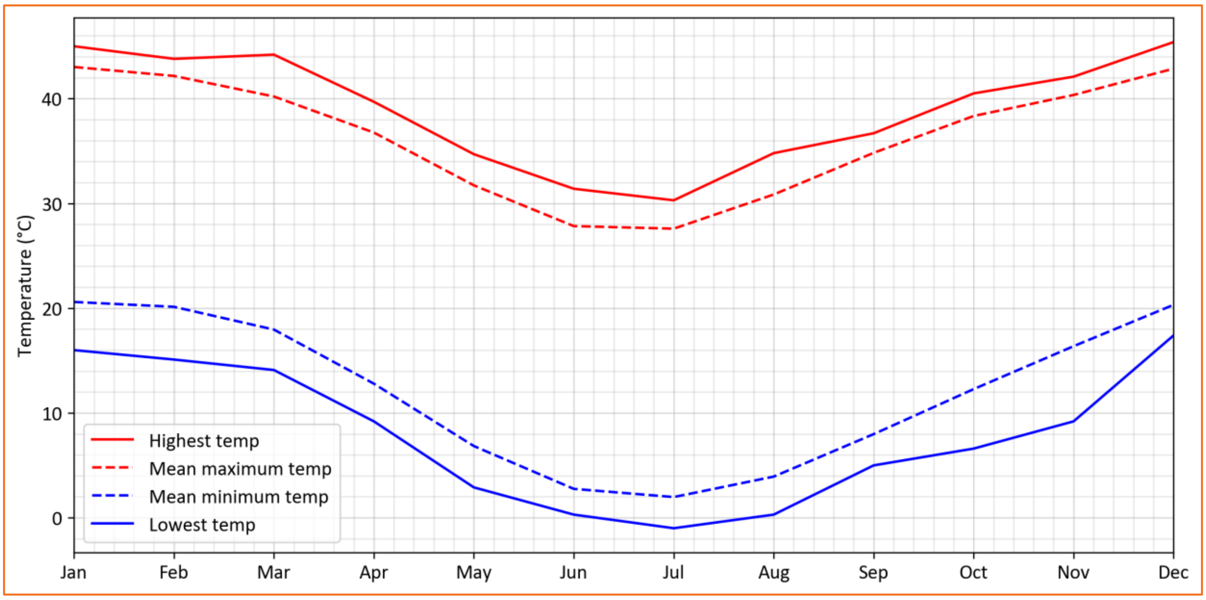

Figure 2-2: Long term temperature statistics, 2010 to 2023 (BoM, 2024).

2.1.2 Rainfall

The impact of cyclonic and monsoonal rainfall is evident in where the maximum monthly rainfall is significantly greater than the average rainfall, particularly during the cyclone period from December to March.

The long term annual average rainfall at Newman is 330 millimetres (mm). While rainfall is mainly associated with the formation of the occasional afternoon thunderstorms, the impact of cyclonic rainfall is evident in Figure 2-3 where the maximum monthly rainfall is significantly greater than the average rainfall, particularly during the cyclone period from December to March.

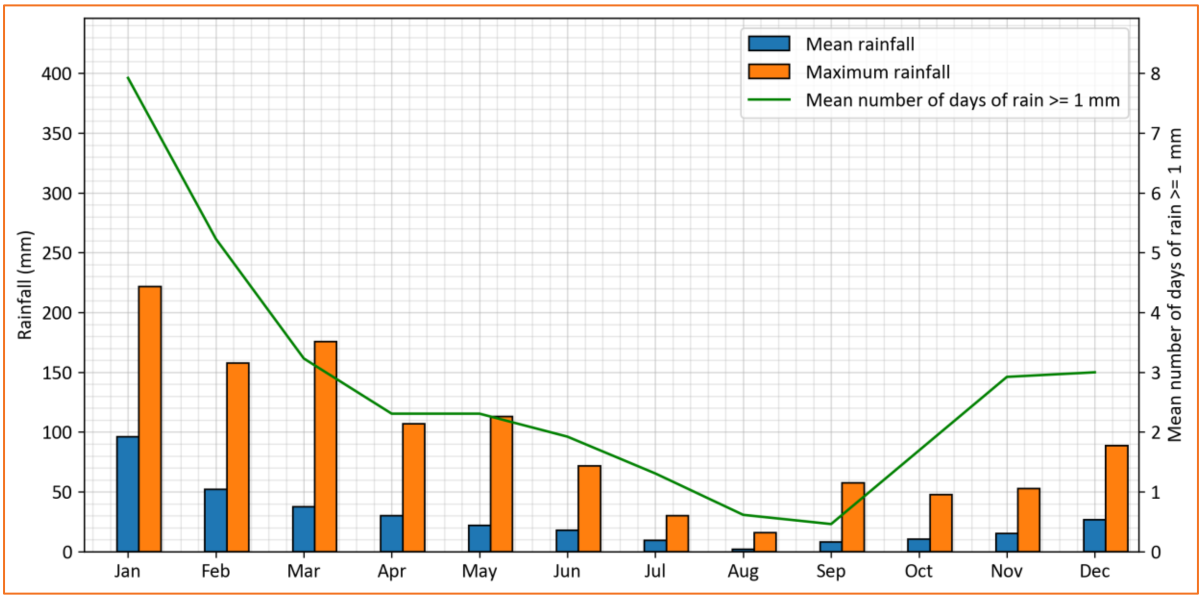

Figure 2-3: Long term rainfall statistics, 2010 to 2023 (BoM, 2024).

2.1.3 Wind speed/direction

As shown in Figure 2-4, the wind characteristics at the BoM Newman Aero AWS are characterised by variable winds throughout the year including:

- Summer winds come from the northeast to southeast along with a southwest component, the mean wind speed is 3.9 m/s.
- In Autumn winds come from the southeast and east, the mean wind speed is 3.2 m/s.
- In Winter winds come from the southeast and South-west, the mean wind speed is 3.0 m/s.
- In Spring winds come from the southwest, the mean wind speed is 3.8 m/s.

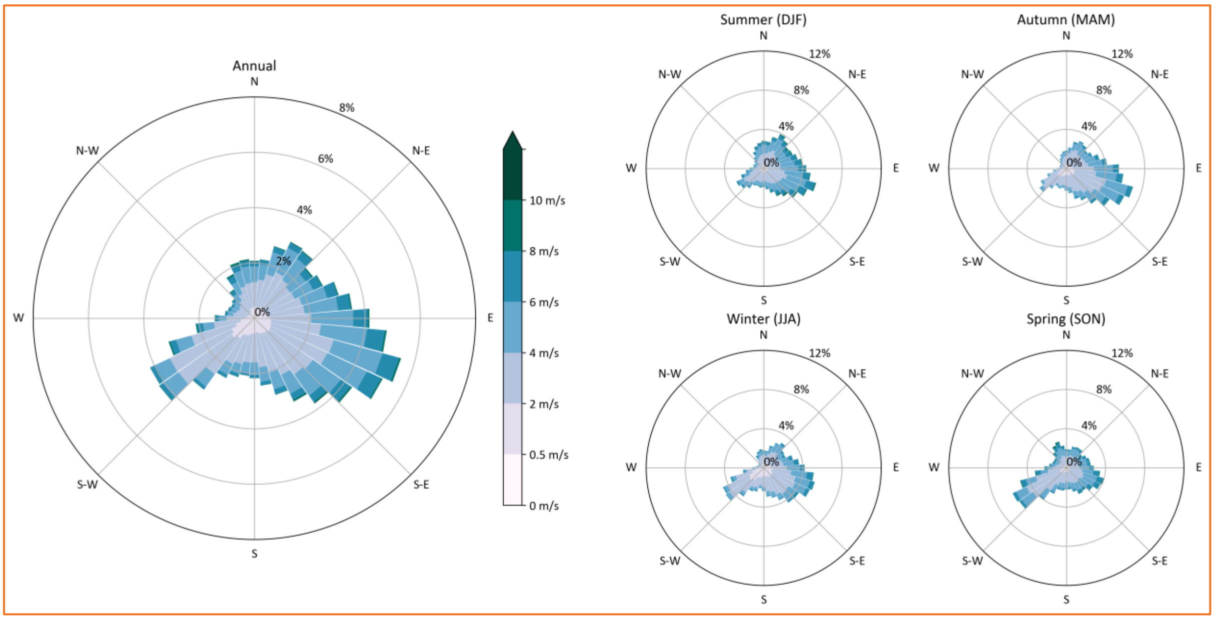

Figure 2-4: Annual and seasonal windrose from 2019 to 2023 (BoM, 2024).

2.2 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 2-1.

Table 2-1: 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 $PM_{2.5}$). An image of their respective sizes is presented in Figure 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

Pollutant to be Assessed		
		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.

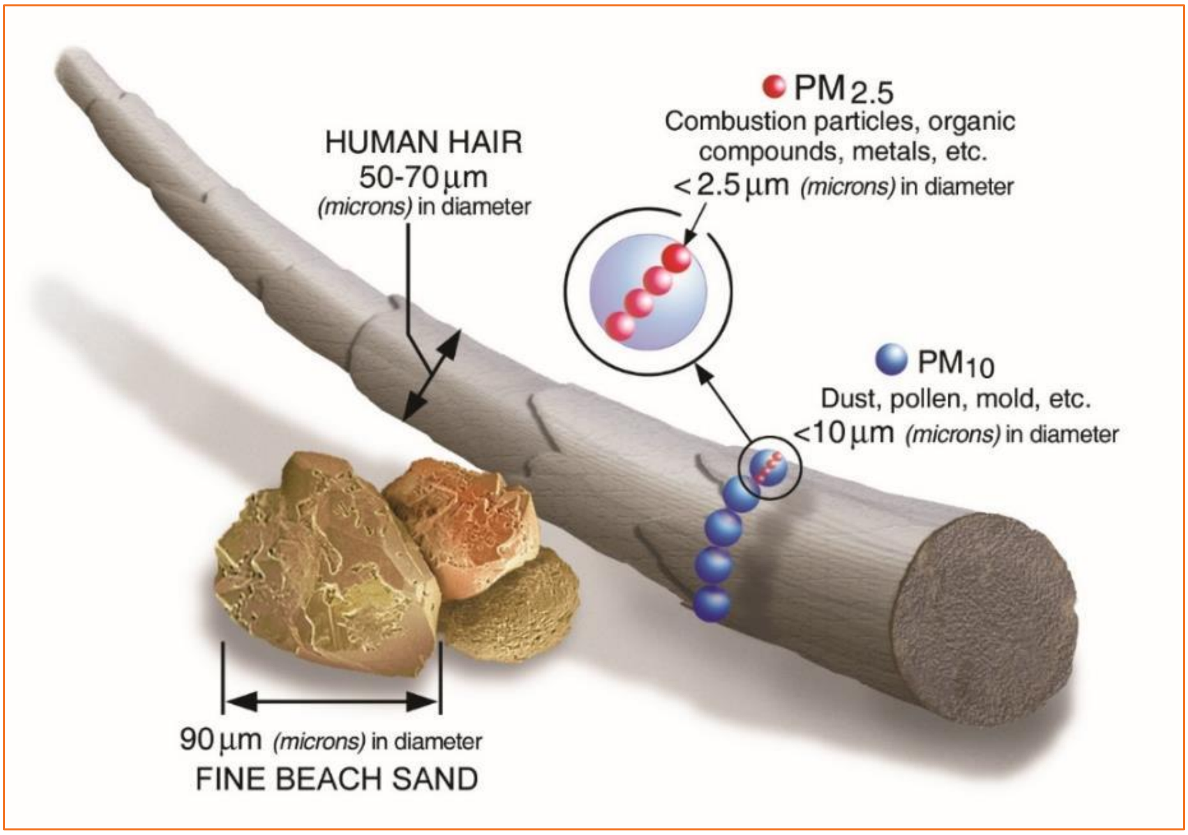

Figure 2-5: Example of particle sizes (USEPA, 2022).

2.3 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.

Within the Pilbara region BHP operate a network of ambient monitors. The closest monitor to the proposed Project is the Beta Attenuation Monitor (BAM) at the Yandi Spinifex camp and the location of this monitor, in relation to the Project, is presented in Figure 2-4.

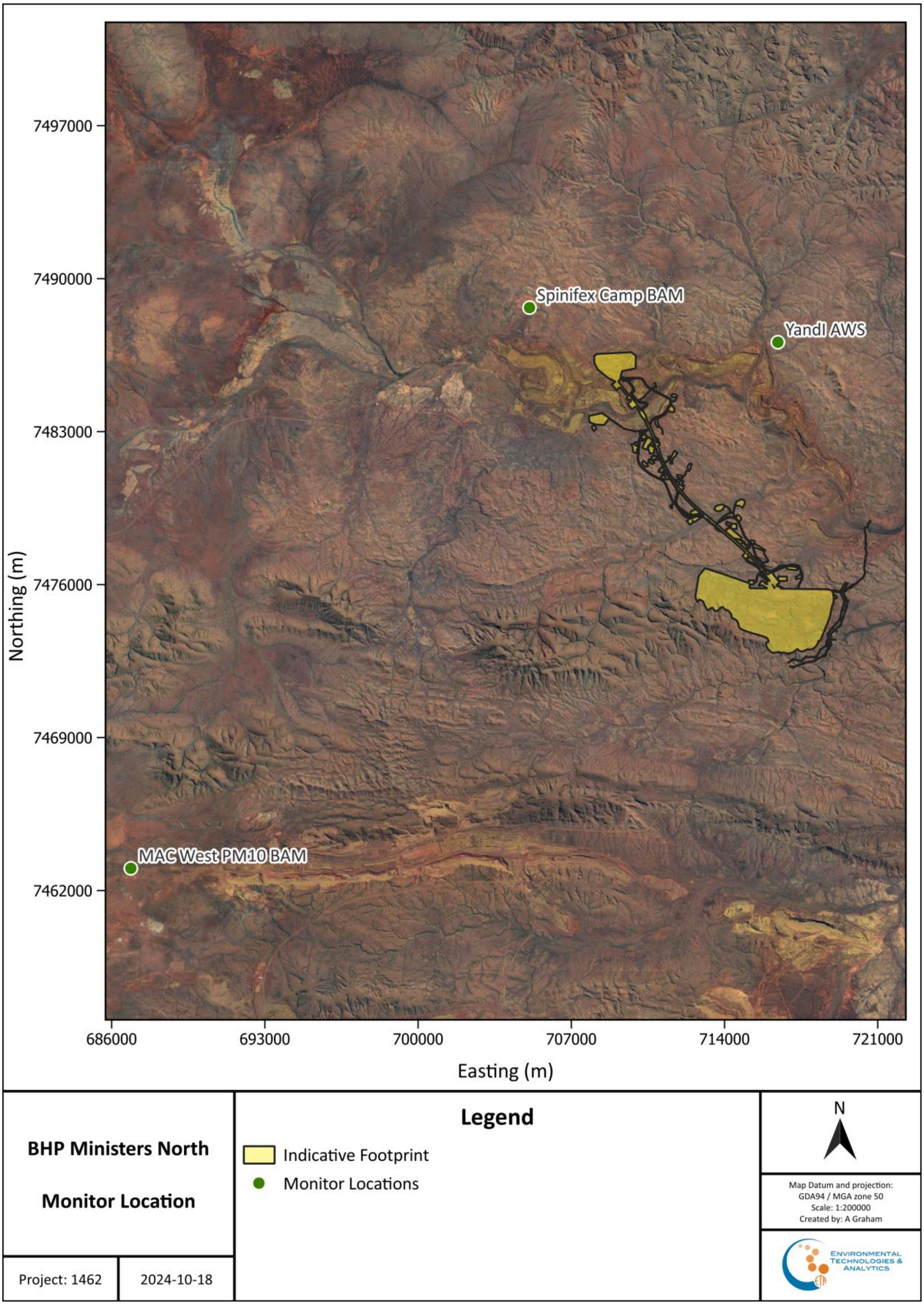

Figure 2-6: Location of PM_{10} monitors in the region.

To gain an understanding of the variation in dust concentrations over time the 24-hour averaged PM_{10} monitoring data from the BHP Spinifex Camp monitor is presented in Figure 2-7. It is highly probable this monitor is being impacted by nearby mining operations (Figure 2-6) and is not suitable for use as a background monitor.

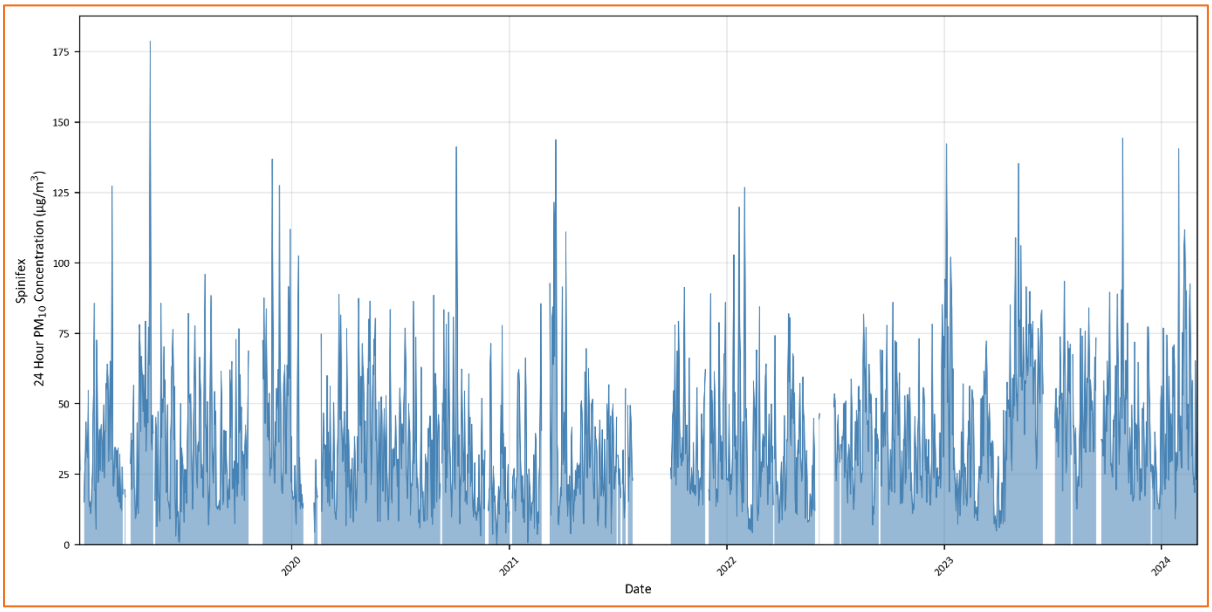

Figure 2-7: 24-hour PM_{10} concentrations from the Spinifex monitor (2019-2024).

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}: 18.2 µg/m^3 (24-hour average)
- $PM_{2.5}$: 2.7 µg/m^3 (24-hour average) (represents the ratio of $PM_{2.5}$:PM_{10} used in the emission estimation as presented in Section 4.3)
- TSP: 33.1 µg/m^3 (24-hour average)

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

2.4 Sensitive Receptors and Environmental Values

The discrete receptor locations used in the assessment are listed in Table 2-2, and are shown in Figure 2-8. These receptors are used for interpreting the model results at identified sensitive locations.

Table 2-2: Discrete sensitive receptor locations.

ID	Location	Easting (m)	Northing (m)	Approximate distance from mine
R1	Yandi Camp 1	705,040	7,488,640	18.1 km
R2	Yandi Camp 2	717,113	7,487,374	12.4 km
R3	Rio Yandi Camp	731,760	7,483,610	17.1 km
R4	Weeli Wolli Spring/Outfall	726,288	7,464,069	14.3 km
R5	Yandicoogina Gorge	719,778	7,473,830	1.5 km
R6	KCHA 1	714,050	7,474,250	1.0 km
R7	KCHA 2	713,150	7,474,250	2.0 km
R8	KCHA 3	711,950	7,474,250	3.0 km
R9	KCHA 4	711,050	7,474,250	4.0 km

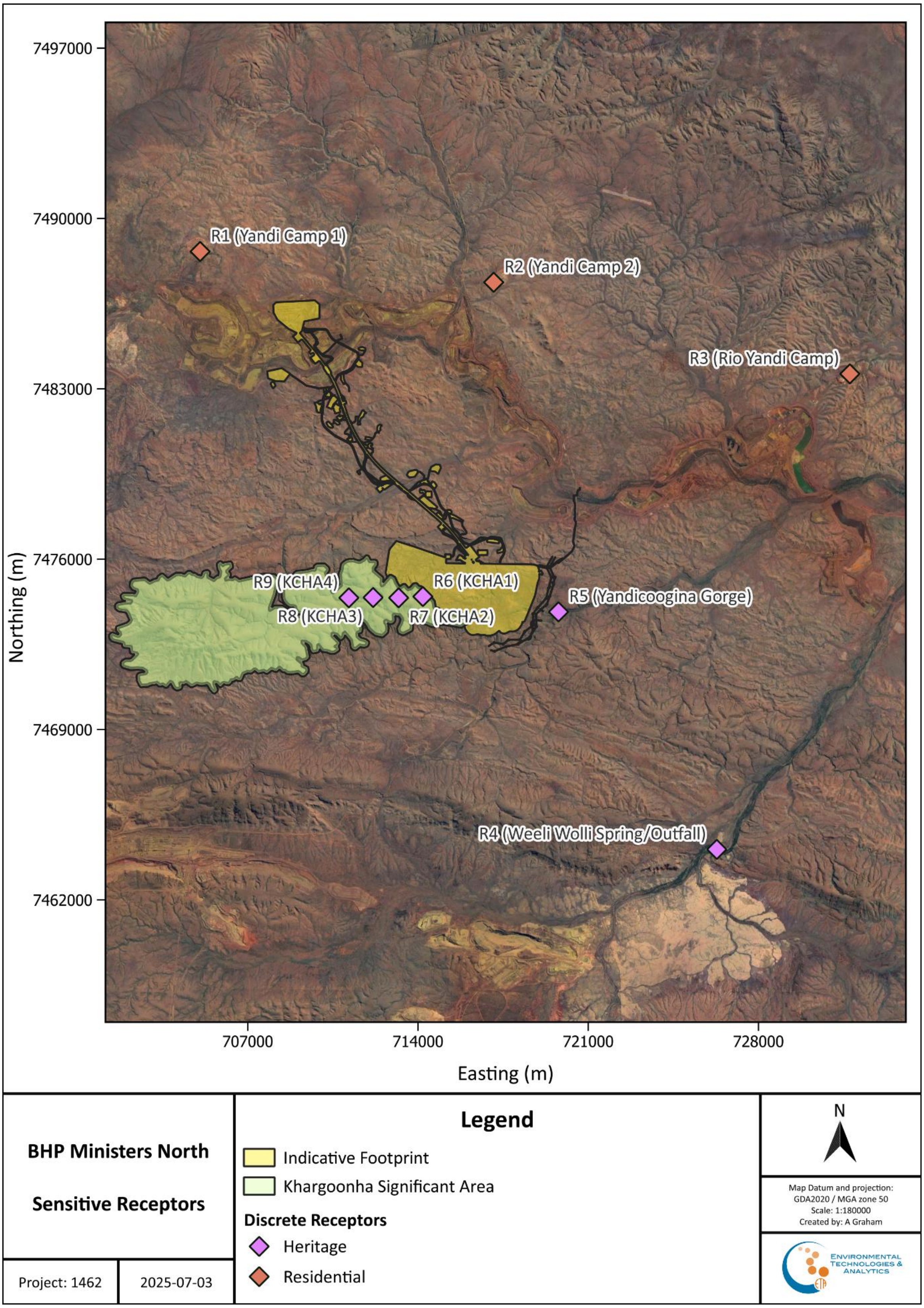

Figure 2-8: Discrete receptor locations.

3 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 operations, as well as the cumulative (background) impact (i.e. in conjunction with the existing emission sources in the area).

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 (nominated criteria). 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.

3.1 Human Health Assessment and Amenity 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 the time of this assessment both guidelines are draft and subject to post-public consultation finalisation.

Within Port Hedland the Port Hedland Dust Management Taskforce (Taskforce), in their final report to government (DSD, 2016), recommended that the interim guideline of 70 µg/m^3 for PM_{10} (24-hour average and excluding natural events) continue to be applied to residential areas. This value is used to assess the potential health impact on community receptors within the project model domain. In its response to the final recommendations of the Taskforce, in October 2018 the State Government agreed that the air guideline value of 70 µg/m^3 should apply to residential areas, wherever people live on a permanent basis in Port Hedland. In addition, the DoH agreed to the continuation of the 10 exceedances per year of the air guideline value, as measured at Taplin Street, on the understanding that the overall population for the Port Hedland peninsula does not exceed 17,000 (ie the modelled population in the Health Risk Assessment). Consistent with the approach adopted by the NEPM, there is no limit on exceedances solely as a result of natural events.

3.2 Impact on Vegetation Criteria

With respect to vegetation health, research on the effects of dust deposition has been undertaken in Australia by Doley (2006). Doley concluded that "*critical dust loads that result in significant alterations in the most sensitive plant functions vary with the particle size distribution and colour of the dust, from about 1 g/m^2 for carbon black with a median diameter of about 0.15 µm to about 8 g/m^2 for coarse road or limestone dusts with median diameters greater than about 50 µm. The critical loads vary with the plant function, and it is not possible to predict precisely the nature of one plant response from the knowledge of another*". For mineral dust, Farmer (1993) showed that direct physical effects of mineral dusts on vegetation became apparent only at relatively high surface loads (e.g. greater than 7 g/m^2).

For this study, 7 g/m^2/month is used as an indicative criterion for potential effects on vegetation. A modelling result that is higher than the assessment criteria is interpreted as an indication that results may need further consideration for the sensitive receptor, and is not necessarily a predicted impact or loss of environmental value.

3.3 Impact on Aboriginal Cultural Heritage

EPA's Technical Guidance for Aboriginal Cultural Heritage (ACH) (EPA, 2023) provides the framework for considering potential impacts that may arise due to air quality including dust. To date there are no published air quality ambient guidelines that would guide evaluation of ACH specifically. In the absence of any documented criteria for assessing air quality impact ACH, the ambient air quality assessment criteria intended to protect human amenity and nuisance values, are assumed to be 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.

3.4 Summary of Applied Assessment Criteria

A consolidated summary of the applicable assessment criteria and relevant receptor application is provided in Table 3-1.

Table 3-1: 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		
	70 $\mu g/m^3$	-	24-hour average	Not more than 10 days a year		Taskforce criteria (DSD, 2016)
$PM_{2.5}$	25 $\mu g/m^3$	23 $\mu g/m^3$	24-hour	exception event		DWER (2019) consistent with NEPM (NEPC, 2021)
	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	Amenity Proxy for protection of ecological values	DWER (2019)
Dust deposition	2 g/m^2/30 days		30-days	Maximum increase above background	Human Amenity | Nuisance | Heritage (ACH and other)	DWER (2021) referencing NZ MfE (2016)
	4 g/m^2/30 days		30-days	Maximum		DWER (2021) referencing NSW EPA (2017)

Pollutant	Air quality assessment criteria					Reference
	Concentration [1]	Concentration [2]	Averaging Period	Allowable Exceedances	Environmental value protected	
	7 g/m²/30 days		30-days	None	Proxy for protection of ecological values (protected fauna species) Ecological (vegetation/leaf) impact	Doley (2006)

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

4 Model Assessment

For this assessment, air dispersion modelling has been conducted using CALPUFF (Version 6.42, Level: 110325). The use of CALPUFF is consistent with the SEA (BHP, 2015). The model has been used to predict ground level concentrations across the model domain and at identified sensitive receptor locations. The potential air quality impacts associated with the Project have been considered in isolation of other emission sources. 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 grid cell at 767,000 km Easting and 7,406,000 km Northing (UTM Zone 50 S). 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 V3.7) model (http://wrf-model.org/index.php) was used to generate hourly 3-dimensional data for the Newman 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 are provided in Appendix A.

4.1.2 CALMET

The 3-Dimensional meteorological data generated by WRF was input to CALMET (Version 6.33 Level: 110324) 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 150 x 150 grid domain at a spatial resolution of 300 m. Vertically, the model consisted of 12 levels extending to 3,000 m. The southwest corner coordinates of the domain were 692,000 km Easting and 7,460,000 km Northing (UTM Zone 50 S).

Shuttle Radar Topography Mission (SRTM) data with 90 m resolution was 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 default CALMET land use scheme is sourced from the Australian Collaborative Land Use and Management Program (ACLUMP).

The CALMET results are provided in Appendix A.

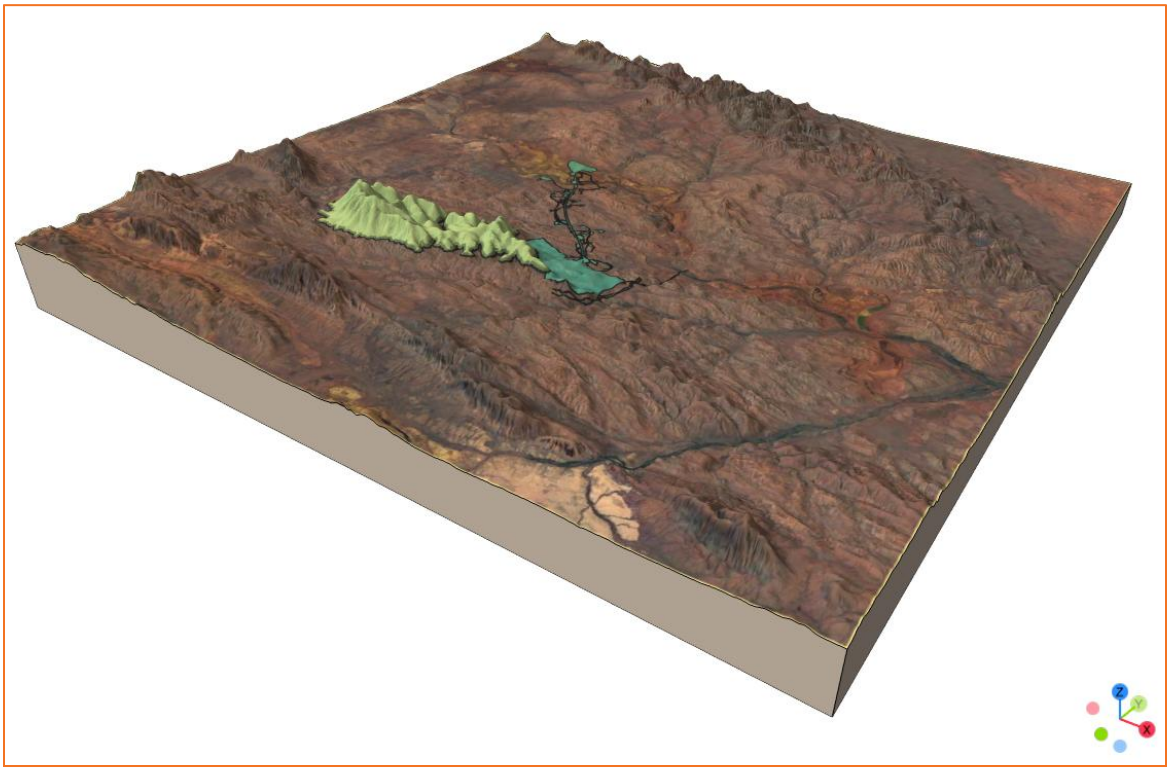

Figure 4-1: Image of SRTM terrain elevation used in CALMET (vertical height is exaggerated by 5x).

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 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 both on a set grid (gridded receptors) and at 6 specified locations (discrete receptors). The model domain was defined as 40 km in the east–west direction and 38 km in the north-south direction at a spacing of 300 m x 300 m.

4.2.1 Emission sources

Sources have been characterised as either area sources or volume sources in the dispersion model. Area sources were assigned to open areas while volume sources were assigned to mining activities in the pits, haulage and sources within the processing facility. The locations of sources for the proposed Ministers North mine are presented in Figure 4-2.

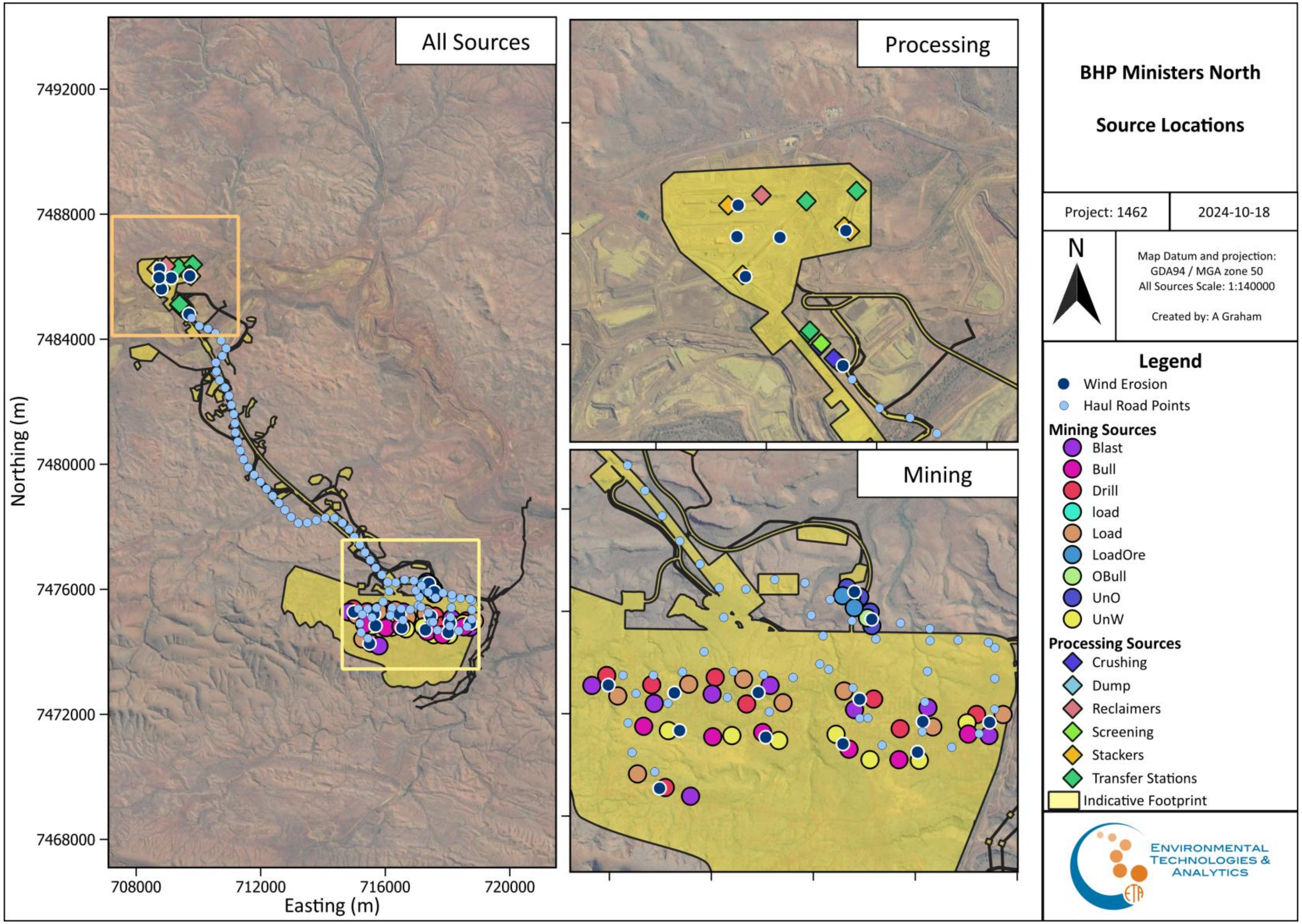

Figure 4-2: Emission sources in the model for mining at the proposed Ministers North mine.

4.3 Particle Size Distribution

Since dust is subject to gravitation settling, assumptions need to be made regarding particle sizes.

A particle size distribution for modelling dust dispersion was therefore estimated using composite data from USEPA (1999) for dust emissions from “aggregate handling and storage piles”, “industrial wind erosion” and “unpaved roads”. These categories are considered the most appropriate for mining sources. The resulting distributions are shown in Table 4-1.

Table 4-1: Particle size distribution (USEPA, 1999).

Size range (µm)	Representative size (µm)	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. It includes the emissions from mine operations, facilities and associated infrastructure including the road network. 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.

5.1 Emission Sources Inventory

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

- Drilling and blasting
- Material handling from loading and unloading activities involving
  - loading trucks
  - unloading trucks
  - bulldozing
  - crushing
  - screening
  - stacking
  - reclaiming
  - rail load out
  - conveyors
  - transfer stations
- Wheel generated dust from roads and haul roads
- Wind erosion from stockpiles and open areas.

A summary of the estimated forecast annual tonnages for the proposed Project are presented in Table 5-1. From this table it is apparent that FY30 represents the maximum forecast tonnage. To ensure that the model is conservative the emission estimation is based on this mining year.

Table 5-1: Annual mining tonnages (Mtpa).

Project Activity	FY27	FY28	FY30	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38	FY39
Ore	2.5	8.6	16.9	21.1	24.9	18.1	15.2	15.2	16.4	14.7	20.1	19.5	4.2
Waste	2.7	16.4	19.7	27.4	22.4	28.7	31.6	31.5	30.4	32.1	26.7	19.9	3.8
Total	5.2	25.0	36.6	48.5	47.3	46.8	46.8	46.7	46.8	46.8	46.8	39.4	8.0

5.1.1 Drilling

Emissions for drilling have been calculated using the default emissions outlined in Appendix A, consistent with the National Pollutant Inventory (NPI) Emissions Estimation Technique (EET) Manual for Mining (EA, 2012a). The default values are:

- TSP: 0.59 kg/hole
- PM_{10}: 0.31 kg/hole

- $PM_{2.5}$: 15% of PM_{10} emissions.

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

5.1.2 Blasting

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

Equation 1 $\mathbf{EF_{TSP\ (kg/blast)} = 0.00022 * A^{1.5}}$

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 emissions from blasting for PM_{10} are contained in Appendix B.

5.1.3 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 from loading for PM_{10} are contained in Appendix B.

5.1.4 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 emissions from unloading for PM_{10} are contained in Appendix B.

5.1.5 Bulldozing

Emissions for the operation of bulldozers on both ore and waste have been determined using Equation 16 and 17 outlined in Appendix A of the EET for Mining. The silt and moisture contents used were the defaults listed in the manual (10% moisture, 2% silt).

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

5.1.6 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 EET for Mining.

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

5.1.7 Handling and transferring

The emissions for the handling and transferring, including stacking and reclaiming, were determined using the default emission factors for high moisture content ores from Table 3 of the EET for Mining.

The emission factor for $PM_{2.5}$ emissions is taken as 15% of the PM_{10} emissions. The statistics of the annual emissions from handling and transferring for PM_{10} are contained in Appendix B.

5.1.8 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 272 tonnes – being the average of an empty and fully laden CAT793E haul truck and the default silt content of 10% was utilised.

Equation 2: $$EF_{(kg/VKT)} = \frac{0.4536}{1.6093} \times k \times \left(\frac{s_{(\%)}}{12}\right)^{a} \times \left(\frac{W_{(t)}}{3}\right)^{b}$$

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 from haul roads for PM_{10} are contained in Appendix B.

5.1.9 Wind erosion

The default emission factor for wind erosion in the EET 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 3:

Equation 3 $$PM_{10}\ (g/m^2/s) = k\,[WS^3 * (1- (WS_0^2/WS^2)] \quad WS > WS_0$$

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

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

For this assessment the following parameters were used:

WS_0 = 5.4 m/s
K = 4.5 x 10^{-6} (for Yandi processing area)
K = 2.4 x 10^{-6} (for Ministers North mining area)

The wind speed for this assessment was derived from extracts from CALMET (Appendix A). Given the distance between the proposed mining operations and the existing processing facilities at Yandi (Figure 1-1), the emission estimation process utilised two extracts – one for the mining operations and one of the processing area. For this assessment an overall PM_{10} emission rate of 0.41 kg/ha/hr was applied. This is higher than the emission rate of 0.2 kg/ha/hr specified in the EETM for Mining (EA, 2012) which, as outlined in SKM (2005), is derived for the Hunter Valley region of New South Wales (NSW). The SKM (2005) report notes that an applicable rate for the Pilbara region is 0.4 kg/ha/hr for PM_{10} which is the value used in this assessment. This increase in wind erosion emissions is based on a range of factors including increased wind speed, lower rainfall and higher evaporation rates in 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.

5.2 Emission Controls

Emissions controls (for dust abatement) were included in the emissions estimation, based on information provided by BHP. 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	Bulldozing	None	-
	Loading ore and waste	None	-
	Loading ore from ROM pad to crusher	Water sprays	50%
	Unloading waste	None	-
	Unloading ore at ROM pad	None	-
	Unloading ore onto primary crusher	Water sprays	50%
	Drilling	None	-
	Blasting	None	-
	Wind erosion (OSA and ROM pad)	Watering	50%
	Pit reduction	-	PM_{10} – 5%
Haul road	Hauling	Watering Chemical	Watering – 50% Chemical – 80%
Processing Facility	Unloading ore into primary crusher	Water sprays	50%
	Primary crushing of ore	Water sprays	50%
	Screening plant	Enclosed with extraction	75%
	Secondary crushing building	Enclosed with extraction	75%
	Transfer station	-	-
	Stackers	Luffing/water sprays	75%
	Train load out	Water sprays	50%
	Wind erosion (open area)	Watering	50%

A summary of the estimated annual emissions from the Project is shown in Table 5-3.

Table 5-3: Estimate of annual particle emissions from the Project (kg/yr).

Project Activity	TSP	PM_{10}	$PM_{2.5}$
Drilling	32,264	32,209	4,831
Blasting	66,826	66,024	9,904
Loading (pit)	606,713	553,322	82,998
Unloading waste	328,690	117,781	17,667
Unloading ore	38,487	13,791	2,069
Loading (ore)	176,033	84,496	12,674
Bulldozers	339,844	82,734	12,410
Dump pocket (crusher)	150,322	53,865	8,080
Crushing	137,795	52,613	7,892
Screening	100,215	75,161	11,274
Stacking	172,330	68,932	10,340
Transfer stations	112,793	45,117	6,768
Reclaimers	62,720	25,088	3,763
Haulage	1,724,904	509,124	76,369
Wind erosion	363,762	252,739	37,911
TOTAL	**4,413,698**	**2,032,996**	**304,950**

6 Predicted air quality impact

Comparison of the modelled results to the assessment criteria is intended to provide an objective evaluation of the potential impact of the operations at the nearest sensitive receptors. Modelled ground-level concentrations for key air pollutants have been compared to ambient air quality assessment criteria to determine the potential impacts.

The results of the modelling are presented in two formats:

- Project only: modelled results for the project scenario, representing the "project only" potential impact.
- Project with background: the project emissions inclusive of the background concentrations (Section 2.3).

6.1 Particulates as PM_{10}

The key aspects of the impact assessment of PM_{10} with and without background concentration are presented in Table 6-1. From this table it can be interpreted that:

- The predicted annual average PM_{10} concentration at any discrete receptor (including background) is not predicted to exceed the NEPM criteria of 25 µg/m^3.
- The highest 24-hour PM_{10} concentration of 68 µg/m^3 (including background) is predicted to occur at the Yandicoogina Gorge receptor.
- The Yandicoogina Gorge receptor is predicted to have up to 11 excursions of the NEPM criteria.
- The KCHA1 receptor is predicted to have up to 2 excursions of the NEPM criteria.
- All other receptors are not predicted to have any excursion of the NEPM criteria.
- It should be noted that the modelling represents the highest potential mining year and therefore the results are very conservative.

Table 6-1: Receptor locations - Statistics for predicted 24-hour average PM_{10} concentrations.

ID	Receptor	Statistics - predicted 24-hour average PM_{10} concentrations (µg/m^3)							Comments
		Maximum	Percentile				Annual Average	Days >50 µg/m^3	
			99th	98th	95th	70th			
R1	Yandi Camp 1	29	19	18	13	4	3.3	0	Isolation
		47	37	36	31	22	21.5	0	+Background
R2	Yandi Camp 2	12	9	9	6	2	1.8	0	Isolation
		30	27	27	25	21	20.0	0	+Background
R3	Rio Yandi Camp	6	4	3	2	1	0.5	0	Isolation
		24	22	22	21	19	18.7	0	+Background
R4	Weeli Wolli Spring	3	3	2	1	0	0.3	0	Isolation
		22	21	21	20	19	18.5	0	+Background
R5	Yandicoogina Gorge	50	39	34	21	8	5.8	0	Isolation
		68	57	52	39	26	24.0	11	+Background

ID	Receptor	Statistics - predicted 24-hour average PM_{10} concentrations (µg/m³)							Comments
		Maximum	Percentile				Annual Average	Days >50 µg/m³	
			99th	98th	95th	70th			
R6	**KCHA1**	32	17	17	13	5	4.5	0	Isolation
		50	35	35	31	23	22.5	2	+Background
R7	**KCHA2**	23	10	10	7	3	2.7	0	Isolation
		41	28	28	25	21	20.7	0	+Background
R8	**KCHA3**	19	6	6	4	2	1.6	0	Isolation
		37	24	24	22	20	19.6	0	+Background
R9	**KCHA4**	16	5	5	3	1	1.3	0	Isolation
		34	23	23	21	19	19.3	0	+Background

The annual average PM_{10} concentrations, without and with background, are presented in Figure 6-1 and Figure 6-2. The dispersion pattern along a southeast-northwest axis reflects the prevailing south-easterly winds of the region.

The maximum predicted 24-hour PM_{10} concentrations with and without background are presented in Figure 6-3 and Figure 6-4. As expected, highest 24-hour maximum concentration occurs over the pit and processing areas.

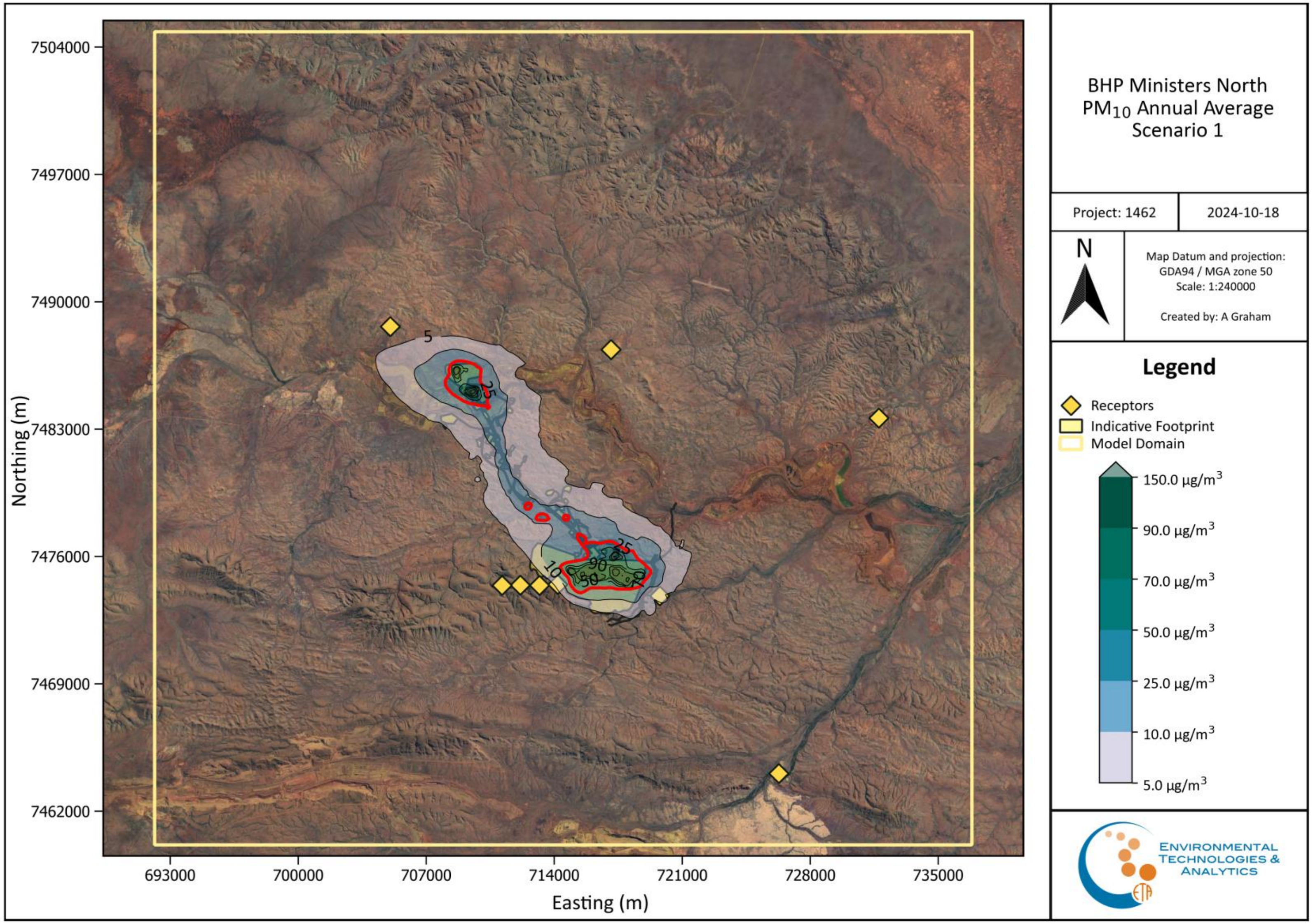

Figure 6-1: Annual average PM_{10} concentration – without background.

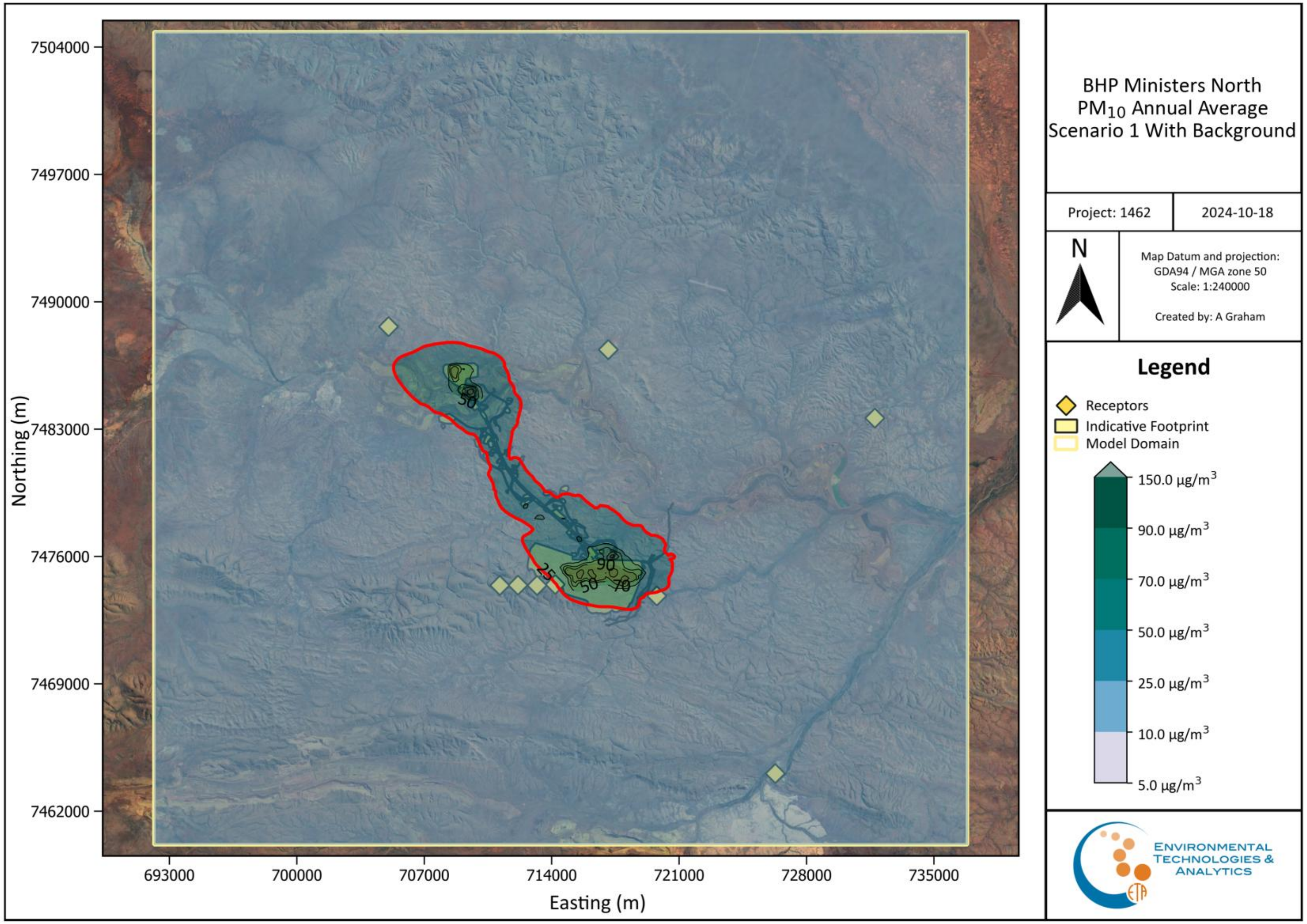

Figure 6-2: Annual average PM_{10} concentration – with background.

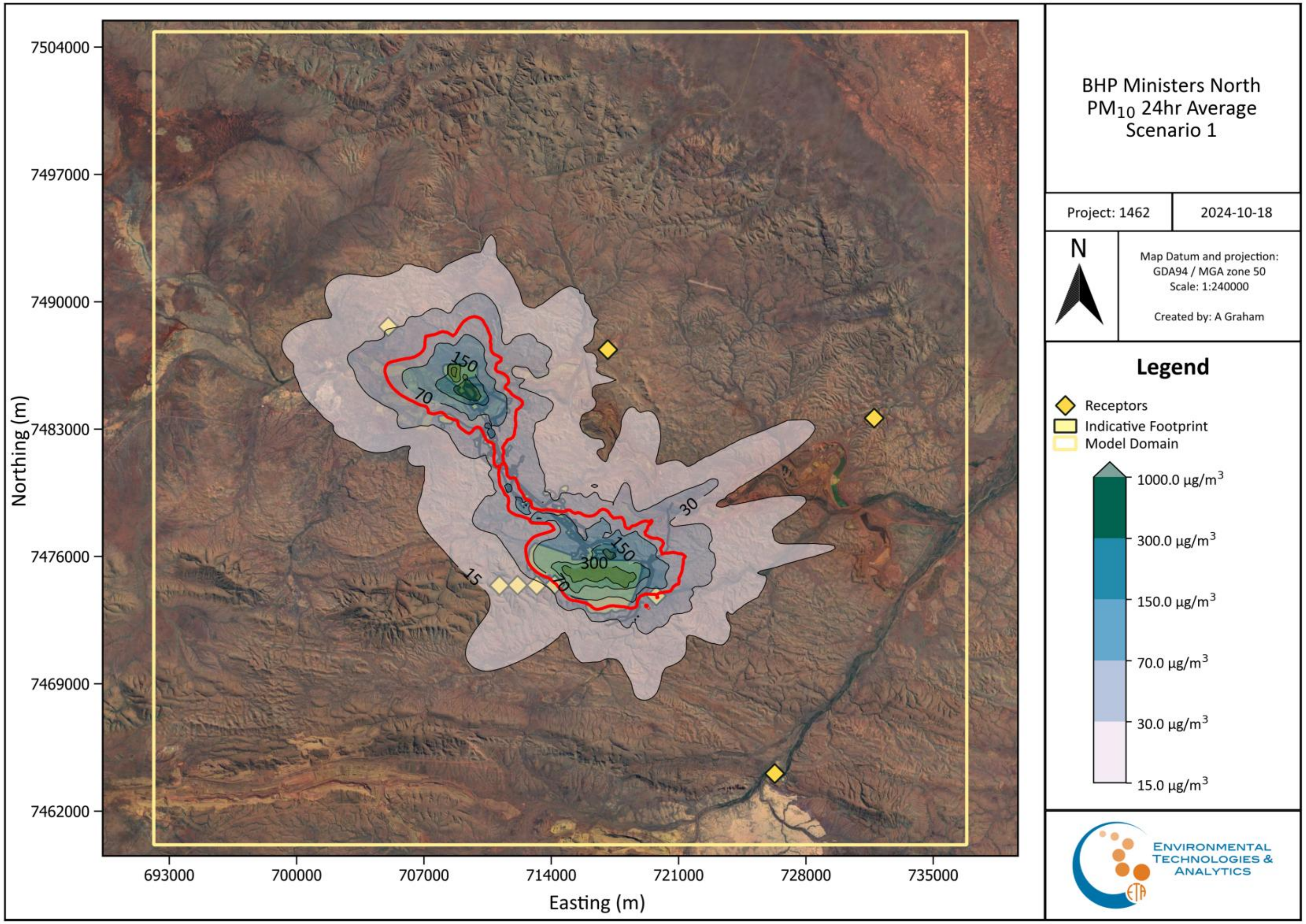

Figure 6-3: 24-hour average PM_{10} concentration –without background.

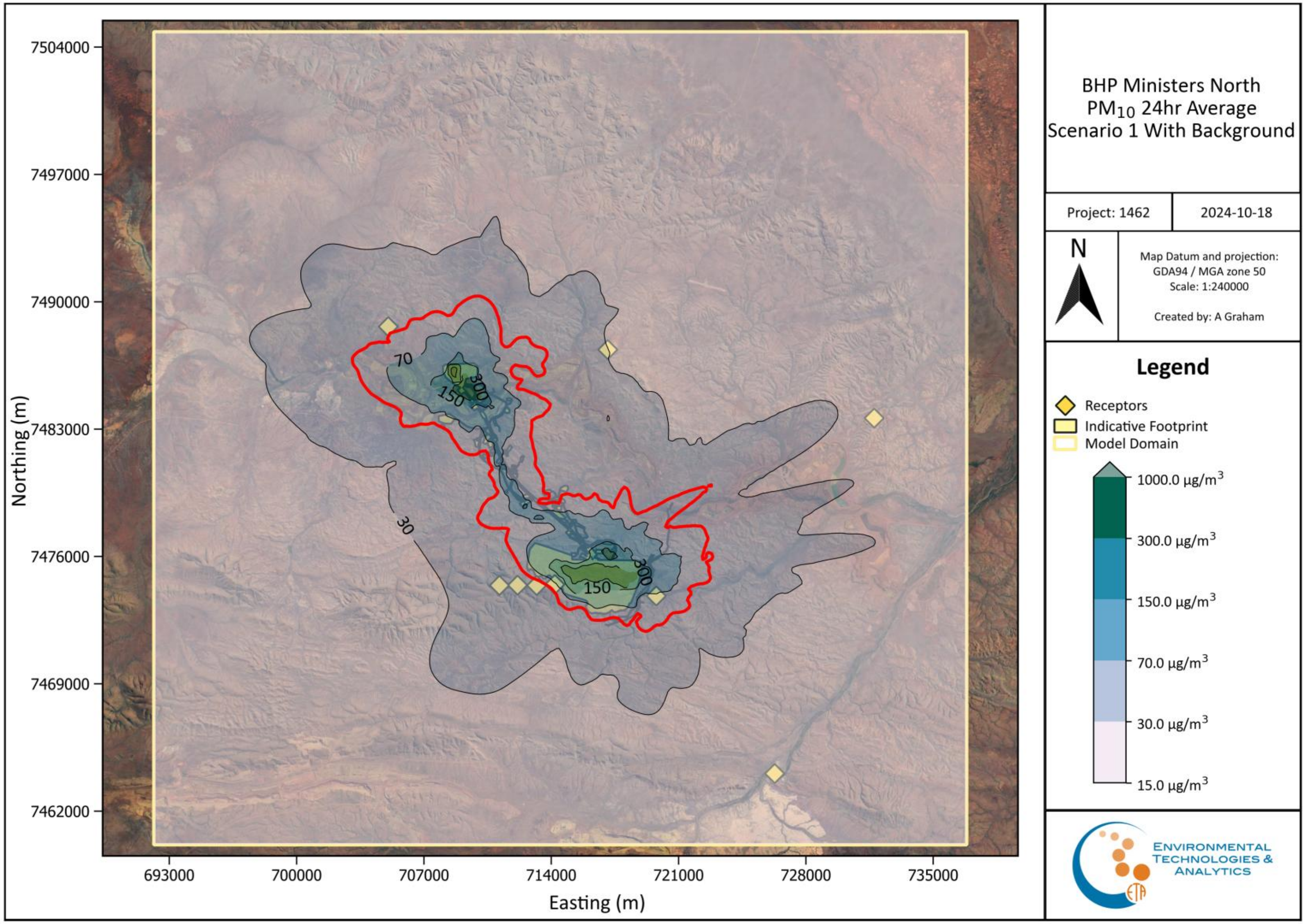

Figure 6-4: 24-hour average PM_{10} concentration – with background.

6.2 Particulates as $PM_{2.5}$

The key aspects of the impact assessment of $PM_{2.5}$ with and without background concentration are presented in Table 6-2. From this table it can be interpreted that:

- The maximum predicted annual average $PM_{2.5}$ concentration of 3.6 µg/m^3 (including background) occurs at the Yandicoogina Gorge receptor.
- The maximum predicted annual average PM_{10} concentration of 10.2 µg/m^3 (including background) occurs at the Yandicoogina Gorge receptor.
- Yandi Camp 1 and Yandi Camp 2, the Rio Yandi Camp and Weeli Wolli Spring are not predicted to have any excursion of the NEPM criterion.
- It should be noted that the modelling represents the highest potential mining year and therefore the results are very conservative.

Table 6-2: Receptor locations - Statistics for predicted 24-hour average $PM_{2.5}$ concentrations.

ID	Receptor	Statistics - predicted 24-hour average PM_{10} concentrations (µg/m^3)							Comments
		Maximum	Percentile				Annual Average	Days >25 µg/m^3	
			99th	98th	95th	70th			
R1	Yandi Camp 1	4.4	2.8	2.6	2	0.6	0.5	0	Isolation
		7.1	5.5	5.4	4.7	3.3	3.2	0	+Background
R2	Yandi Camp 2	1.8	1.4	1.3	1	0.3	0.3	0	Isolation
		4.5	4.1	4	3.7	3.1	3	0	+Background
R3	Rio Yandi Camp	0.8	0.6	0.5	0.3	0.1	0.1	0	Isolation
		3.6	3.3	3.2	3.1	2.8	2.8	0	+Background
R4	Weeli Wolli Spring	0.5	0.4	0.3	0.2	0	0	0	Isolation
		3.2	3.1	3.1	2.9	2.8	2.8	0	+Background
R5	Yandicoogina Gorge	7.4	5.9	5.1	3.1	1.2	0.9	0	Isolation
		10.2	8.6	7.8	5.8	3.9	3.6	0	+Background
R6	KCHA1	5	2	2	2	1	1	0	Isolation
		7	5	5	5	3	3	0	+Background
R7	KCHA2	3.4	1.5	1.5	1.1	0.5	0.4	0	Isolation
		4	4	4	3	3	4	0	+Background
R8	KCHA3	2.8	0.9	0.9	0.6	0.3	0.2	0	Isolation
		4	4	3	3	3	4	0	+Background
R9	KCHA4	2.5	0.7	0.7	0.5	0.2	0.2	0	Isolation
		3	3	3	3	3	3	0	+Background

The annual average $PM_{2.5}$ concentrations, without and with background are presented in Figure 6-5 and Figure 6-6. The dispersion pattern along a southeast-northwest axis reflects the prevailing south-easterly winds of the region.

The maximum predicted 24-hour PM_{10} concentrations without background are presented in Figure 6-7 and Figure 6-8.

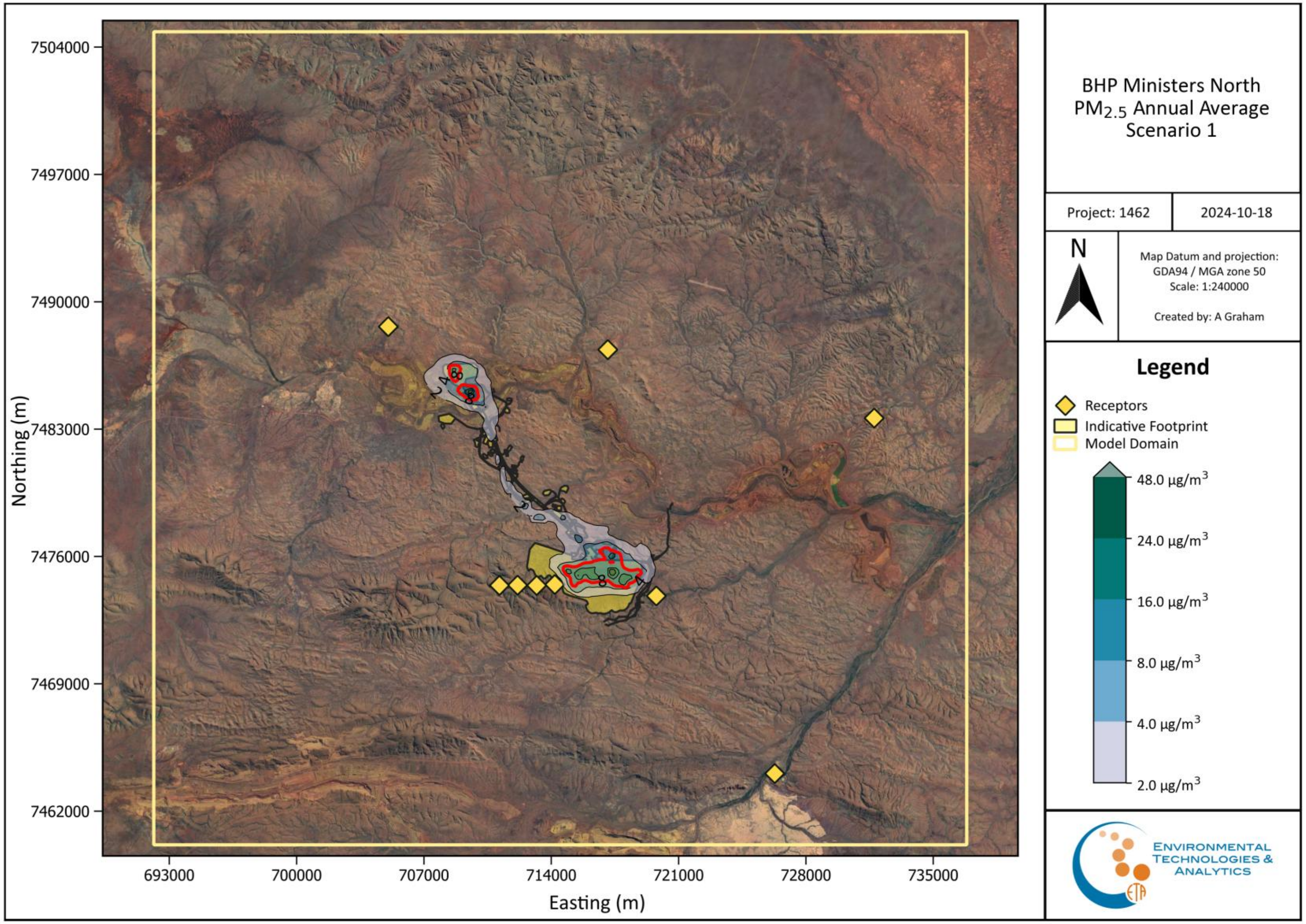

Figure 6-5: Annual average $PM_{2.5}$ concentration – without background.

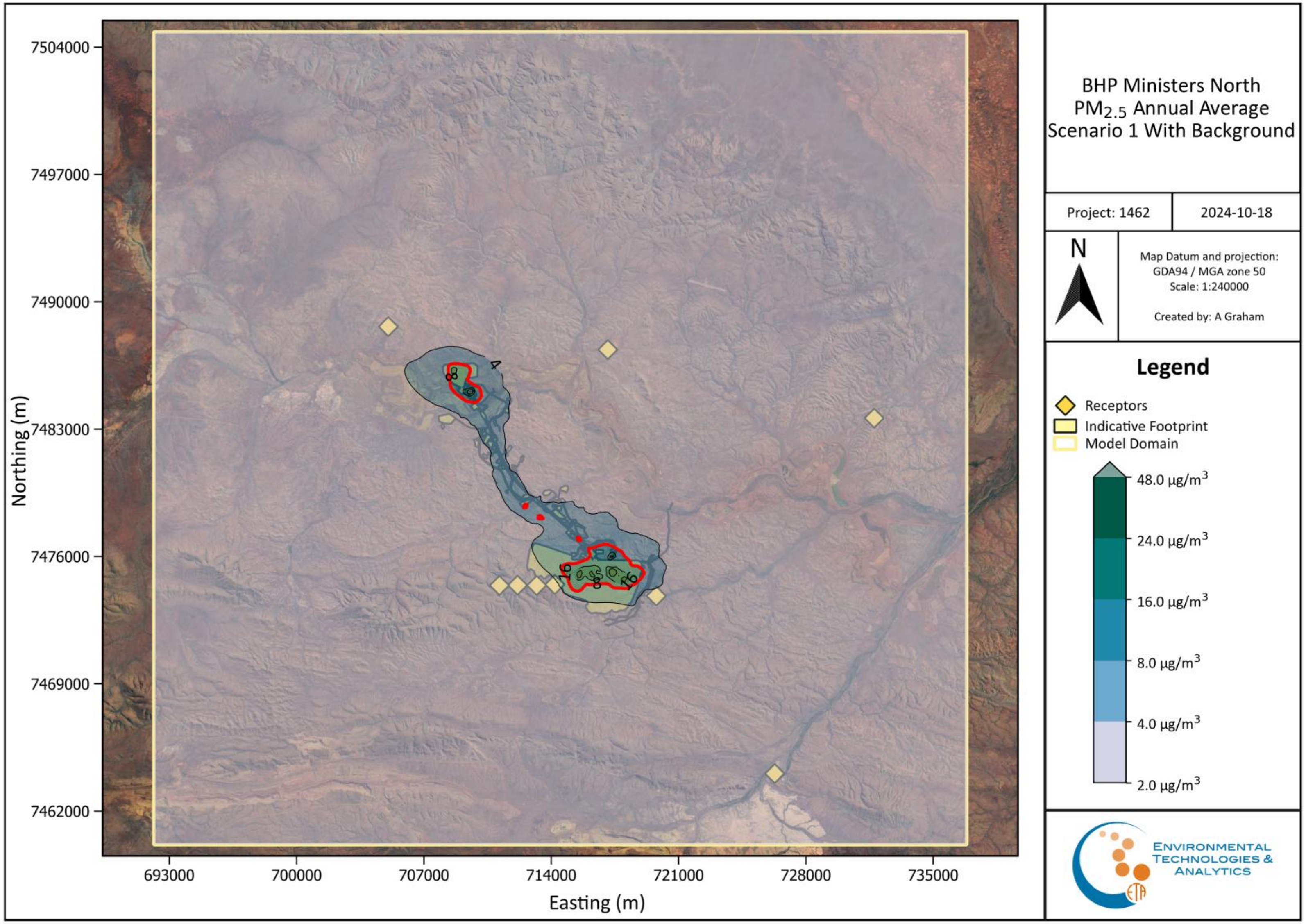

Figure 6-6: Annual average $PM_{2.5}$ concentration – with background.

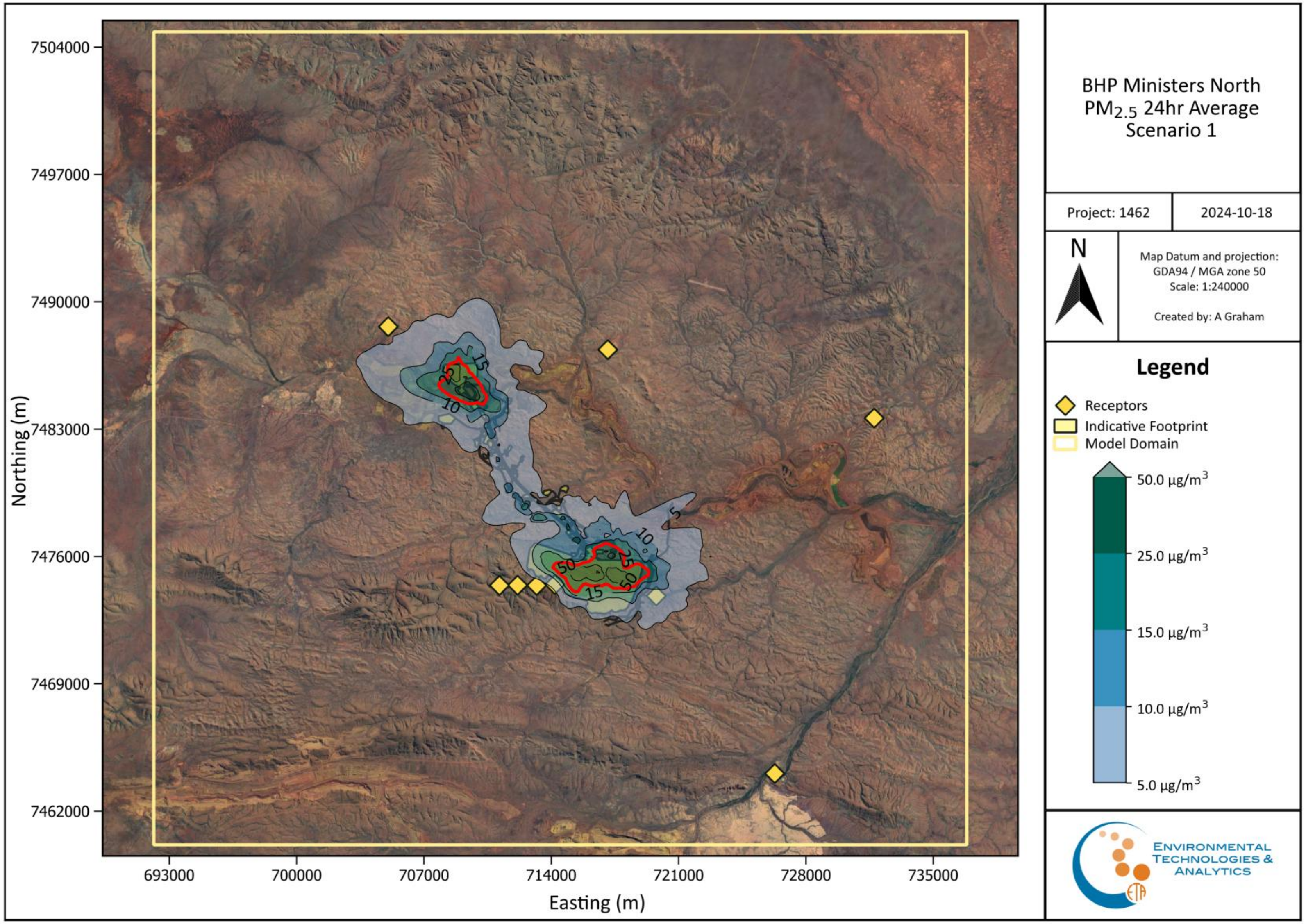

Figure 6-7: 24-hour average $PM_{2.5}$ concentration –without background.

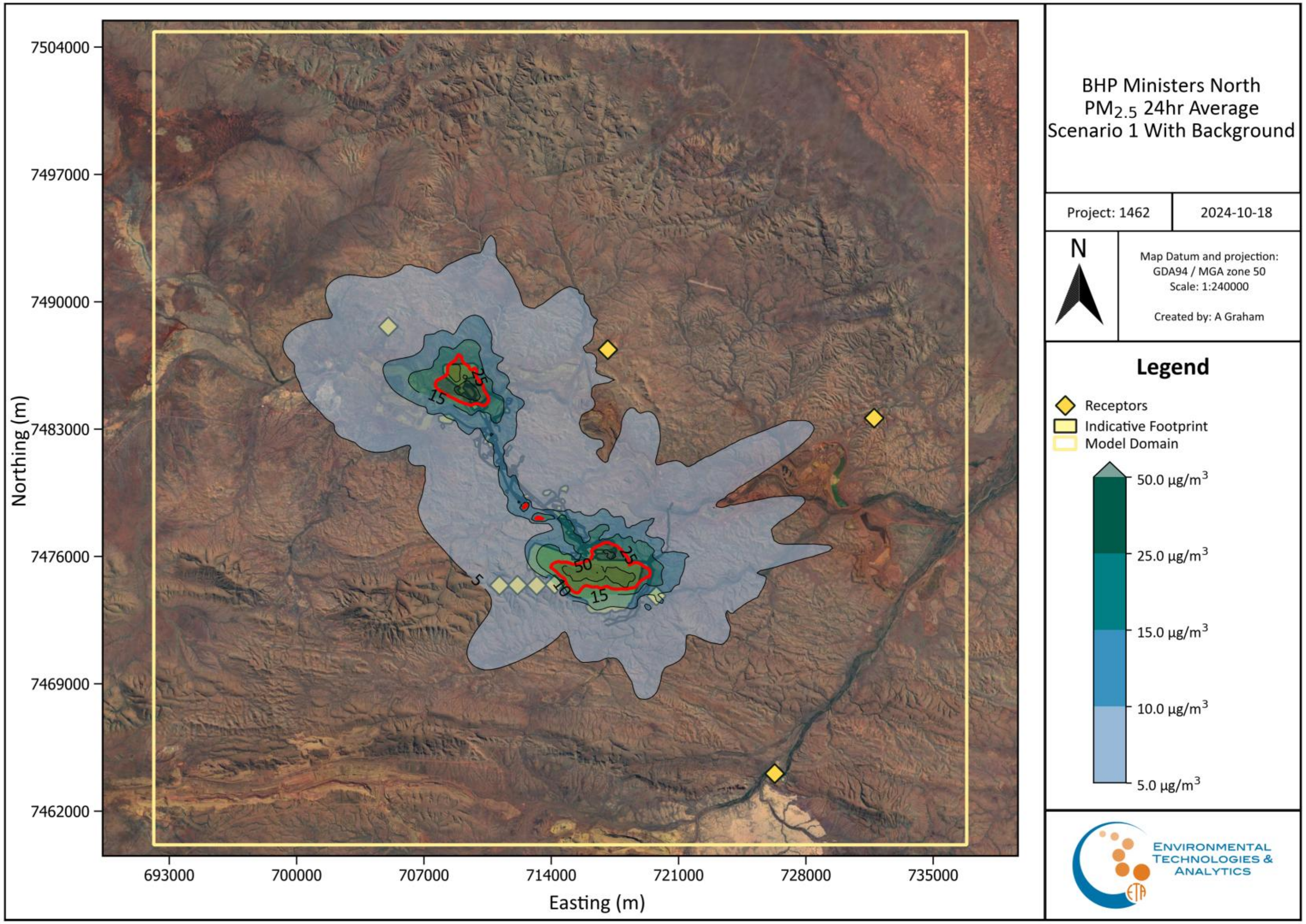

Figure 6-8: 24-hour average $PM_{2.5}$ concentration – with background.

6.3 Total Suspended Particulates

The key aspects of the impact assessment of TSP with, and without, background concentration are presented in Table 6-3. From this table it can be interpreted that:

- The highest 24-hour TSP concentration of 136 µg/m³ (including background) is predicted to occur at the Yandicoogina Gorge receptor.
- It is predicted that there will be 14 excursions of the TSP criteria at the Yandicoogina Gorge receptor.
- The modelling is predicting two excursions of TSP criteria at Yandi Camp 1.
- The KCHA1 receptor is predicted to have up to 2 excursions of the TSP criteria.

Table 6-3: Receptor locations - Statistics for predicted 24-hour average TSP concentrations – Scenario 1 (haulage option).

ID	Receptor	Statistics - predicted 24-hour average PM_{10} concentrations (µg/m³)							
		Maximum	Percentile				Annual Average	Days >90 µg/m³	Comments
			99th	98th	95th	70th			
R1	Yandi Camp 1	73	46	43	32	9	8.1	0	Isolation
		106	79	76	65	42	41.1	2	+Background
R2	Yandi Camp 2	29	22	20	16	6	4.2	0	Isolation
		62	55	53	49	39	37.3	0	+Background
R3	Rio Yandi Camp	11	9	7	6	1	1.1	0	Isolation
		45	42	40	39	34	34.2	0	+Background
R4	Weeli Wolli Spring	7	6	5	3	1	0.6	0	Isolation
		40	39	38	36	34	33.7	0	+Background
R5	Yandicoogina Gorge	103	87	76	44	16	12.4	3	Isolation
		136	120	109	77	49	45.4	14	+Background
R6	KCHA1	64	32	32	25	10	8.6	0	Isolation
		97	65	65	58	43	41.6	2	+Background
R7	KCHA2	46	19	19	14	6	5.2	0	Isolation
		79	52	52	47	39	38.2	0	+Background
R8	KCHA3	37	11	11	8	4	3.3	0	Isolation
		70	44	44	41	37	36.3	0	+Background
R9	KCHA4	33	9	9	7	3	2.6	0	Isolation
		66	42	42	40	36	35.6	0	+Background

The maximum predicted 24-hour TSP concentrations, without background, are presented in Figure 6-9 and the same results but including background are presented in Figure 6-10. Exceedances of the Kwinana EPP assessment criteria are restricted to the mine site and an area approximately 650 m on either side of the haul road. The relatively small extent of the exceedance is due to significant plume depletion through deposition.

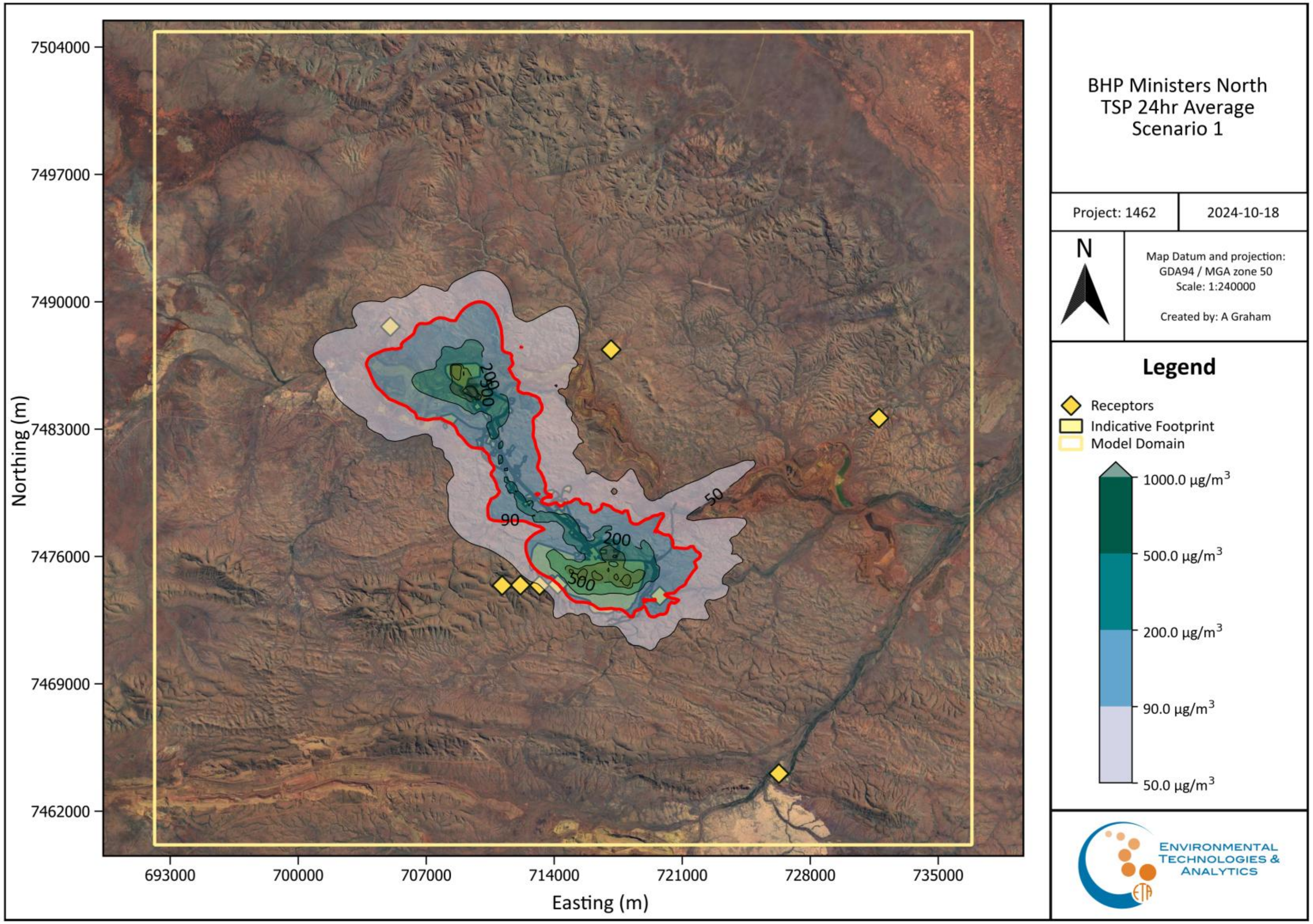

Figure 6-9: 24-hour average TSP concentration –without background.

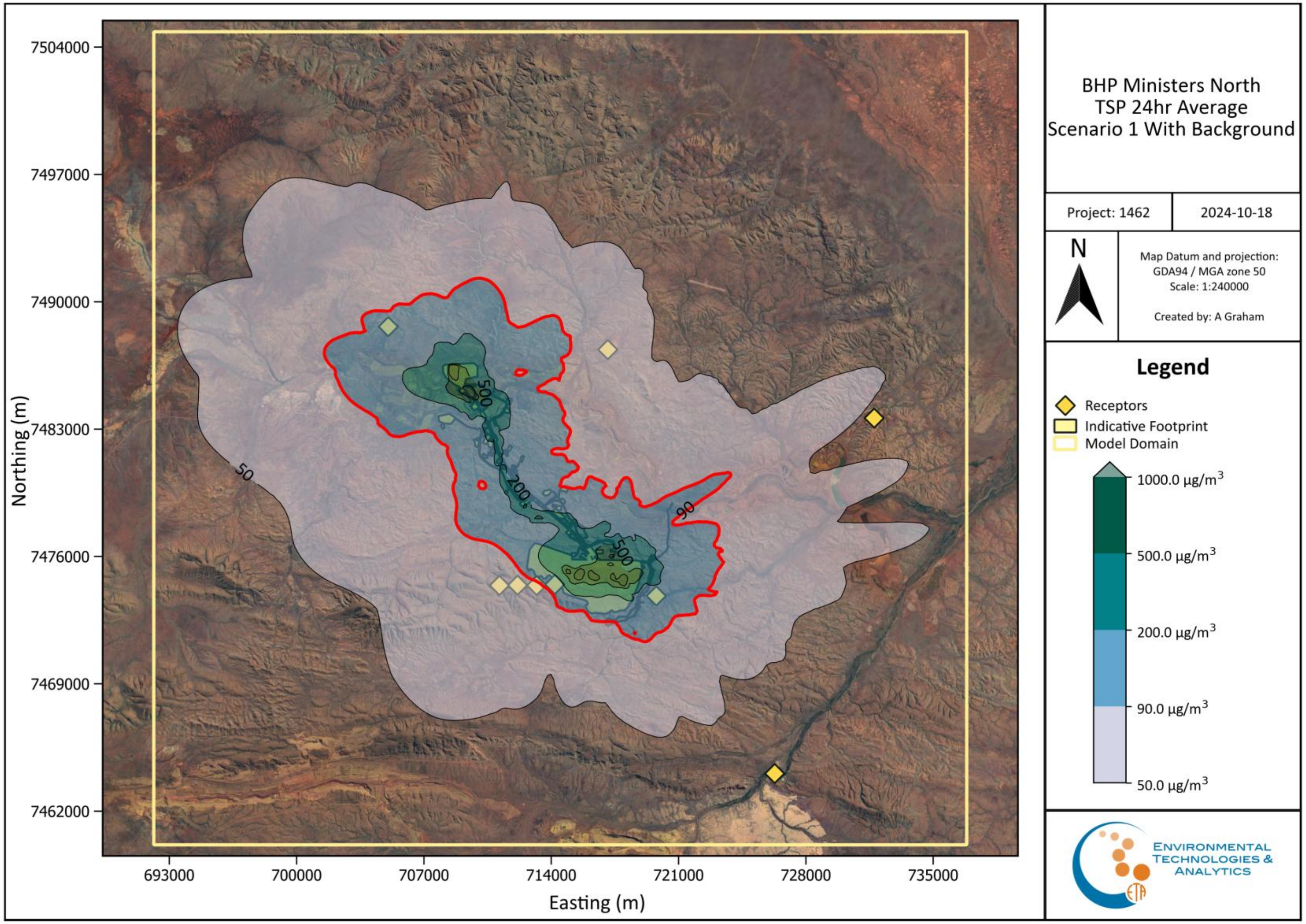

Figure 6-10: 24-hour average TSP concentration – with background.

6.4 Dust Deposition

The maximum predicted monthly deposition rate for the Project are presented in Table 6-4. From this table it is apparent that the model is predicting deposition rates, without background, that are well below the relevant criteria (Table 3-1).

Table 6-4: Monthly dust deposition from Ministers North activities.

ID	Location	Monthly Deposition (g/m^2)
R1	Yandi Camp 1	0.08
R2	Yandi Camp 2	0.05
R3	Rio Yandi Camp	0.02
R4	Weeli Wolli Spring/Outfall	0.01
R5	Yandicoogina Gorge	0.29
R6	KCHA 1	0.21
R7	KCHA 2	0.12
R8	KCHA 3	0.07
R9	KCHA 4	0.05

The monthly deposition rates for the Project are presented in Figure 6-11.

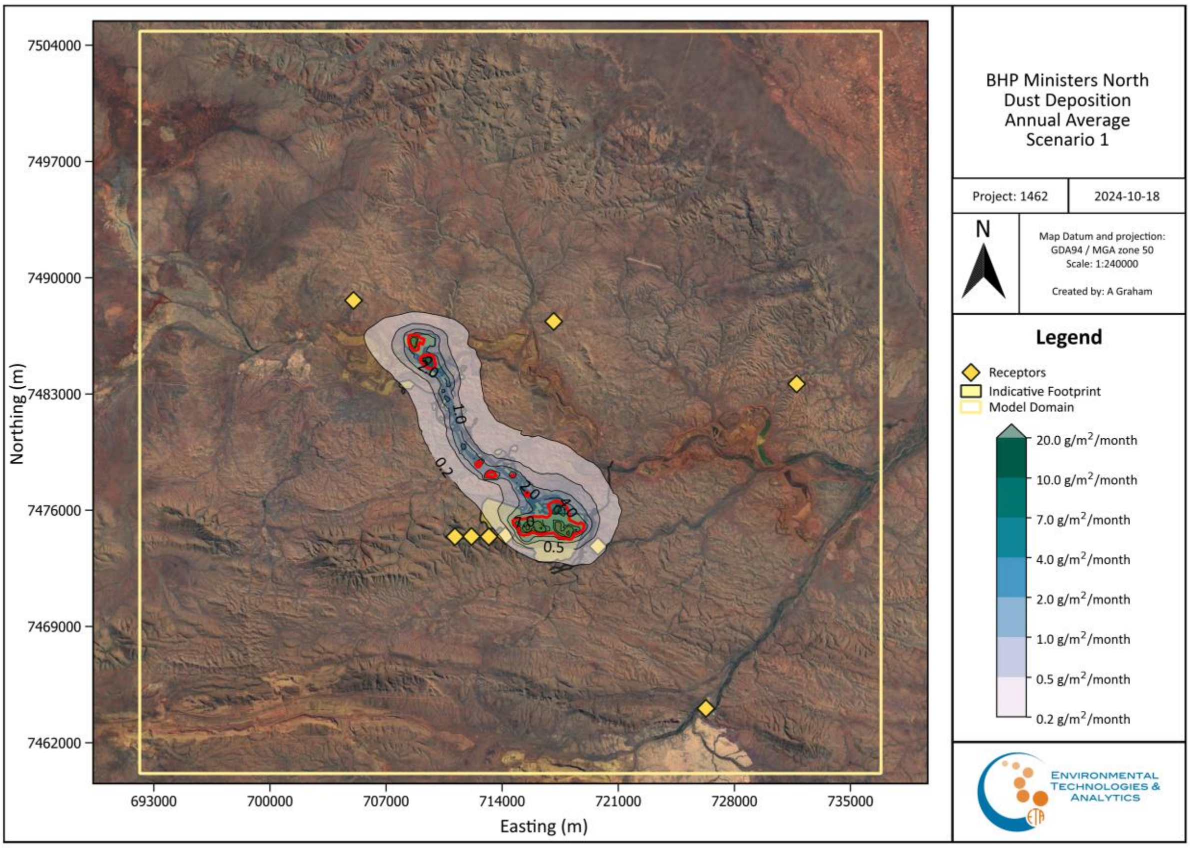

Figure 6-11: Monthly deposition rates (g/m^2/month) for Ministers North.

7 Conclusions

This assessment has assessed the air quality impacts associated with mining, processing and transport activities at the proposed Ministers North mine in the Pilbara, Western Australia. Modelled ground level concentrations for the key pollutants (particulates as TSP, PM_{10}, $PM_{2.5}$) and dust deposition have been compared to relevant ambient air quality assessment criteria to determine the potential impact on key sensitive receptors.

Modelling impacts of PM_{10}, $PM_{2.5}$ and TSP emissions was undertaken using the CALMET/CAPUFF modelling suite. Three-dimensional meteorological fields in the region of the proposed 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 ALUMP land-use data to characterise the geophysical environment.

Emissions were estimated for the mining year with the maximum total tonnage (FY30) using methodologies outlined in the NPI EET for Mining manual and input into the CALPUFF dispersion model as volume sources to simulate mining, haulage and processing, and area sources to simulate wind-blown dust. Background air quality was also estimated, and concentrations were also included.

The key findings of the assessment are:

- For TSP:
  - The highest 24-hour TSP concentration of 136 µg/m^3 (including background) is predicted to occur at the Yandicoogina Gorge receptor.
  - It is predicted that there will be 14 excursions of the TSP criteria at the Yandicoogina Gorge receptor.
  - The modelling is predicting two excursions of TSP criteria at Yandi Camp 1.
- For PM_{10}:
  - The predicted annual average PM_{10} concentration at any discrete receptor (including background) is not predicted to exceed the NEPM criteria of 25 µg/m^3.
  - The highest 24-hour PM_{10} concentration of 68µg/m^3 (including background) is predicted to occur at the Yandicoogina Gorge receptor.
  - The Yandicoogina Gorge receptor is predicted to have up to 11 excursions of the NEPM criteria.
  - The KCHA1 receptor is predicted to have up to 2 excursions of the NEPM criteria.
  - All other receptors are not predicted to have any excursion of the NEPM criteria.
- For $PM_{2.5}$:
  - The maximum predicted annual average $PM_{2.5}$ concentration of 3.6 µg/m^3 (including background) occurs at the Yandicoogina Gorge receptor.
  - The maximum predicted annual average $PM_{2.5}$ concentration of 10.2 µg/m^3 (including background) occurs at the Yandicoogina Gorge receptor.
  - Yandi Camp 1 and Yandi Camp 2, the Rio Yandi Camp and Weeli Wolli Spring are not predicted to have any excursion of the NEPM criterion.
- For deposition:
  - the model is predicting deposition rates, without background, that are well below the relevant criteria.

As outlined in Section 5.1 the modelling was undertaken for the FY30 year as this represents the maximum forecast tonnage. This mining year was chosen to ensure that the modelling was conservative, with the identified excursions expected to occur in the highest production years, but not in all years. As noted in Section 3.2 a modelling result that is higher than the assessment criteria is interpreted as an indication that results may need further consideration for the sensitive receptor, and is not necessarily a predicted impact or loss of environmental value.

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9 Acronyms and Glossary

Acronym	Description
BAM	Beta Attenuation Monitor
BoM	Bureau of Meteorology
BWS	Belt wash station
C	Degrees Celsius (temperature)
CV	Conveyor
DSD	Department of State Development
DWER	Department of Water and Environmental Regulation
EE	Emissions estimation
EET	Emissions Estimation Technique
EF	Emission factor
EPAV	Environmental Protection Authority Victoria, Australia
EPPA	Environmental Protection Policy
ETA	Environmental Technologies& Analytics Pty Ltd
FEL	Front end loader
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
kg/t	kilogram per tonne
kg/yr	kilograms per year
kPa	kiloPascals
km	kilometre
m	metre
m/s	metres per second
mm	millimetre
Mt	Million tonnes
Mtpa	Million tonnes per annum
NEPC	National Environment Protection Council
NEPM	National Environmental Protection Measure
NPI	National Pollutant Inventory
NSW	New South Wales
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.
SEA	Strategic Environmental Assessment
SRTM	Shuttle Radar Topography Mission
t	Tonnes
t/h	Tonnes per hour
tpa	tonnes per annum
tph	tonnes per hour
TS	Transfer station
TSP	Total suspended particulates
$\mu g/m^3$	micro grams (one millionth of a gram) per cubic metre
µm	micrometre
USEPA	United States Environment Protection Agency
WRF	Weather Research Forecast Model

10 Appendices

Appendix A – Meteorology

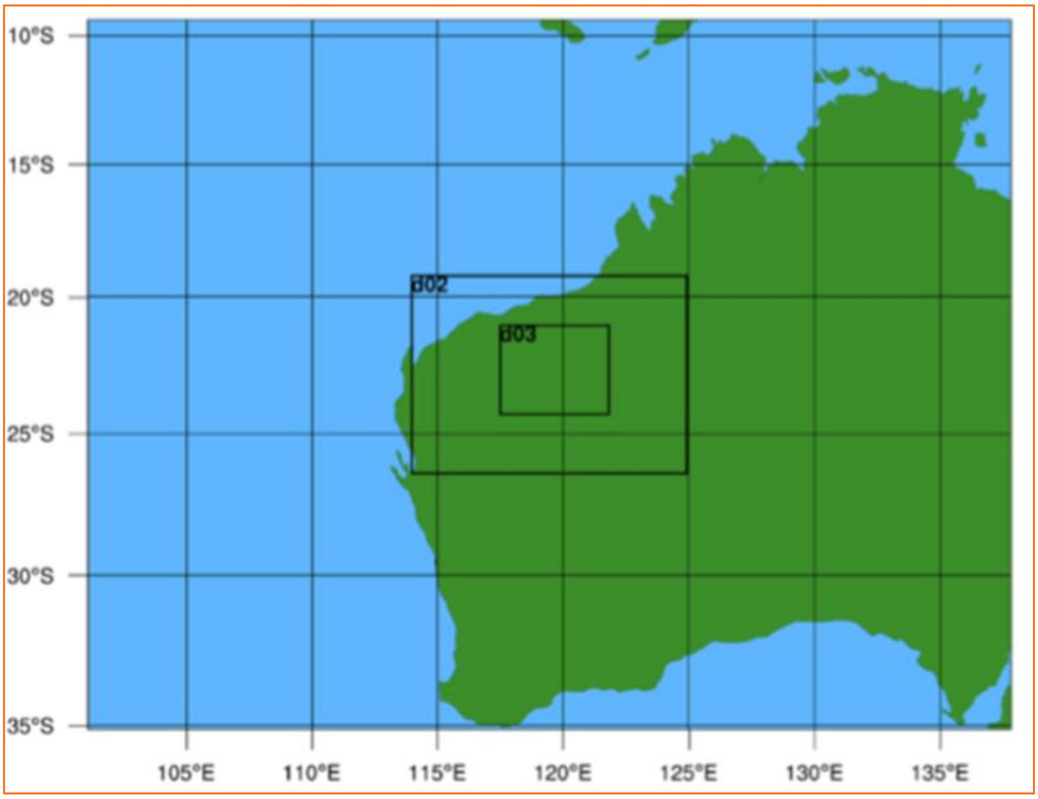
A.1: WRF

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[1] 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 (40 km, 13.3 km and 4.4 km horizontal grid space resolution) centred on 23.055°S and 119.25°E. This is shown in Appendix Figure 1. The model vertical resolution consists of 28 pressure levels.

[1] 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.



Appendix Figure 1 Three nest structure, WRF model

Physics options in WRF are to represent atmospheric radiation, surface and boundary layer as well as cloud and precipitation processes. The physics options selected for the modelling are summarised in Appendix Table 1.

Appendix Table 1 WRF Physics Options Selected for Model

	Domain 1	Domain 2	Domain 3	Explanatory Notes
mp_physics	3	3	3	WRF single moment 3-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	30	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 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[2] reveals that these are based on North American parameterisations, with marked seasonal differences to allow for winter snow cover. These are clearly inappropriate for the Pilbara region. 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 in the Pilbara. 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 Pilbara.

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:

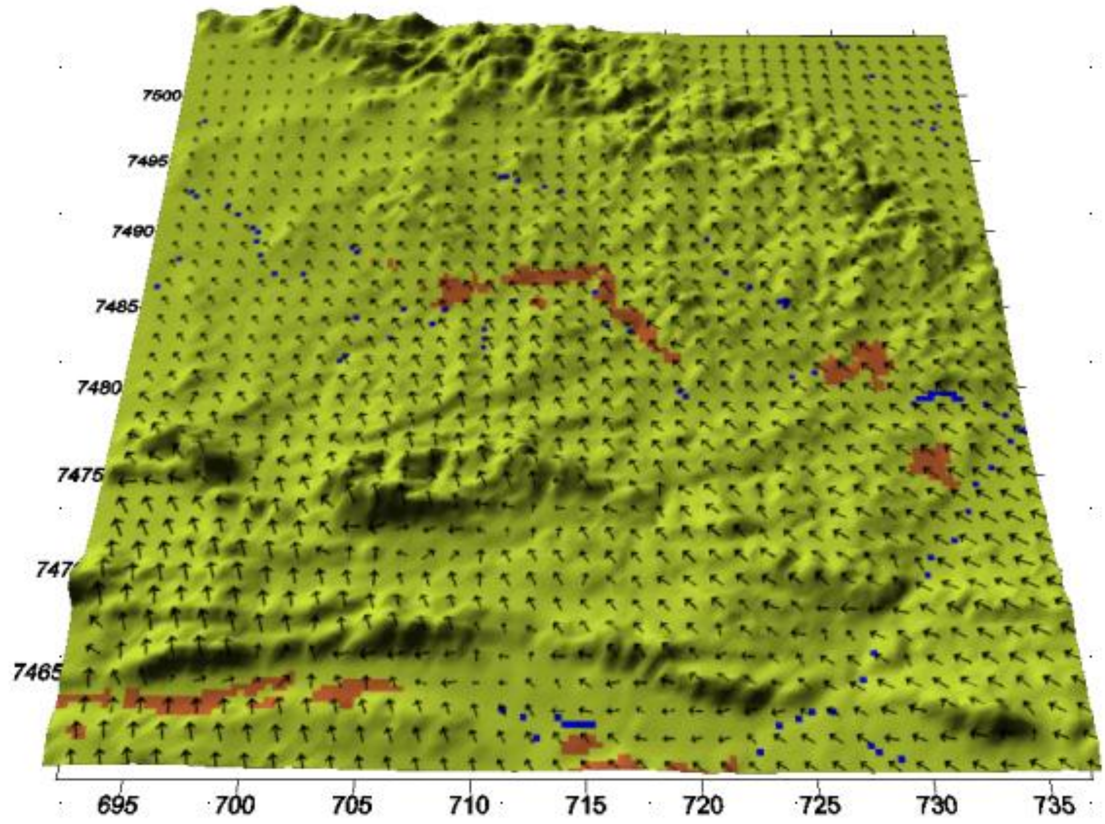
- surface sensible heat flux
- surface latent heat flux
- upward longwave radiation
- upward (reflected) shortwave radiation.

[2] A table consisting of land-use specific surface roughness, albedo and Bowen ratio.

A.2: CALMET

CALMET Results

An example of early morning surface wind fields generated by CALMET for the model domain is shown in Appendix Figure 2. The existence of non-steady state meteorology as depicted by the flow along valleys and deflection around terrain is clearly demonstrated in Appendix Figure 2. In this figure the colours depict dominant land cover (yellow/green = range land, blue = watercourses, brown = barren land).

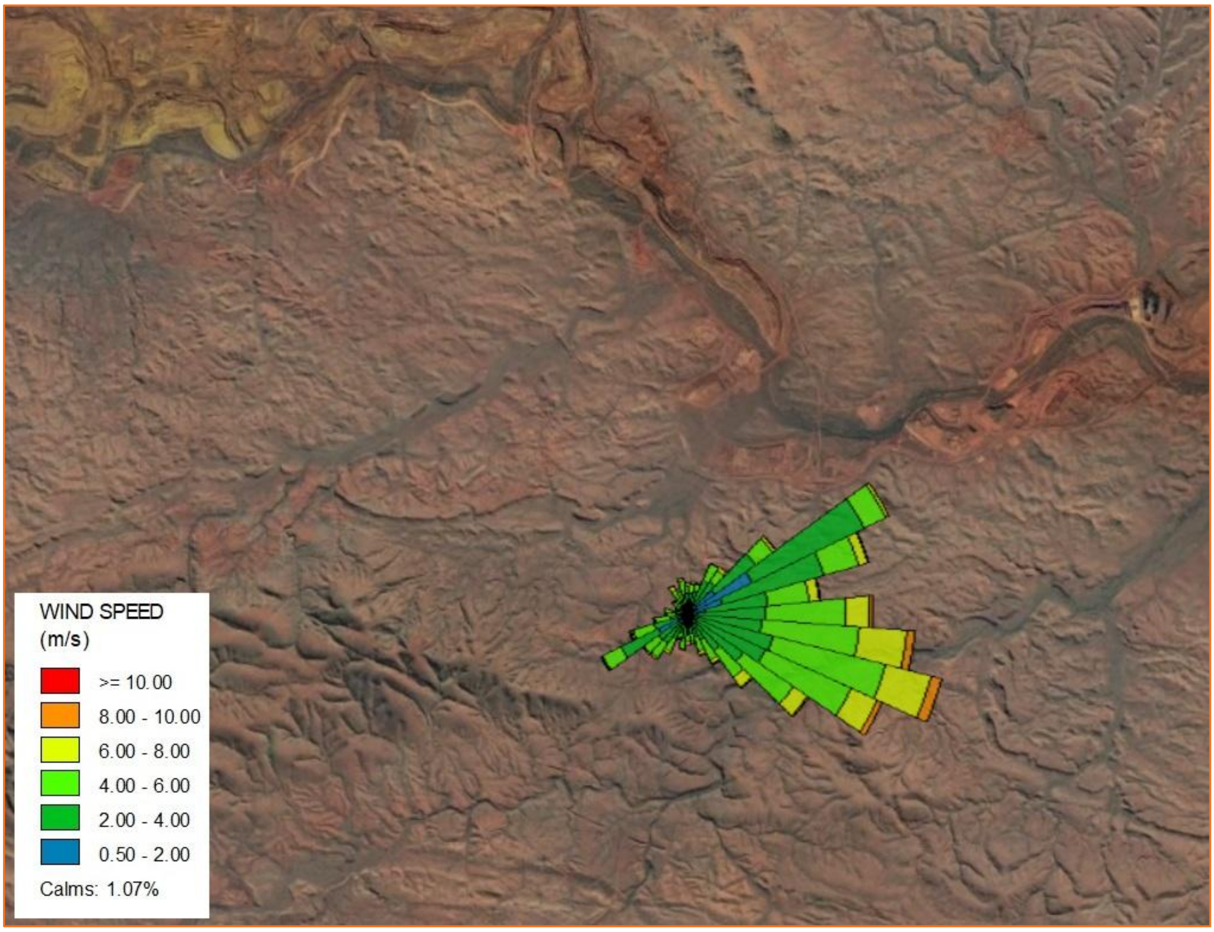


Appendix Figure 2 Example of surface wind vectors generated by CALMET

Selected meteorological variables were also extracted from the gridded CALMET output for points corresponding to the Eastern Ridge mines. The general features of the 10 m winds illustrated in the annual wind rose diagrams for the two facilities for the 12-month period from January 2010 – December 2010 are shown in Appendix Figure 3. 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 displays a bimodal distribution with greatest frequency from the southeast and a secondary maximum from the northeast.
- Strongest winds are from the southeast and lightest winds from the northeast.
- Average annual wind speed is 3.8 m/s.
- Calm conditions occur with a frequency of 1.1 %.



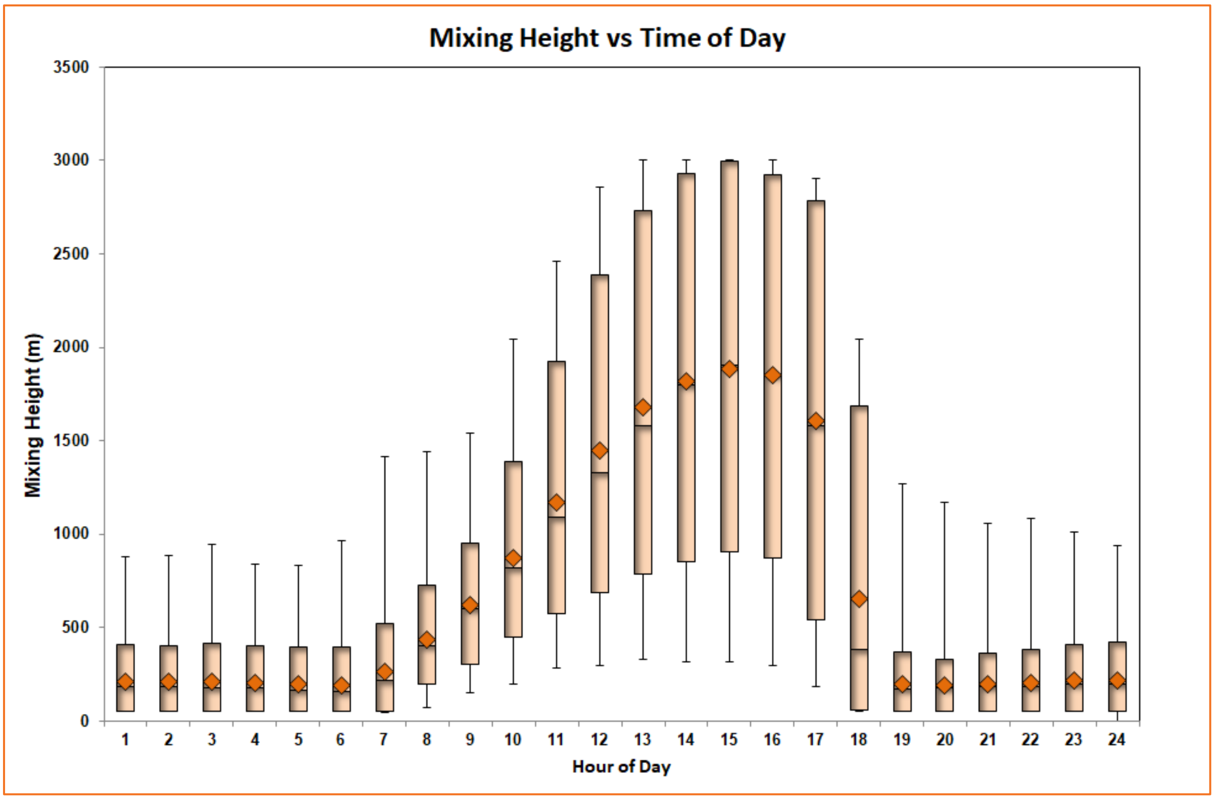
Appendix Figure 3 Wind roses generated from WRF/CALMET for proposed Ministers North

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. 2008). 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 Ministers North is summarised in Appendix Figure 4 with the diurnal cycle clearly evident. At night, mixing height is normally low and after sunrise it typically increases to between 800 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. The diurnal mixing height profile is clearly defined owing to the inland, sheltered location of the proposed mine.



Appendix Figure 4 Simulated annual statistics[3] of hourly mixing heights, Ministers North

A.3: 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

[3] The bars in the figure depicts 10^{th} and 90^{th} percentile values while the tringles show the average conditions. The whiskers indicate minimum and maximum values.

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.

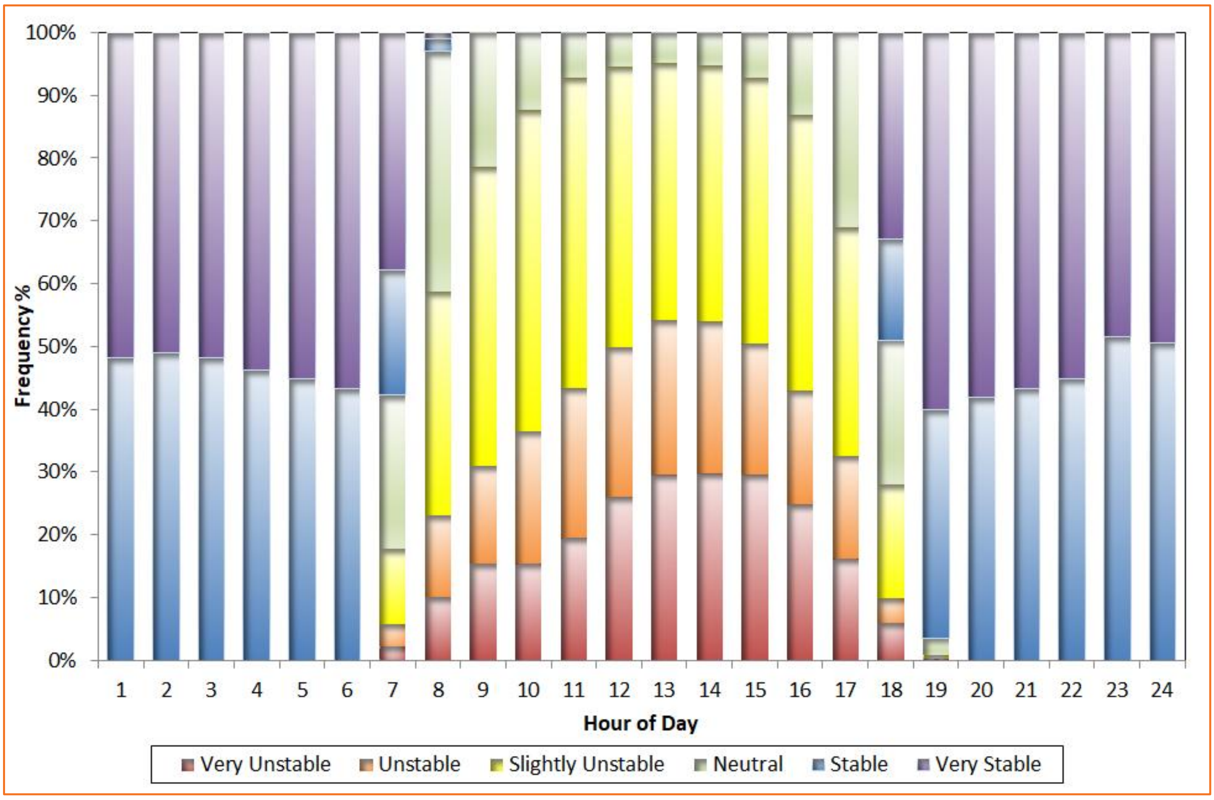
Turbulence in the boundary layer is influenced by the vertical temperature gradient, which is one of several indicators of stability. Plume models use indicators of atmospheric stability in conjunction with other meteorological data to estimate the dispersion conditions in the atmosphere.

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 Ministers North computed from all data in the CALMET surface file is presented in Appendix Figure 5. This plot indicates that the PBL is stable to very stable overnight becoming unstable as radiation from the sun heats the surface layer of the atmosphere and drives convection.



Appendix Figure 5 Simulated annual statistics of hourly stability, Ministers North

Appendix B – Emission Rates

B.1: Variable emissions

A summary of the volume sources (statistical characteristics for emission rates) input into the future scenario model are shown in Appendix Table 2 for the mining emissions and Appendix Table 3 for the processing emissions.

Appendix Table 2 PM_{10} emission rate for mining at Ministers North - statistical summary.

Source Id	Maximum (g/s)	99th Percentile (gs)	95th Percentile (gs)	90th Percentile (gs)	70th Percentile (g/s)	Average (g/s)
Drill1	0.25	0.25	0.25	0.25	0.25	0.13
Drill2	0.25	0.25	0.25	0.25	0.25	0.13
Drill3	0.25	0.25	0.25	0.25	0.25	0.13
Drill4	0.25	0.25	0.25	0.25	0.25	0.13
Drill5	0.25	0.25	0.25	0.25	0.25	0.13
Drill6	0.25	0.25	0.25	0.25	0.25	0.13
Drill7	0.25	0.25	0.25	0.25	0.25	0.13
Drill8	0.25	0.25	0.25	0.25	0.25	0.13
Blast1	18.85	18.85	18.85	18.85	18.85	0.26
Blast2	18.85	18.85	18.85	18.85	18.85	0.26
Blast3	18.85	18.85	18.85	18.85	18.85	0.26
Blast4	18.85	18.85	18.85	18.85	18.85	0.26
Blast5	18.85	18.85	18.85	18.85	18.85	0.26
Blast6	18.85	18.85	18.85	18.85	18.85	0.26
Blast7	18.85	18.85	18.85	18.85	18.85	0.26
Blast8	18.85	18.85	18.85	18.85	18.85	0.26
Load1	3.31	3.31	3.31	3.31	3.31	2.81
Load2	3.31	3.31	3.31	3.31	3.31	2.81
load3	1.77	1.77	1.77	1.77	1.77	1.32
Load4	1.77	1.77	1.77	1.77	1.77	1.32
Load5	3.65	3.65	3.65	3.65	3.65	3.09
Load6	3.65	3.65	3.65	3.65	3.65	3.10
Load7	1.98	1.98	1.98	1.98	1.98	1.19
Load8	2.32	2.32	2.32	2.32	2.32	1.85
UnW1	0.75	0.75	0.75	0.75	0.75	0.60
UnW2	0.75	0.75	0.75	0.75	0.75	0.60
UnW3	0.75	0.75	0.75	0.75	0.75	0.60
UnW4	0.75	0.75	0.75	0.75	0.75	0.59

Source Id	Maximum (g/s)	99th Percentile (gs)	95th Percentile (gs)	90th Percentile (gs)	70th Percentile (g/s)	Average (g/s)
UnW5	0.75	0.75	0.75	0.75	0.75	0.59
UnW6	0.75	0.75	0.75	0.75	0.75	0.60
Bull1	1.13	1.13	1.13	1.13	1.13	0.34
Bull2	1.13	1.13	1.13	1.13	1.13	0.32
Bull3	1.13	1.13	1.13	1.13	1.13	0.33
Bull4	1.13	1.13	1.13	1.13	1.13	0.32
Bull5	1.13	1.13	1.13	1.13	1.13	0.33

Appendix Table 3 PM_{10} emission rate for processing at Ministers North - statistical summary.

Source Id	Maximum (g/s)	99th Percentile (g/s)	95th Percentile (g/s)	90th Percentile (g/s)	70th Percentile (g/s)	Average (g/s)
Dump	2.01	2.01	2.01	2.01	2.01	1.70
PC1	0.37	0.37	0.37	0.37	0.37	0.32
SC1	1.12	1.12	1.12	1.12	1.12	0.95
Screen	2.80	2.80	2.80	2.80	2.80	2.38
TC1	0.47	0.47	0.47	0.47	0.47	0.40
TS1	0.56	0.56	0.56	0.56	0.56	0.48
Cos_Sk	0.93	0.93	0.93	0.93	0.93	0.79
TS2	0.56	0.56	0.56	0.56	0.56	0.48
Stk1	0.70	0.70	0.70	0.70	0.70	0.59
Rec1	2.22	2.22	2.22	2.22	2.22	0.79

Appendix Table PM_{10} emissions rates for Wind Erosion at Ministers North

Source Id	Maximum (g/s)	99th Percentile (g/s)	95th Percentile (g/s)	90th Percentile (g/s)	70th Percentile (g/s)	Average (g/s)
WE1	43.04	6.17	1.27	-	-	0.26
WE2	19.13	2.71	0.56	-	-	0.11
WE3	38.26	5.42	1.11	-	-	0.23
WE4	59.78	8.48	1.73	-	-	0.35
WE5	13.77	1.95	0.40	-	-	0.08
WE6	38.26	5.42	1.11	-	-	0.23
WE7	38.26	5.48	1.13	-	-	0.23
WE8	59.78	8.57	1.76	-	-	0.36

Source Id	Maximum (g/s)	99th Percentile (g/s)	95th Percentile (g/s)	90th Percentile (g/s)	70th Percentile (g/s)	Average (g/s)
WE9	113.57	16.28	3.34	-	-	0.68
WE10	113.57	16.28	3.34	-	-	0.68
WE11	113.57	16.28	3.34	-	-	0.68
WE12	113.57	16.28	3.34	-	-	0.68
WE13	113.57	16.28	3.34	-	-	0.68
WE14	113.57	16.28	3.34	-	-	0.68
WE15	113.57	16.28	3.34	-	-	0.68
WE16	59.78	8.57	1.76	-	-	0.36
WE17	59.78	8.57	1.76	-	-	0.36
WE18	59.78	8.57	1.76	-	-	0.36
WE19	59.78	8.57	1.76	-	-	0.36

Appendix C – Emission Parameters

C.1: Volume sources

Appendix Table 4 Ministers North Mining model parameters

Source Id	Easting	Northing	Effective Height	Sigma Y	Sigma Z
Drill1	714,973	7,475,372	1.5	75	0.70
Drill2	715,414	7,475,281	1.5	75	0.70
Drill3	716,037	7,475,354	1.5	75	0.70
Drill4	716,346	7,475,094	1.5	75	0.70
Drill5	717,592	7,475,142	1.5	75	0.70
Drill6	717,852	7,474,852	1.5	75	0.70
Drill7	718,602	7,474,991	1.5	75	0.70
Drill8	715,547	7,474,277	1.5	75	0.70
Blast1	714,827	7,475,275	20	22	9.30
Blast2	715,438	7,475,100	20	22	9.30
Blast3	716,007	7,475,190	20	22	9.30
Blast4	716,575	7,475,275	20	22	9.30
Blast5	717,404	7,475,039	20	22	9.30
Blast6	718,124	7,475,057	20	22	9.30
Blast7	718,723	7,474,785	20	22	9.30
Blast8	715,795	7,474,193	20	22	9.30
Load1	715,082	7,475,172	6	75	2.79
Load2	715,777	7,475,287	6	75	2.79
load3	716,315	7,475,336	6	75	2.79
Load4	716,702	7,475,106	6	75	2.79
Load5	717,301	7,475,221	6	75	2.79
Load6	718,172	7,474,870	6	75	2.79
Load7	718,862	7,474,991	6	75	2.79
Load8	715,275	7,474,410	6	75	2.79
UnW1	715,577	7,474,834	3	75	1.40
UnW2	716,200	7,474,785	3	75	1.40
UnW3	716,660	7,474,737	3	75	1.40
UnW4	717,223	7,474,797	3	75	1.40
UnW5	717,555	7,474,549	3	75	1.40
UnW6	718,039	7,474,543	3	75	1.40
Bull1	715,336	7,474,876	2	75	0.93
Bull2	716,013	7,474,773	2	75	0.93

Source Id	Easting	Northing	Effective Height	Sigma Y	Sigma Z
Bull3	716,503	7,474,815	2	75	0.93
Bull4	717,350	7,474,652	2	75	0.93
Bull5	717,840	7,474,549	2	75	0.93
UnW7	718,508	7,474,909	3	75	1.40
Bull6	718,520	7,474,800	2	75	0.93
UnO1	717,332	7,476,231	3	50	1.40
UnO2	717,456	7,476,140	3	50	1.40
UnO3	717,558	7,475,992	3	50	1.40
UnO4	717,573	7,475,859	3	50	1.40
OBull1	717,377	7,476,149	2	50	0.93
OBull2	717,531	7,475,934	2	50	0.93
LoadOre1	717,286	7,476,152	6	50	2.79
LoadOre2	717,401	7,476,034	6	50	2.79

Appendix Table 5 Scenario 1 Ministers North processing model parameters

Source Id	Easting	Northing	Effective Height	Sigma Y	Sigma Z
Dump	709,645	7,484,842	3	3.8	1.40
PC1	709,611	7,484,872	3	3.8	1.40
SC1	709,482	7,484,983	5	12.5	2.33
Screen	709,498	7,485,006	6	17.5	2.79
TC1	709,380	7,485,103	5	12.5	2.33
TS1	709,395	7,485,121	4.0	2.0	1.86
Cos_Sk	708,786	7,485,625	10	12.5	4.65
TS2	709,363	7,486,292	4.0	2.0	1.86
Stk1	708,654	7,486,255	8.0	50.0	3.72
Rec1	708,956	7,486,345	8.0	50.0	3.72
TS3	709,818	7,486,384	4.0	2.0	1.86
Stck_F	709,706	7,486,062	10	12.5	4.65
Stk_L	709,760	7,486,021	10	12.5	4.65

Appendix Table 6: Ministers North Wind Erosion parameters

Source ID	Centroid Easting	Centroid Northing	Area	Effective radius	Effective Ht	Sigma Z
WE1	709,695	7,484,806	22,500	85	1	0.5
WE2	708,810	7,485,611	10,000	56	1	0.5

Source ID	Centroid Easting	Centroid Northing	Area	Effective radius	Effective Ht	Sigma Z
WE3	709,123	7,485,964	40,000	113	1	0.5
WE4	708,745	7,486,255	62,500	141	1	0.5
WE5	709,721	7,486,026	14,400	68	1	0.5
WE6	708,734	7,485,971	40,000	113	1	0.5
WE7	717,403	7,476,189	40,000	113	1	0.5
WE8	717,573	7,475,922	62,500	141	1	0.5
WE9	714,989	7,475,279	62,500	141	1	0.5
WE10	715,637	7,475,202	62,500	141	1	0.5
WE11	716,460	7,475,206	62,500	141	1	0.5
WE12	717,454	7,475,140	62,500	141	1	0.5
WE13	718,073	7,474,922	62,500	141	1	0.5
WE14	718,729	7,474,915	62,500	141	1	0.5
WE15	715,491	7,474,270	62,500	141	1	0.5
WE16	715,688	7,474,834	62,500	141	1	0.5
WE17	716,533	7,474,769	62,500	141	1	0.5
WE18	717,290	7,474,703	62,500	141	1	0.5
WE19	718,022	7,474,623	62,500	141	1	0.5