Sheffield Resources Limited

Thunderbird Mineral Sands Project

Technical Report

Thunderbird Mine Air Quality Assessment

17 October 2016

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Contents

EXECUTIVE SUMMARY

This air quality assessment has been prepared for the mine site component of the Thunderbird Mineral Sands Project (Thunderbird Project), proposed by Sheffield Resources Limited (Sheffield Resources), as part of the overall environmental approvals process.

The Thunderbird Project involves the extraction and processing of mineral sands from the Thunderbird mine site, located approximately 98 km northeast of Broome and 72 km west of Derby, Western Australia. The minerals will be mined using conventional earth moving machinery and mobile equipment, such as dozers, and passed through screening prior to wet concentration and further processing before being prepared for transport and export. The final products, comprising zircon, leucoxene and ilmenite, will be transported by road trains to the Port of Derby, where they will be stockpiled inside a warehouse (up to 60,000 t). The products will subsequently be conveyed out to barges at the port jetty for subsequent transfer to an oceangoing vessel located in deeper water, off Point Torment.

This report focuses on the air quality aspects associated with the mine site activities. Air quality impacts at the port are covered in a separate report (Reference 14).

The proposed activities have the potential to generate dust and combustion product emissions at the remote mine site area, with the main emission sources including heavy mobile equipment (dozers, a scraper and a grader), onsite processing and screening, power generation, and product transport. Combustion emissions for the road trains and mobile equipment are not considered to be significant sources; as such the focus will be on their potential for dust generation.

There are no sensitive receivers in the vicinity of the mine site. An accommodation camp will be constructed as part of the mine site, and will be located approximately 4 km from the mine site and 3 km from the power plant. There are no other industrial activities in the vicinity.

The emissions from the Project have been estimated using current design data and operating conditions, in combination with emissions estimation factors from the National Pollutant Inventory handbooks. The AERMOD dispersion model has been utilised for the modelling, which is considered suitable given the lack of complicated terrain and significant features which, if present, would warrant the use of a more advanced dispersion model. AERMOD's meteorological pre-processor AERMET has been used to prepare input meteorological data files based on 2015 MM5 inputs.

Dust emissions have been modelled for the total suspended particulates (TSP) emitted, as well as particles with an aerodynamic diameter less than 10 microns (PM_{10}) and 2.5 microns ($PM_{2.5}$). In addition, dust deposition has been modelled. The priority combustion products have been modelled, including nitrogen dioxide (NO_2), carbon monoxide (CO) and sulphur dioxide (SO_2). NO_2, CO, SO_2, PM_{10} and $PM_{2.5}$ emissions have been compared against the National Environment Protection Measure for Ambient Air Quality (NEPM AAQ) criteria (the advisory reporting threshold for $PM_{2.5}$), whilst TSP and

dust deposition have been compared to the New South Wales Environmental Protection Agency (NSW EPA) criteria in the absence of NEPM criteria.

Based on the results of the modelling, the mine site activities are not predicted to result in any exceedances of the pollutant criteria specified previously at any sensitive receivers or at the accommodation camp, and as such the Project is not expected to have any adverse impact on air quality in the area.

1. INTRODUCTION

Sheffield Resources Limited (Sheffield Resources) are seeking environmental approvals to develop the Thunderbird Mineral Sands Project (Thunderbird Project).

The Thunderbird Project involves the extraction and processing of mineral sands from the Thunderbird mine site located approximately 98 km northeast of Broome and 72 km west of Derby in the west Kimberley region of Western Australia. The minerals will be mined using conventional machinery and mobile equipment (including dozers, a grader and a scraper), and passed through screening prior to wet concentration and further processing. The final products, comprising zircon, leucoxene and ilmenite, will then be transported by road trains to the Port of Derby, where they will be stockpiled inside a purpose built storage facility (up to 60,000 t).

The final products will be exported by ship. Due to the extreme tidal conditions experienced in the Kimberley, ocean going vessels are unable to berth at the port. Products will therefore be loaded onto barges via the existing conveyor system (refurbished) and transferred to the ocean going vessel located in deeper water off Point Torment.

This air quality assessment has been prepared for the mine site component of the Thunderbird Project, as part of the overall environmental approvals process. The Thunderbird product transport and Derby Port operations are covered in a separate report (Reference 14).

2. OBJECTIVES AND SCOPE OF WORK

The primary objective of this study was to characterise air quality impacts on sensitive receptors associated with the Thunderbird Project mine site operations. The scope of work involved the following:

- Identify the emission sources associated with the Thunderbird Project Mine Site Operations;
- Characterise and inventory the emission sources;
- Characterise the baseline air quality in the area via desktop assessment; and
- Perform atmospheric dispersion modelling to assess the potential for air quality impacts on sensitive receptors in the vicinity and for comparison with the air quality criteria.

3. EMISSIONS INVENTORY

The emissions for the Thunderbird Project can be split up between two main areas, the mine site and the port. The two are linked by road, with road trains taking the product in bulk from the mine site and delivering it to the port storage facility, prior to conveying out to barges for shipment.

This report focuses on the emissions associated with the mine site, which includes assessing the impact of the extraction and processing activities, as well as the initial road trains transportation along the unpaved road connecting the mine site to the main road.

A moving open face pit will be used for the mineral sand extraction, utilising four dozers, a scraper and a grader, as well as a water truck to minimise dust emissions. Raw mineral sands will be processed onsite, utilising low temperature roasting and magnetic separation, prior to being transported to the port for shipping. A number of baghouses will be constructed to contain dust emissions during the processing activities. At peak production, 2,300 tonnes of product will be extracted, processed and transported per day. Transportation will consist of 5 quad road trains, each carrying a 115 t payload, which will each make 2 deliveries to the port every 24 hours. The mine site will include a 35 MW natural gas fired power generation plant. In addition, an accommodation camp will be constructed to accommodate workers, approximately 4 km from the mine site and 3 km from the power plant.

Based on the above, the primary emission for the port will be dust in the form of airborne particulates (TSP, PM_{10} and $PM_{2.5}$), as well as deposited dust (considered for the purposes of amenity). Other significant emissions will be combustion emissions, including nitrogen dioxide (NO_2), carbon monoxide (CO) and sulphur dioxide (SO_2), which will be generated by the power generation plant and the low temperature roaster.

The only other emissions are related to the combustion of fuel associated with the mobile equipment, both onsite vehicles and the road trains, all of which are not considered significant enough to warrant investigation in respect to the air quality limits for combustion products.

The emission factors for the mining activities have been based on the National Pollutant Inventory (NPI) Emissions Estimation Handbook (EEH) for Mineral Sands (Reference 3) and the NPI EEH for Mining (Reference 4). It should be noted that where $PM_{2.5}$ emission factors are not present in the NPI EEHs, a conservative factor of 50% of the PM_{10} rate has been used.

Road train dust emissions have been calculated based on the NPI EEH for Mining factors, using the average weight of 171 t empty with a 115 t payload, giving an average weight for their return journey of 228.5 t.

Emissions factors for the mine site activities are summarised in Table 1 for dust and Table 2 for combustion emissions. The overall mine site emissions are summarised in Table 3 for dust and Table 4 for combustion emissions.

Table 1: Dust Emissions Factors

Mining Operations:	TSP	PM_{10}	$PM_{2.5}$	Units
Road Trains[1]	8.24	2.52	1.26	kg/VKT
Scraper Operations	0.029	0.0073	0.00365	kg/t
Dozer Operations	17	4.1	0.24	kg/h/ vehicle
Grader Operations	0.060	0.030	0.015	kg/t
Wind Erosion	0.40	0.20	0.10	kg/ha/h
Power Generation	0.000006	0.000003	0.000003	kg/kWh
Low Temperature Roaster[2]	100	50	25	mg/m^3
Bag House – HAL Dryer[2]	100	50	25	mg/m^3
Bag House – HAL Dust Extraction[2]	100	50	25	mg/m^3
Bag House – HAL Fume Scrubber[2]	100	50	25	mg/m^3
Bag House – Primary Dry Mill Dryer[2]	100	50	25	mg/m^3
Bag House – Primary Dry Mill Dust Extraction[2]	100	50	25	mg/m^3
Bag House – Ilmenite Dry Plant Dryer[2]	100	50	25	mg/m^3
Bag House – Ilmenite Dry Plant Dust Extraction[2]	100	50	25	mg/m^3
Bag House – Post Roast Magnetic Circuit Dust Extraction[2]	100	50	25	mg/m^3
Road Train Loading[2]	0.00040	0.00017	0.000085	kg/t

Notes: 1. Emission factors from the NPI EEH for Mining, Tables 2 and 3, based on an average weight of 228.5 t and assuming a 50% reduction for use of water truck.
2. The baghouse design limits have been incorporated as a highly conservative emissions rate for the baghouse exhaust stacks, and based on the minimum design conditions of 20 m/s exit velocity at a 0.5 m stack diameter and stack height of 25 m.
3. The power generation plant is based on 35 MW output, natural gas fuelled, with an exit velocity of 15 m/s at a stack diameter of 0.5 m and stack height of 15 m.
4. Where $PM_{2.5}$ emission factors are not present in the NPI EEHs, a conservative factor of 50% of the PM_{10} rate has been used.

Table 2: Combustion Emissions Factors

Mining Operations:	NO_2	CO	SO_2	Units
Power Generation[1]	0.00015	0.00013	0.00000079	kg/kWh
Low Temperature Roaster	4.93	4.28	0.095	kg/h

Notes: 1. Based on 90% natural gas operation and 10% low sulphur diesel operation.
2. NO_2 has been assumed to be 30% of all NO_X, which is considered a conservative assumption, and will likely be much lower.
3. Where $PM_{2.5}$ emission factors are not present in the NPI EEHs, a conservative factor of 50% of the PM_{10} rate has been used.

Table 3: Dust Emissions from the Mine Site

Mine Site Operations:	TSP		PM_{10}		$PM_{2.5}$	
	g/s	tpa	g/s	tpa	g/s	tpa
Road Trains[1]	47.7	1,278	14.6	391	7.30	196
Scraper Operations	6.52	175	1.64	44.0	0.82	22.0
Dozer Operations	9.44	253	2.28	61.1	1.14	30.5
Grader Operations	2.11	56.6	0.94	25.3	0.47	12.7
Wind Erosion	0.56	14.9	0.28	7.4	0.14	3.7
Power Generation	0.06	1.5	0.03	0.8	0.10	2.7
Low Temperature Roaster[2]	1.46	39.2	0.73	19.6	0.36	9.8
Bag House – HAL Dryer[2]	0.39	10.5	0.20	5.3	0.10	2.6
Bag House – HAL Dust Extraction[2]	0.39	10.5	0.20	5.3	0.10	2.6
Bag House – HAL Fume Scrubber[2]	0.39	10.5	0.20	5.3	0.10	2.6
Bag House – Primary Dry Mill Dryer[2]	0.39	10.5	0.20	5.3	0.10	2.6
Bag House – Primary Dry Mill Dust Extraction[2]	0.39	10.5	0.20	5.3	0.10	2.6
Bag House – Ilmenite Dry Plant Dryer[2]	0.39	10.5	0.20	5.3	0.10	2.6
Bag House – Ilmenite Dry Plant Dust Extraction[2]	0.39	10.5	0.20	5.3	0.10	2.6
Bag House – Post Roast Magnetic Circuit Dust Extraction[2]	0.39	10.5	0.20	5.3	0.10	2.6
Road Train Loading[2]	0.01	0.3	0.005	0.2	0.002	0.1
Total from Mine	71.0	1,902	22.1	592	11.1	298

Notes: 1. Road train emissions for the journey on the unpaved road section from the site to the main access road only.
2. Annual emissions are based on the planned operating hours of 7,446 per annum.

Table 4: Combustion Emissions from the Mine Site

Mine Site Operations:	NO_2		CO		SO_2	
	g/s	tpa	g/s	tpa	g/s	tpa
Power Generation	1.46	39.1	1.26	33.9	0.008	0.2
Low Temperature Roaster[2]	1.37	36.7	1.19	31.8	0.026	0.7
Total from Mine	2.83	75.8	2.45	65.7	0.034	0.9

Notes: 1. Annual emissions are based on the planned operating hours of 7,446 per annum.
2. Particulate matter from combustion emissions have been included under the dust emissions tables.

4. POLLUTANT INFORMATION

The primary pollutants which will be generated by the Thunderbird Project have been identified as dust / particulate emissions, as discussed in the previous chapter, along with a contribution by combustion emissions.

4.1. Total Suspended Particulates (TSP, PM_{10} and $PM_{2.5}$)

Total suspended particulates (TSP) consist of coarse and fine particles. In the atmosphere particles range in size from 0.1 to 50 µm. Even without human activity, the atmosphere contains particles from sources such as wind-blown dust, fires, sea salt, pollens, and bacteria. From human activity, industry is by far the largest producer of TSPs.

Respirable particles, defined as those with a diameter of less than 10 µm (PM_{10}), are a particular health concern as they are easily inhaled and retained in the lungs, and may potentially pass into the blood stream. Respirable particles may also adsorb potentially health threatening organic "air toxics" (such as benzene, 1,3-butadiene, acetaldehyde and formaldehyde).

The size of the particles determines how far into the respiratory system the particles penetrate. Particles with an aerodynamic diameter greater than 10 µm are screened out in the upper respiratory tract, while particles smaller than 10 µm (PM_{10}) may penetrate into the lower respiratory tract in humans. There is increasing evidence that the adverse health effects of particulates are more closely associated with the $PM_{2.5}$ size fraction (particulate matter with a diameter less than 2.5 µm). Their small size increases the likelihood that the $PM_{2.5}$ particles will carry irritants and potentially toxic compounds deep into the lungs.

The National Environment Protection Measure for Ambient Air Quality (NEPM AAQ) includes a limit for PM_{10} of 50 µg/m^3 over a 24 hour period (with the initial NEPM AAQ criteria allowing for 5 exceedances in a year), as well as an advisory standard for $PM_{2.5}$ of 25 µg/m^3 over a 24 hour period, and 8 µg/m^3 averaged over one year (Reference 1). Whilst not included in the NEPM AAQ, a common limit for dust deposition is set at 4 g/m^2/month, and for TSP is 90 µg/m^3 on an annual average (e.g. NSW, Reference 12).

The following dispersion modelling includes comparisons against the above-mentioned criteria at the maximum model result output, as well as the 6th highest for PM_{10} to take into consideration the allowable exceedances.

4.2. Oxides of Nitrogen

Oxides of nitrogen (NO_X) include nitric oxide (NO) and nitrogen dioxide (NO_2). NO is a colourless gas with a sharp, sweet odour, whereas NO_2 is a dark brown gas with a pungent, acrid odour. NO_X in the atmosphere contributes significantly to haze. NO_2 is a brown gas and NO_X can produce nitrate particles, both of which reduce visibility. NO_X contributes to regional air pollution as a precursor to photochemical pollution and is also a factor in the formation of acid rain.

NO_X are produced by the combustion of fuel in the presence of nitrogen, however approximately 95% of NO_X present in the exhaust gas is NO, with the remaining 5% NO_2 (sometimes called 'thermal NO_2'). On release, NO reacts with available ozone (O_3) to form NO_2, increasing the ratio of NO_2 to NO. Subsequently, NO_2 breaks down in the presence of sunlight to form NO and O_3. It is this (highly simplified) series of reactions that contributes to photochemical smog, which is a significant problem in populated cities. In the project location, there will be limited background O_3 levels to allow for significant NO_2 generation. However, to be conservative, NO_2 rates have been assumed to be 30% of total NO_X.

Excessive levels of NO_X, particularly NO_2, can cause death in plants and roots and damage the leaves of many agricultural crops. Excessive levels increase the acidity of rain (i.e. lower the pH) and thus lower the pH of surface and ground waters as well as soil. In turn, this lowered pH can have harmful effects, including death, on a variety of biota. NO_2 is a toxic gas, and a priority air pollutant. Exposure to NO_2 can result in decreased lung function and increases in respiratory illness, including cardiovascular disease.

The limit for NO_2 in the NEPM AAQ is 0.12 ppm, or 246 μg/m^3, on an hourly average (Reference 1).

4.3. Carbon Monoxide

Carbon monoxide (CO) is an odourless, colourless gas which is produced via natural sources such as the oxidation of methane, and from the incomplete combustion of fossil fuels. CO is eventually converted to carbon dioxide in the atmosphere as well as through the action of soil micro-organisms and some plants.

CO is a toxic gas that combines with haemoglobin in the blood to produce carboxy-haemoglobin which prevents the absorption and transport of oxygen. CO is toxic at high concentrations where exposure can be fatal but there can also be health affects at low concentrations which can include nausea, headaches and a reduction in response time.

The limit for CO in the NEPM AAQ is 9.0 ppm, or 11,250 μg/m^3, on an 8 hourly average (Reference 1).

4.1. Sulphur Dioxide

Sulphur dioxide (SO_2) is the most abundant sulphur-containing compound caused by man-made sources. The main contributor globally is the burning of coal, with considerable contributions also from petroleum combustion (diesel fuel) and smelting.

SO_2 in the atmosphere is eventually oxidised to sulphur trioxide (SO_3) which combines with water (H_2O) to form sulphuric acid (H_2SO_4). This is removed from the atmosphere by rainfall (and to a lesser extent by adsorption to particulate matter and the resulting particulate deposition) and is the main component of acid rain, which has a critical effect on human and animal health and plants. Even low concentrations of SO_2 can harm plants and trees and reduce crop productivity. Higher levels, and especially the acidic deposits from acid rain, will adversely affect both land and water ecosystems.

Human exposure to low concentrations of SO_2 can cause irritation of the eyes, nose and throat, choking and coughing. Those with impaired heart or lung function and asthmatics are at increased risk. Repeated or prolonged exposure to moderate concentrations may cause inflammation of the respiratory tract, wheezing and lung damage. It has also been proved to be harmful to the reproductive systems of animals and cause developmental changes in their newborn.

The limit for SO_2 in the NEPM AAQ is 0.2 ppm, or 570 μg/m^3, on an hourly average (Reference 1).

5. EMISSIONS MODELLING

Dispersion modelling has been carried out in accordance with the principles of the Air Quality Guidance Notes (Reference 2) and in line with previous studies within the region.

The emissions modelling program AERMOD has been chosen to perform the dispersion modelling for the Project, which is seen as a more advanced model to the previous standard model AUSPLUME, and is now the preferred model of the Victoria EPA (the creators of AUSPLUME). However, given the lack of significant topographical features and the character of the sources, either model would be expected to perform adequately. AERMOD's meteorological pre-processor AERMET has been used to prepare input meteorological data files based on MM5 inputs from Lakes Environmental, which provide upper air data otherwise unavailable onsite. The annual wind rose for the meteorological data used is shown in Figure 5-1, for the year 2015, which is the most recent complete year of meteorological data available for the area.

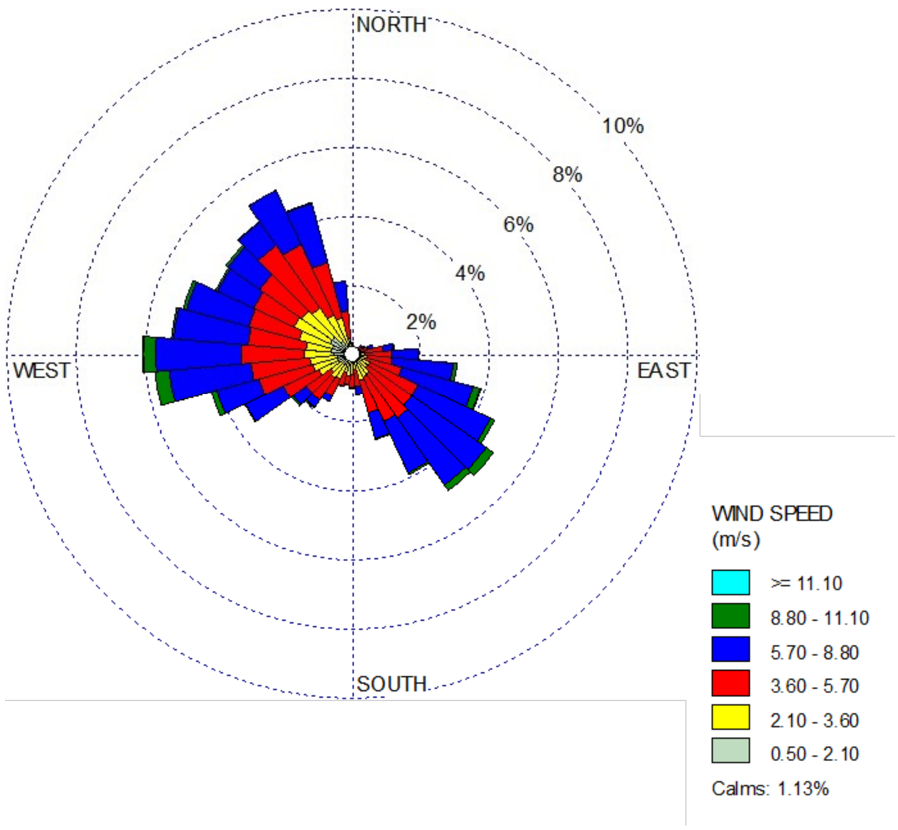

Figure 5-1: 2015 Annual Wind Rose for the Derby Area.

The modelling has included the mine site and the unpaved access road to the site, in order to capture the significant emissions to be generated by the project and ensure cumulative impacts are addressed. The paved road train emissions have not been considered in this report, as they are a large distance to the mine site – paved road emissions have been assessed in the port air quality assessment in relation to potential impacts within the Derby town site (Reference 14).

There are no significant emissions sources in the vicinity of the mine site, as such the main contributors to dust levels are ambient wind-borne dust and smoke from dry season bush fires. As such, background and cumulative emissions from other industrial activities are expected to be negligible, and naturally occurring background particulate concentrations are expected to be minor. However, in order to be conservative, the average ambient dust concentrations found in north-west Western Australia have been used to ensure the worst-case scenario is considered. The background concentrations used are 40 $\mu g/m^3$ for TSP, 20 $\mu g/m^3$ for PM_{10} and 7 $\mu g/m^3$ for $PM_{2.5}$, which are based on a number of studies based on ambient monitoring of the Kimberley and Pilbara regions, which both experience a higher level of activity than the Project location and as such are seen to be a conservative choice in lieu of local data (Reference 15, 16). Background combustion emissions are assumed negligible due to the lack of significant sources nor naturally occurring background levels.

The modelling results are presented in the following figures.

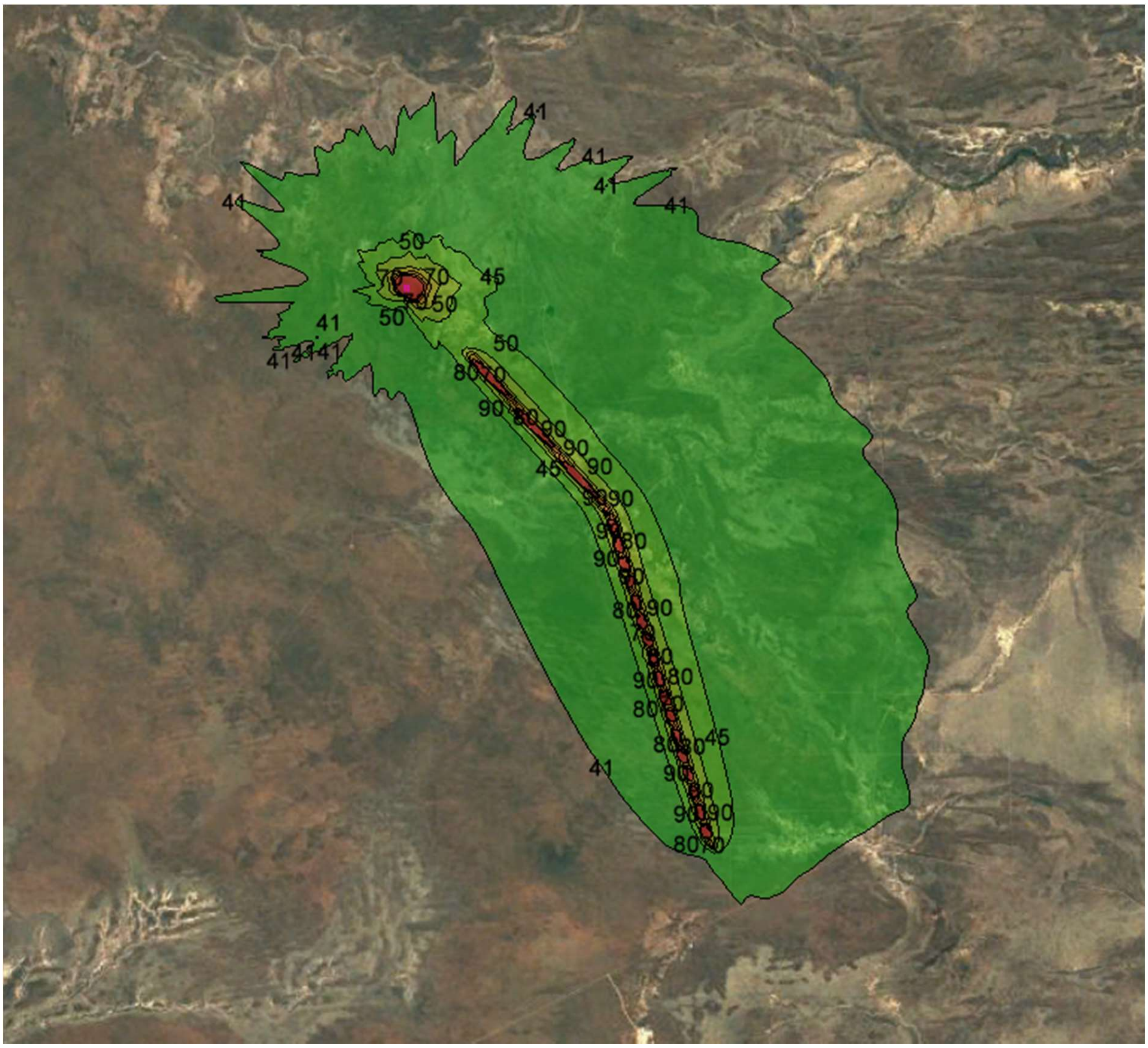

Figure 5-2: Maximum Ambient TSP Concentrations, Annual Average (µg/m^3)

The ambient TSP ground level concentrations are shown in the above figure, which show that TSP levels are elevated in the immediate vicinity of the mine site and unpaved road, which is to be expected given the nature and scale of operations, however quickly fall below the standard within a short distance. Given the lack of sensitive receivers, there is not expected to be any adverse air quality impacts present. The accommodation camp, located 4 km from the mine site, is predicted to experience air quality well within the criteria.

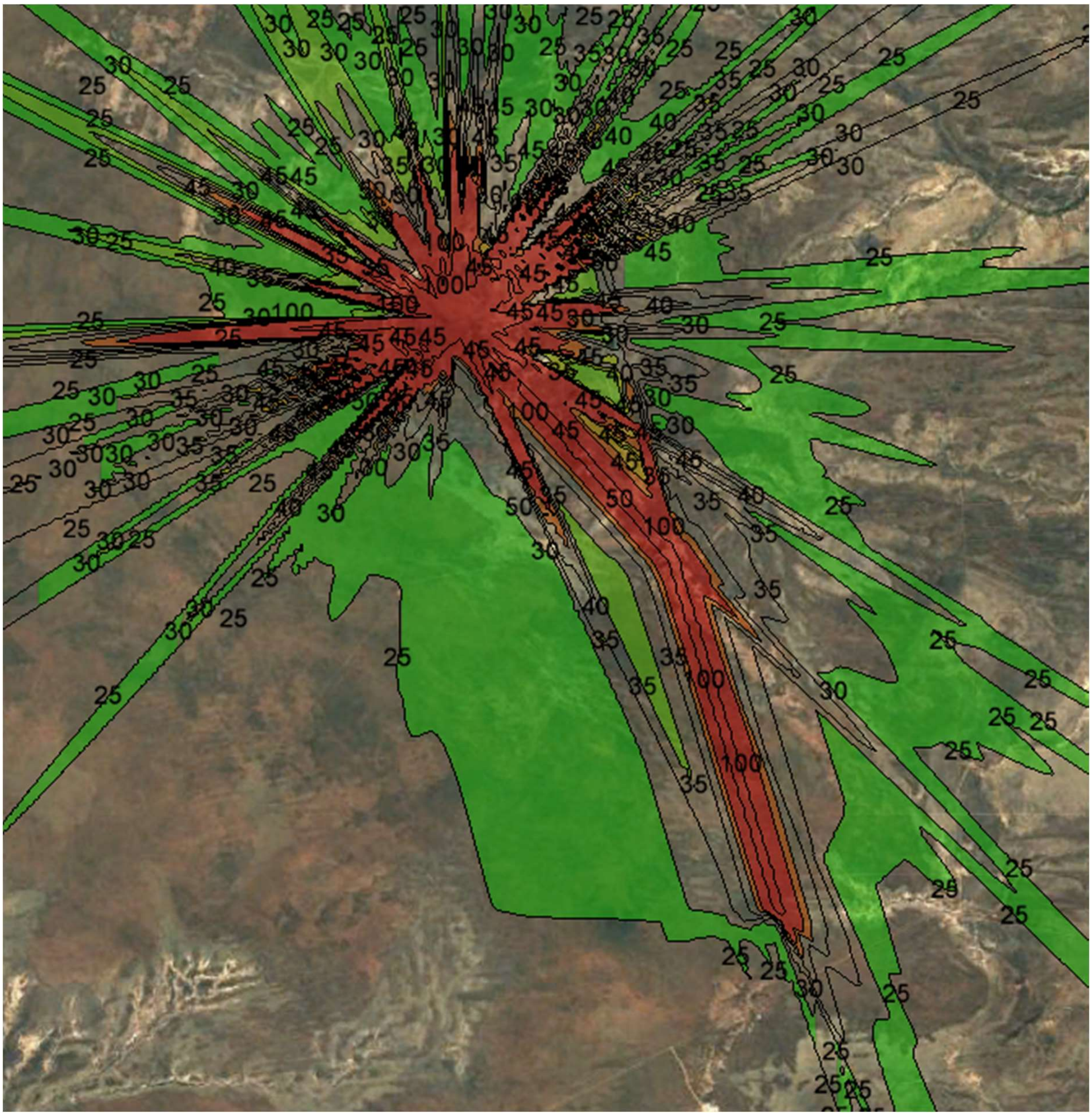

Figure 5-3: Maximum Ambient PM_{10} Concentrations, 24-Hour Average (µg/m^3)

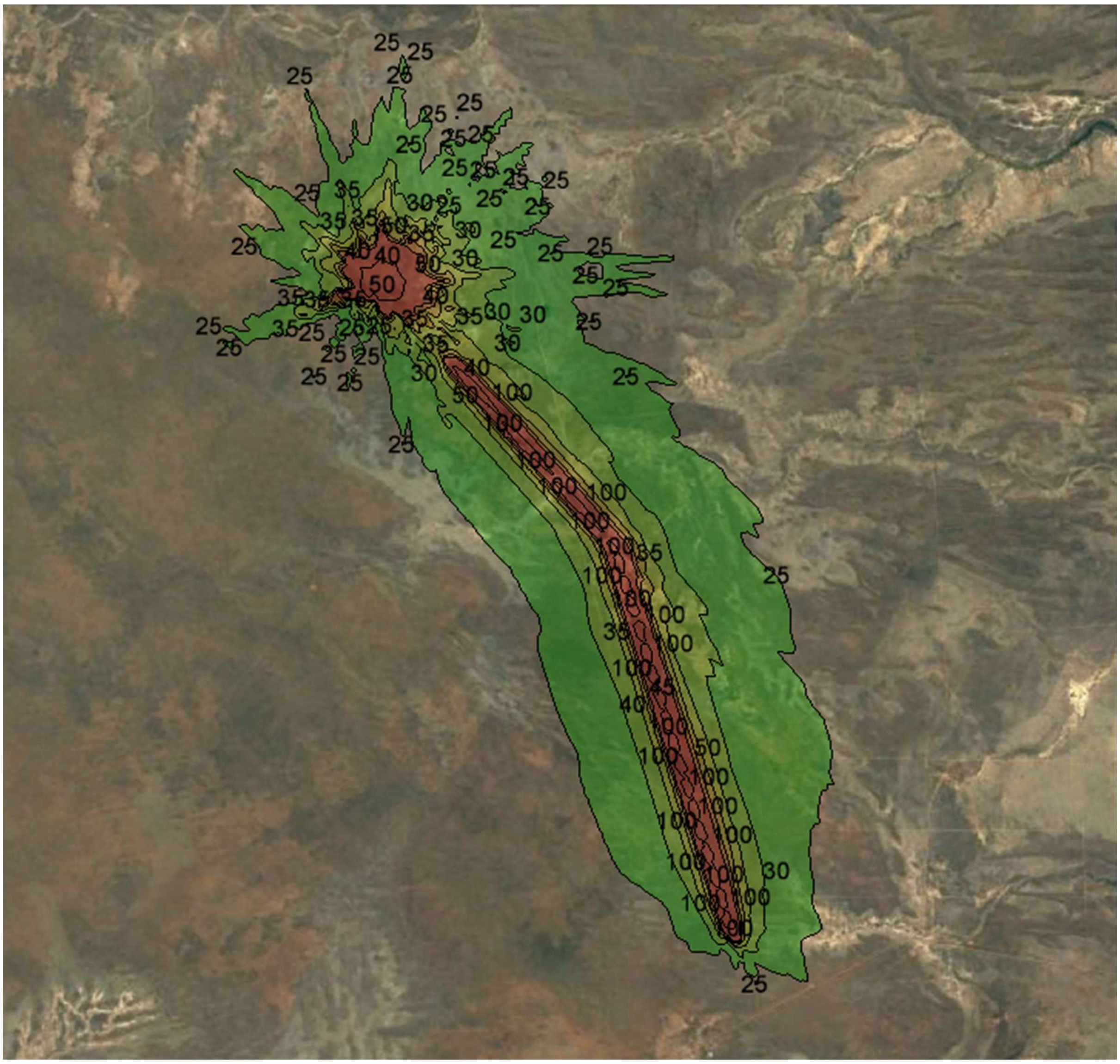

Figure 5-4: 6th Highest Ambient PM_{10} Concentrations, 24-Hour Average ($\mu g/m^3$)

The ambient PM_{10} ground level concentrations are shown in the above figures (both the maximum and the 6th highest in order), which show that PM_{10} levels are elevated in the immediate vicinity of the mine site and unpaved road, which is to be expected given the nature and scale of operations, however quickly fall below the standard within a short distance – particularly for the 6th highest scenario. Given the lack of sensitive receivers, there is not expected to be any adverse air quality impacts present. The accommodation camp, located 4 km from the mine site, is predicted to experience air quality well within the criteria.

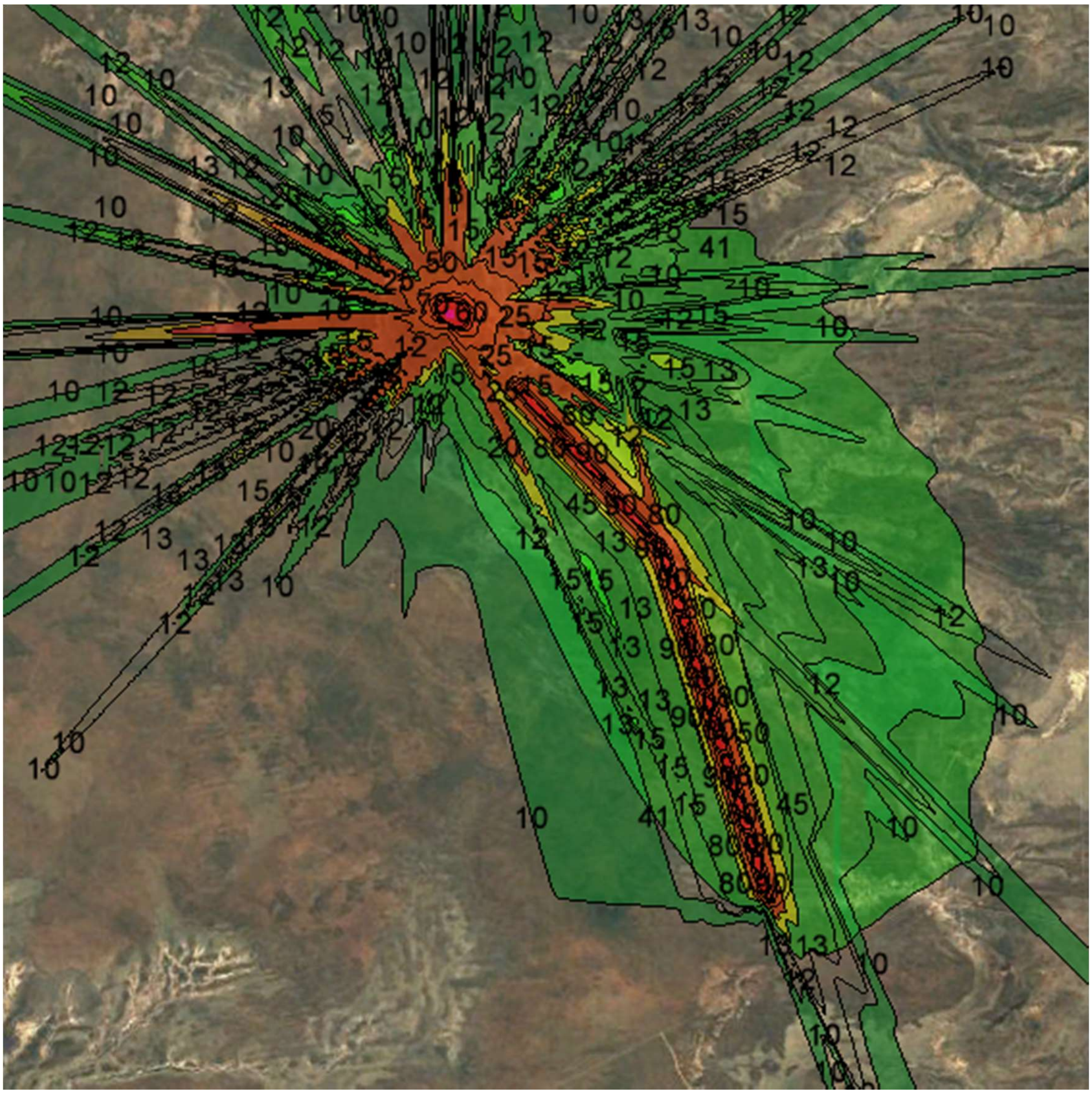

Figure 5-5: Maximum Ambient $PM_{2.5}$ Concentrations, 24-Hour Average ($\mu g/m^3$)

The ambient $PM_{2.5}$ ground level concentrations are shown in the above figure, which show that $PM_{2.5}$ levels are elevated in the immediate vicinity of the mine site and unpaved road, which is to be expected given the nature and scale of operations, however quickly fall below the standard within a short distance. Given the lack of sensitive receivers, there is not expected to be any adverse air quality impacts present. The accommodation camp, located 4 km from the mine site, is predicted to experience air quality well within the criteria.

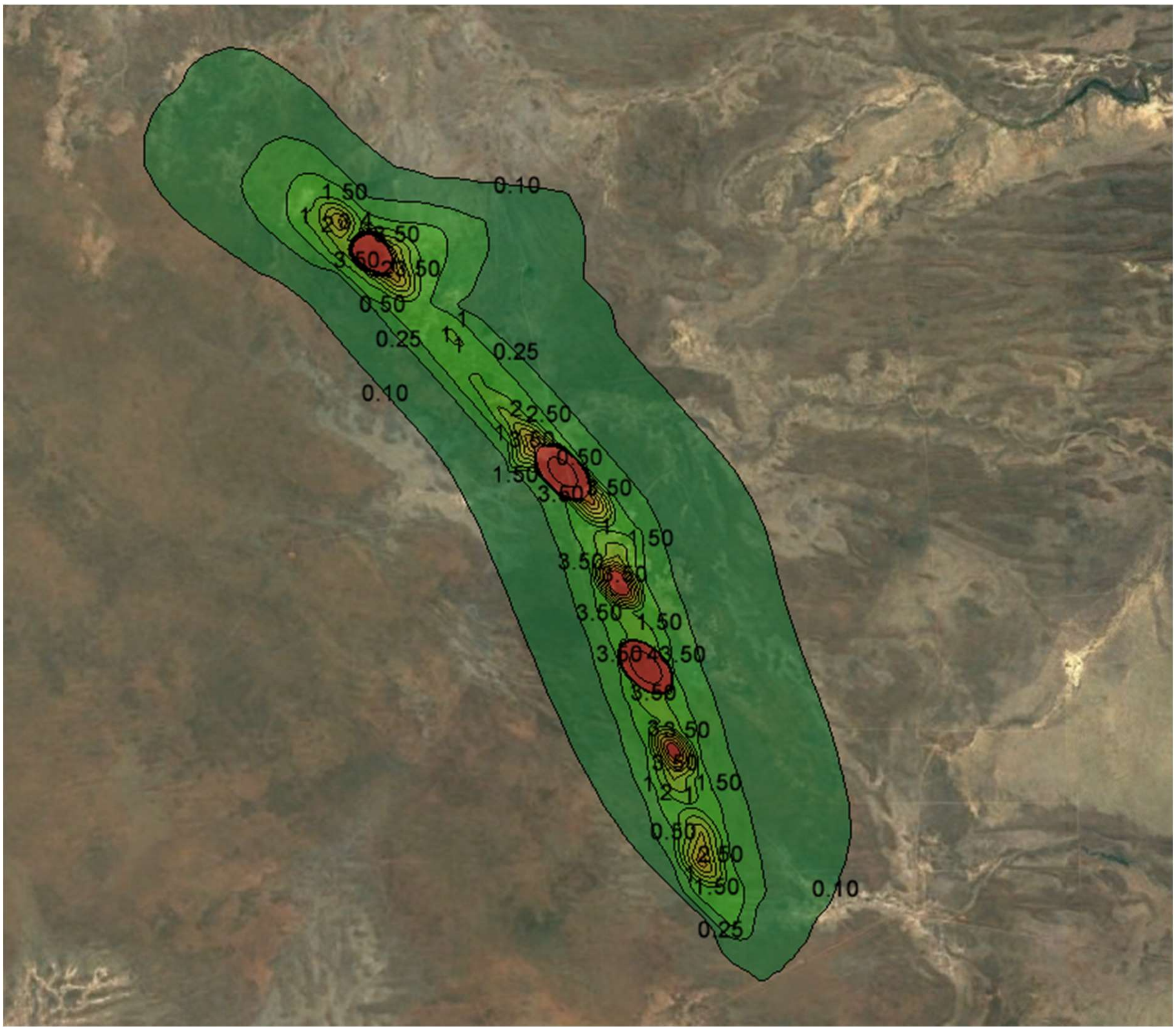

Figure 5-6: Maximum Monthly Dust Deposition Contours (g/m^2/month)

The monthly dust deposition contours are shown in the above figure, which show that the level of dust deposition is expected to be significantly below the criteria of 4 g/m^2/month outside the immediate vicinity of the mine site and unpaved road. Given the lack of sensitive receivers, there is not expected to be any adverse air quality impacts present. The accommodation camp, located 4 km from the mine site, is predicted to experience air quality well within the criteria.

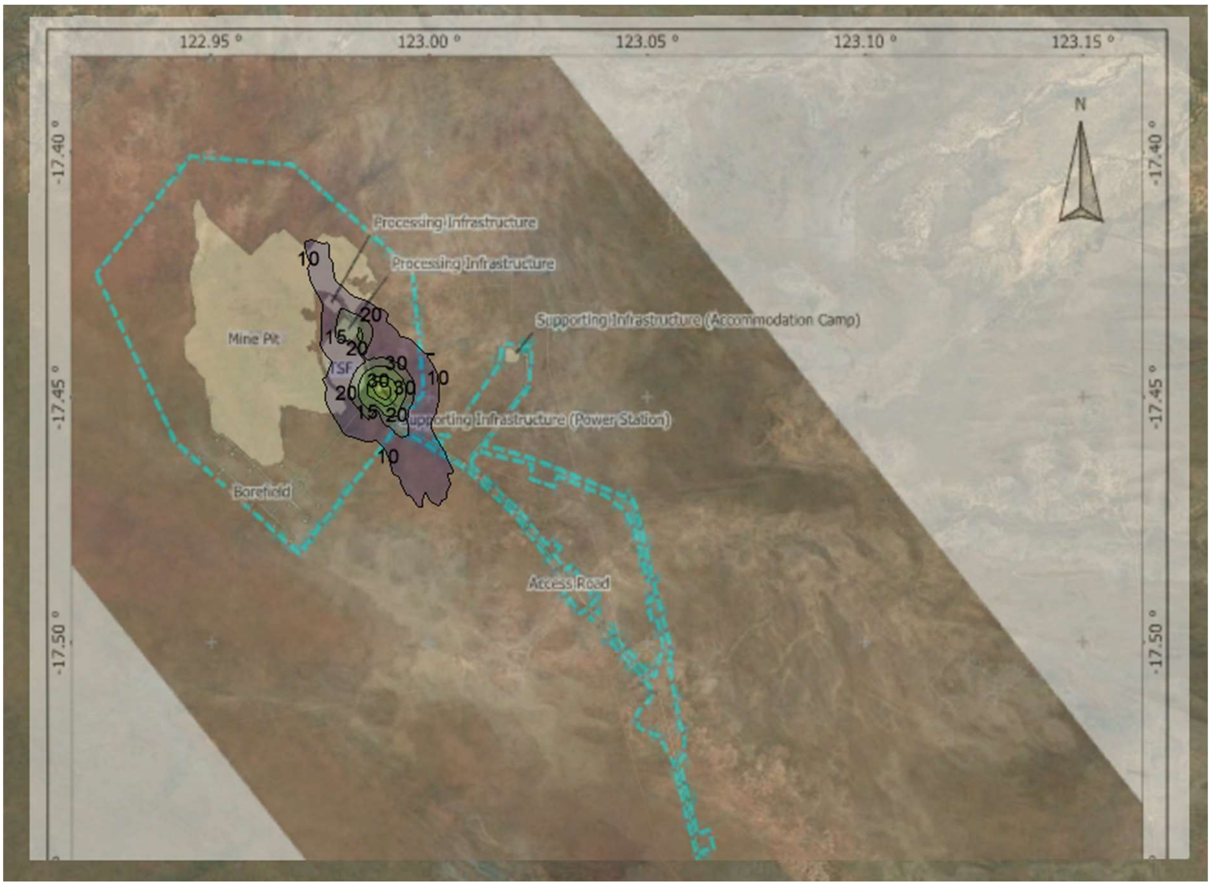

Figure 5-7: Maximum Ambient NO_2 Concentrations, Hourly Average (µg/m³)

The ambient NO_2 ground level concentrations are shown in the above figure, which show that NO_2 levels are expected to be well below the criteria of 246 µg/m³ on an hourly average at all times, due to the relatively low levels of emissions of combustion pollutants.

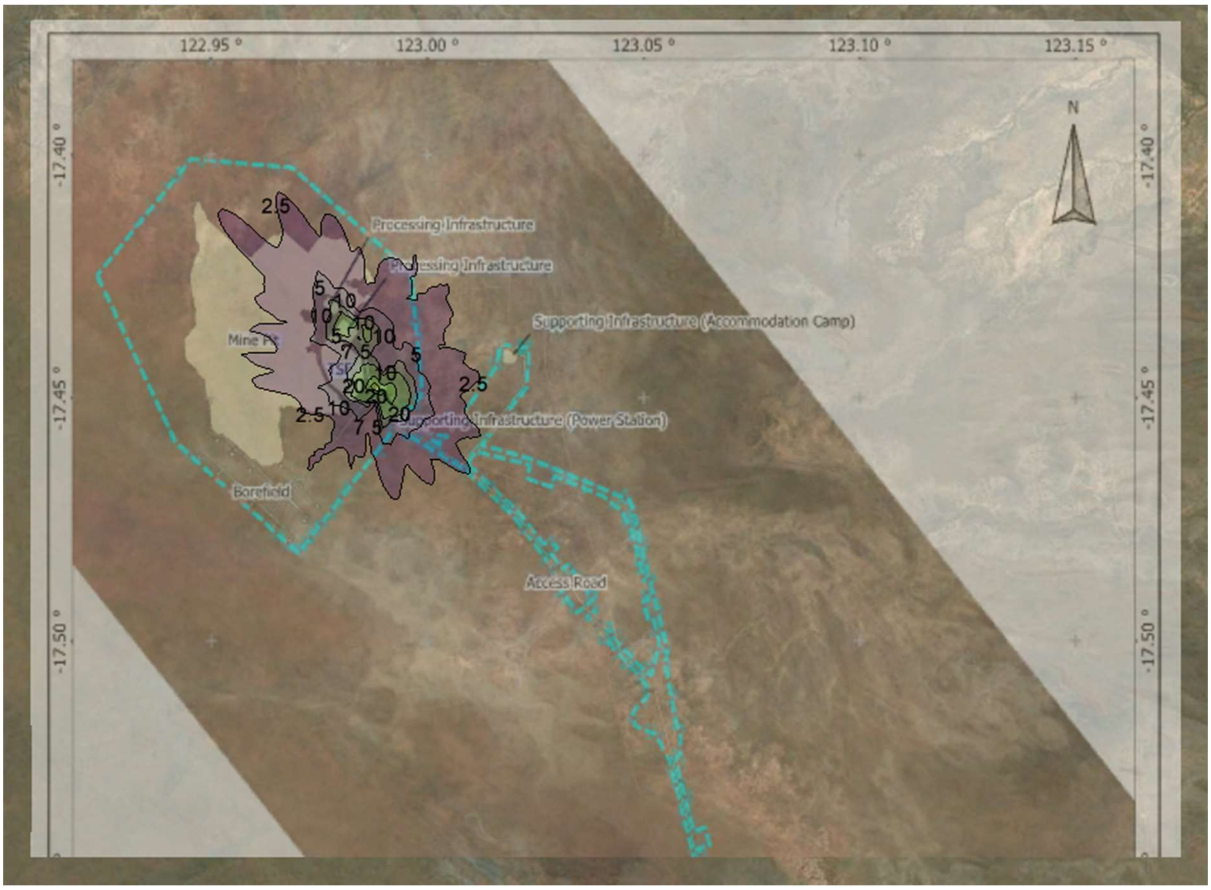

Figure 5-8: Maximum Ambient CO Concentrations, 8-Hour Average (µg/m³)

The ambient CO ground level concentrations are shown in the above figure, which show that CO levels are expected to be well below the criteria of 10,000 µg/m³ on an 8-hourly average at all times, due to the relatively low levels of emissions of combustion pollutants.

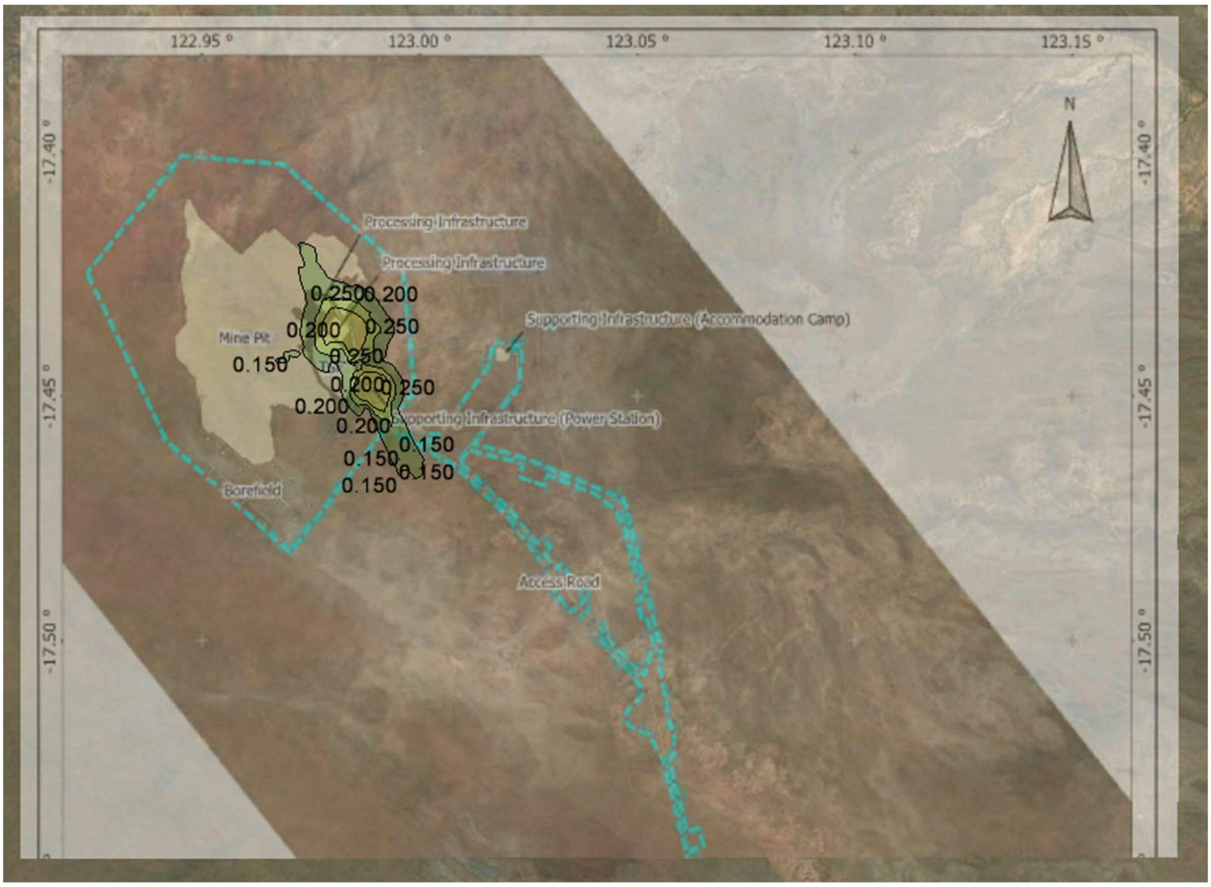

Figure 5-9: Maximum Ambient SO_2 Concentrations, Hourly Average (μg/m³)

The ambient SO_2 ground level concentrations are shown in the above figure, which show that SO_2 levels are expected to be substantially below the criteria of 570 μg/m³ on an hourly average at all areas, due to the low levels of emission from the mine site.

6. CONCLUSIONS

The air quality impacts of the mine site and unpaved access road associated with the overall Thunderbird Project have been assessed. The air quality impacts have been found to be associated mainly with dust impacts generated by the mining, processing, handling and transport of the mined material, as well as combustion emissions from onsite power generation and process heat requirements. These activities have been estimated using the emissions estimation methodologies of the NPI EEH Manuals for Mineral Sands (Reference 3) and Mining (Reference 4), and modelled in accordance with the Air Quality Modelling Guidance Notes (Reference 2).

The results of the modelling indicate that all pollutants, both dust (TSP, PM_{10}, $PM_{2.5}$ and dust deposition) and combustion products (NO_2, CO, SO_2), will be well within the assessment levels discussed in Section 4 at the nearby sensitive receptors, including the accommodation camp itself.

As such the mining and transport activities are not expected to result in any adverse air quality impacts in the region.

7. REFERENCES

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