APPENDIX G: AIR QUALITY STUDY

Project done on behalf of

SLR Consulting (Africa) (Pty) Ltd

AIR QUALITY IMPACT ASSESSMENT FOR A CHROME SAND DRYING PLANT, CHANGES TO THE TAILINGS DAM DESIGN AND OTHER OPERATIONAL AND SURFACE INFRASTRUCTURE CHANGES AT THARISA MINERALS

Report No.: APP/12/SLR04

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Date	August 2014
Client	SLK Consulting (Africa) (Pty) Ltd
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REVISION RECORD

Revision Number	**Date**	**Reason for Revision**
Error! Reference source not ound.1	September 2012	SLR comments
Final Revision 2	August 2014	Additional SLR comments

ABBREVIATIONS

Airshed	Airshed Planning Professionals (Pty) Ltd
C_6H_6	Benzene
CO	Carbon Monoxide
NAAQS	National Ambient Air Quality Standards
NEMAQA	National Environmental Management Air Quality Act
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
NPI	National Pollutant Inventory (Australia)
PM_{10}	Thoracic particulate matter with an aerodynamic diameter of less than 10µm
ppb	Parts per billion
SABS	South African Bureau of Standards
SANS	South African National Standards
SO_2	Sulphur Dioxide
tpa	tons per annum
TSP	Total Suspended Particulates
US EPA	United States Environmental Protection Agency
VOC	Volatile organic compounds

EXECUTIVE SUMMARY

Introduction

Airshed Planning Professionals (Pty) Ltd was appointed by SLR (Pty) Ltd to undertake an air quality impact assessment for changes to the Tharisa Minerals mine infrastructure and concentrator plant near Mooinooi in the North West Province. The main objective of the study was to do an air dispersion impact assessment in order to estimate the potential impacts the changes will have on the surrounding environment and human health.

Tharisa Minerals plan to undertake the following changes at their mine and concentrator plant:

- Construct and operate a chrome sand drying plant (which is also a listed activity under the NEM - Air Quality Act (Act 39 of 2004));
- Deepening and widening of the east and west open pits.
- Proposed increases, reshaping and realignment of the waste rock dumps
- Changes to the tailings dam design; and
- Changes to the general surface infrastructure layout and operations at Tharisa Mine.

An Air Quality Impact study was done in 2008 (Airshed Planning Professionals). This study represents operational conditions before the commencement of construction at the Tharisa mine and therefore represents baseline conditions for the purpose of this study. Changes to the air quality environment expected as a result of the additions to the mine may possibly include the following:

- A chrome sand dryer plant will be built at the Tharisa Minerals processing plant. This chrome sand dryer plant will be fuelled by coal, diesel or heavy fuel oil (HFL). The possible emissions from all three of these fuels was quantified and it turned out that the emissions from using diesel as a fuel where the most significant. In order to get the most conservative results, the chrome dryer plant was modelled to be fuelled by a diesel which will increase concentrations of gaseous pollutants and particular matter (NO_x, SO_2, CO, VOC's, PM_{10} and $PM_{2.5}$).
- The east and west pits will be expanded both in size and in depth. The east pit will be increased by 90 ha and an average depth of 180 m whereas the west pit will be increased by 15 ha and an average depth of 180 m. The new open pit areas will result in additional fugitive dust emissions whereas the deepening may result in a decrease of fugitive dust emissions, as more fugitive dust will be retained within the pit when the pit is deeper.
- The reshaping and realignment of the waste rock dumps may have an effect on fugitive dust emissions as it may increase the susceptibility of the dumps to wind erosion.
- Changes to the tailings dam design may increase the surface area of the dam which is possibly susceptible to wind erosion.

  Changes to the general surface infrastructure layout and operations at Tharisa Mine may increase the amount of materials handling points and surfaces susceptible to wind erosion. It may also increase the road area utilised, thereby increasing fugitive dust entrainment from vehicles as they drive on the unpaved roads.

Methodology

The establishment of a comprehensive emissions inventory including new sources arising from developments at the project site formed the basis for this study. The establishment of an emissions inventory comprised the identification of sources of emission, and the quantification of each source's contribution to ambient air pollution concentrations.

Fugitive dust emissions mainly occur as a result of vehicle-entrained dust from unpaved haul roads, wind erosion from open areas, materials handling operations, drilling, blasting, dozing, crushing and screening operations. In the quantification of fugitive dust emissions use was made of emission factors which associate the quantity of a pollutant to the activity associated with the release of that pollutant. Due to the absence of locally generated emission factors, use was made of the comprehensive set of emission factors published by the US Environmental Protection Agency (US EPA) in its AP-42 document Compilation of Air Pollution Emission Factors as well as the Australian National Pollutant Inventory (NPI) documents.

In the estimation of emissions and the simulation of patterns of dispersion, a distinction was made between Total Suspended Particulates (TSP) and inhalable particulates (PM_{10}), particulate matter with an aerodynamic diameter of less than 10 µm and $PM_{2.5}$ particulate matter with an aerodynamic diameter of less than 2.5 µm). Whereas TSP is of interest due to its implications in terms of nuisance dust impacts, the PM_{10} and $PM_{2.5}$ fractions are taken into account to determine the potential for human health risks.

Gaseous pollutants including NO_x, SO_2, CO and VOC's are of a possible concern at the study site, as the chrome sand dryer will possibly make use of a diesel fuel boiler as energy source. Emissions factors associated with boilers were obtained from the NPI, 2011.

As local meteorological data was unavailable, reference was made to hourly average meteorological data modelled by the SAWS Unified Model for the period January 2009 to December 2011 for a point within the Tharisa Minerals boundary.

PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, VOC concentrations and dustfall rates were simulated for the project. The simulation of ambient air pollutant concentrations and dust deposition due to the project emissions were undertaken through the application of the US -EPA AERMOD (version 7). The US EPA (EPA, 1986) considers the range of uncertainty to be -50% to 200%. Dispersion modelling was undertaken for routine unmitigated emissions; routine mitigated emissions and upset emissions (unplanned and unmitigated).

Assumptions and Limitations

Due to data limitations some assumptions had to be made during the assessment. These were:

- As no onsite meteorological data was available for use in the current study, use was made of meteorological data modelled by the SAWS Unified Model for the period January 2009 to December 2011.

- In all cases where data or information for the project was limited, use was made of data from similar projects and operations in the area.

- Construction activities will be limited to the chrome sand drying plant with the other expansion activities forming part of the operational phase. The construction phase activities were assessed qualitatively since these will be temporary and occur concurrently with the mining activities,

- The dispersion model cannot compute real-time mining processes; average mining throughputs were therefore used. Operational locations and periods were selected to reflect the worst case scenarios.

- This study did not take account of gasses released by vehicle tailpipe emissions as it was assumed that these concentrations will be negligible.

- It is important to note that dispersion modelling done for this study represents the predicted impacts from the Tharisa Minerals mine only. There was not enough information available to do a cumulative assessment of air quality in the area. As the area in which Tharisa is situated is an area where many platinum mines are found (it falls under the Waterberg-Bonjanala Priority Area), air quality is already low and therefore the impacts predicted in this study will most probably be higher than predicted in this report.

Dispersion Modelling

The dispersion of pollutants that is expected to arise from the project was modelled for an area covering 30 km (east-west) by 30 km (north-south). The area was divided into a grid matrix with a resolution of 400 m by 400 m, with the site located approximately in the centre of the receptor area. The nearby sensitive receptors identified were included as discrete receptor points. AERMOD simulates ground-level concentrations for each of the receptor grid points. Topography was also included in the model setup.

An air quality impact assessment has been undertaken for the changes to the Tharisa Minerals open pit mine and concentrator plant in the North West Province. Nuisance dust, PM_{10} and $PM_{2.5}$ health impacts for the operation were assessed in order to identify all possible detrimental impacts on the surrounding environment and sensitive receptors. This was doen for the operational phase only, since the construction phase activities could not be quantified and likely to be masked by the current mining operations.

Conclusions

The main findings of the study are as follows and cater for the on-site cumulative impacts taking into account approved activities:

Emissions Inventory:

- Total PM_{10}, $PM_{2.5}$ and TSP emissions were calculated to be 1083, 657 and 5731 tpa respectively during the operational phase (partially mitigated scenario) of the mine. Vehicle entrainment from unpaved haul roads (excluding in pit roads) was estimated to be the most significant contributor to the total unmitigated PM_{10} and $PM_{2.5}$ emissions contributing approximately 49% and 80% respectively. Crushing operations contributed the most to TSP emissions (56%).

- Total PM_{10}, $PM_{2.5}$ and TSP emissions were calculated to be 234, 66 and 678 tpa respectively during the operational phase (mitigated scenario) of the mine. Open pit sources, unpaved roads and blasting were the most significant sources of emissions during this phase with blasting contributing the most to PM_{10} emissions (43%), open pit sources contributing the most to $PM_{2.5}$ emissions (74%) and unpaved roads contributing the most to TSP emissions (29%).

Impact Assessment:

- **Particulate (PM_{10} and $PM_{2.5}$) Impacts**

  - Exceedances of the 2015 South African annual average and highest daily average PM_{10} standards were predicted to occur at the mining rights area boundary for both operational phase (partially mitigated) scenarios. With additional mitigation applied, these exceedances reduced to be mostly contained within the mining rights boundary – exceedances at on-site receptors Silver City, the school and Lepologang Village.

  - Exceedances of the current South African annual average and highest daily average $PM_{2.5}$ standards were predicted to occur outside the mining rights boundary for the operational (partially mitigated) phase. The mitigated scenario of the operational phase was predicted to exceed the annual $PM_{2.5}$ standard only slightly outside the mining rights boundary, with marginal exceedances only at Silver City and the school.

  - Vehicle entrainment from unpaved haul roads (excluding in-pit haul roads) is expected to be the main contributor to predicted PM_{10} and $PM_{2.5}$ exceedances at the mining rights boundary and sensitive receptors for both phases..

It should be noted that the predicted impacts only reflect the contribution from the Tharisa Mineral Mine on the surrounding environment and human health. No background concentrations were included in the predictions due to the lack of information.

- **Dustfall Impacts**

  - Exceedances of the NDCR residential and non-residential limits were only predicted to be exceeded within the mine boundary.

  - Exceedances of the NDCR residential and non-residential limits were not predicted to exceed at any of the sensitive receptors.

  - The main source group contributor to daily dustfall rates was predicted to be crushing operations.

- **Gaseous Impacts**
    - CO, NOx, SO_2 and VOC impacts due to the chrome sand dryer plant is expected to be low.

    - None of the NAAQ gaseous standards were predicted to be exceeded anywhere within or outside of the mine boundary or at any of the sensitive receptors during any of the phases of the mine.

Recommendations

The main objective of Air Quality Management measures is to ensure that all operations at the mine and concentrator plant will be within compliance with South African air quality requirements. In order to define site specific management objectives, the main sources of pollution needed to be identified. Sources can be ranked based on sources' strengths (emissions) and impacts. Once the main sources have been identified, target control efficiencies for each source can be defined to ensure acceptable cumulative ground level concentrations. The main pollutants of concern identified during the impact assessment were identified as particulates (PM_{10} and $PM_{2.5}$).

Target Control Efficiencies

Since the impact assessment and significance ranking proved to be unacceptably high, even with minimum mitigation measures in place, the following target control efficiencies for all routine sources of emissions were determined (as modelled for the mitigated operational phase scenario in this report).

- Vehicle entrainment from the unpaved haul roads – 90% control efficiency through effective water sprays combined with chemicals.
- Crushing and Screening – 98% reduction through enclosure of primary and secondary crushing and screening operations with effective dust extraction and associated bag filters.
- Drilling – 70% reduction through effective water sprays.
- Materials handling (unloading of trucks) – 70% reduction through effective water sprays.
- Materials handling (conveyor transfer/ stockpiling points) – 70% for enclosure.

Project specific management methods that can be used to obtain the control efficiencies as discussed above are discussed in Appendix A.

Monitoring Requirements

A dust fallout network has been installed at Tharisa Minerals in the past; however as particulate matter impacts were predicted to be the most pronounced during this study, it is recommended that PM_{10} monitoring be done. Available ambient monitoring data also indicate that the background concentrations in the region are already elevated. It is therefore pertinent to understand what the ambient concentrations at the Tharisa Minerals operations are.

A PM_{10} monitoring network can serve to meet various objectives, such as:

- Compliance monitoring;
- Validate dispersion model results;
- Use as input for health risk assessment;
- Assist in source apportionment;
- Temporal trend analysis;
- Spatial trend analysis;
- Source quantification; and
- Tracking progress made by control measures.

Based on the fact that particulate limits are exceeded at sensitive receptors inside and outside the mine rights boundary, it is important that PM_{10} monitoring be done at these sites. It is recommended that a PM_{10} ambient monitor be placed at the Piet Retief/President van Rensburg primary school and at the Madithlokwa/Silver City village. It is essential that the PM_{10} monitoring station also record basic hourly average meteorological parameters namely wind speed, wind direction, temperature and rainfall. It is however recommended that relative humidity, pressure and solar radiation also be measured.

If measured PM10 results confirm the high PM_{10} and $PM_{2.5}$ concentrations predicted by the modelling during this study, then sensitive receptors within the mine boundary (Silver City and the school) will have to be relocated outside of the mine where exceedances of the NAAQS does not occur, as exposures to air in exceedance of the NAAQS will be detrimental to the health of all people exposed**.**

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1 INTRODUCTION

Airshed Planning Professionals (Pty) Ltd was appointed by SLR Africa (previously Metago Environmental Engineers (Pty) Ltd) to undertake an air quality impact assessment for the changes to the Tharisa Minerals concentrator plant and general mine infrastructure near Mooinooi in the North West Province. The main objective of the study was to do an air dispersion impact assessment using project specific data to determine potential impacts on the surrounding environment and human health.

1.1 Project Overview

Tharisa Minerals plans to undertake the following changes to their concentrator plant and mine infrastructure:

- deepening and widening of the east and west open pits and related additional waste rock and tailings material storage
- a chrome sand drying plant with associated support facilities, within the concentrator complex
- changes to the tailings storage facility design
- re-shaping and re-alignment of waste rock dumps
- changes to general surface infrastructure layout and operations at the mine.

The details of the changes as described in the Scoping Report (SLR, 2012) are discussed in the sections below.

1.1.1 Increase of the Open Pit Areas

The open pit mining operations at Tharisa Mine are divided into two sections: the western and eastern pits. The two sections are separated by the D1325 (Marikana) road. Tharisa plans to widen the pits and increase the approved depths to ensure an extension in the life of the mine from 12 years as approved (EIA/EMP report 2008) to 18 years. The main changes to the two pits are as follows:

- East Pit:
    - Increase high wall height from 120 m to an average of 180 m
    - Increase footprint by approximately 90 ha
- West Pit:
    - Increase high wall height from 120 m to an average of 180 m
    - Increase footprint by approximately 15 ha

The TSF (tailings storage facilities) and rock waste dumps have also incorporated the related increase in the tailings and waste rock tonnages.

1.1.2 The Chrome Sand Drying Plant

The capacity of the chrome sand drying plant is approximately 25 000 tons per month of chrome concentrate.

It is planned that the wet chrome concentrate will be fed by front-end loader to a conveyor feeding the drier feed bin. This wet chrome will then be fed into the static fluid bed drier where it will be dried by a stream of hot gas blowing through a perforated plate. The hot burner gas will be mixed with air to achieve the correct drier gas temperature. The moisture-laden exhaust gas will be drawn off from the top of the drier chamber and ducted to gas cleaning cyclones and a bag filter to remove particulates before discharge to atmosphere. The dried chrome will be discharged from the drier and fed to a similar static fluid bed cooling unit. The dried and cooled product will be discharged via a conveyor to a storage bin, from where it will be packaged in 1 ton bags, stored in a covered store and loaded by forklift onto trucks for dispatch.

The plant will make use of approximately 475 tons of coal or light fuel oil per month as fuel source. The exhaust gas volume will be approximately 64 000 Am^3/hr at 110^oC. There will be trace amounts of SO_2 in the off-gas due to the combustion process which uses coal. CO_2 will be present as well.

The plant will be located within the existing concentrator plant area and will be operated continuously (24 hours per day).

1.1.3 Realignment and Reshaping of Waste Rock Dumps

The main changes in the waste rock storage facilities design are:

- East Mine waste storage:
    - Combined East 1 and East 2 waste rock dumps into one consolidated dump called Eastern waste rock dump. Footprint of 78 ha, height of approximately 70 m and a volume of 17.58 million m^3.
    - Additional waste dump called North eastern waste dump with a footprint of 95 ha, with a height of 70 m and a volume of 19.98 million m^3.
- West Mine waste storage:
    - Western waste rock dump footprint will increase from 49 ha to 58 ha with an approximate height of 70 m and a volume of 23.2 million m^3.
    - Central waste rock dump footprint will increase from 22 ha to 70 ha, with a height of approximately 70 m and a volume of 18.49 m^3.

1.1.4 Changes to the Tailings Storage Facility

Due to the increase of the open pit high wall and space related constraints at the mine, the designs and sizes of the TSFs have changed as follows.

Table 1-1: Changes to be made to the Tailings storage Facilities (TSFs) (SLR, 2012).

Dimensions	Approved TSF 1	Proposed new TSF 1	Approved TSF 2	Proposed new TSF 1	Units
Footprint	52	74	100	130	Ha
Maximum Height	33	40	31	45	m
Volume	5.4	8.1	12.8	22.7	million m^3

1.1.5 Life of Mine

The life of Tharisa Mine is currently planned for 12 years. The increase of the high wall will increase the life of the mine to 18 years.

1.1.6 General changes

The plant layout will be optimised within the current footprint.

Storage of materials will increase to:

- ROM from 15 000 tonnes chrome to 380 000 tonnes
- PGM concentrate from 10 000 tonnes to 160 000 tonnes
- Met grade spiral from 32 000 tonnes to 130 000 tonnes
- Chemical grade spiral from 4 000 tonnes to 20 000 tonnes
- Mill fed will remain at 4 000 tonnes.

Soil screening berms will increase in height from 5 and 10 m to approximately 30 m and will change orientation.

1.2 Site Description

Tharisa Minerals is situated 25 km east of Rustenburg and 5 km west of the town of Mooinooi, adjacent to the N4 highway. The site is surrounded by other small residential areas such as Thekane (15 km to the north-west), Rooikoppies and Wonderkoppies to the north and Makolokwe and Segwaelane to the north east. The Buffelspoort Dam and Lekkerrus holiday resort are situated 5 km to the south of the mine and concentrator plant.

The topography of the area surrounding the site is presented in Figure 1-1. The landscape consists largely of flat regions with scattered trees and grassland. The Magaliesberg mountain range that extends for about 130 km, from Pretoria to Rustenburg is 10 km to the south of the site.

1.2.1 Sensitive receptors

The sensitive receptors nearest to Tharisa Minerals are shown in Figure 1-2. Sensitive receptors within the mine rights boundary include the Madithlokwa/Silver City (in the north) and Piet Retief/President van Rensburg school and private dwellings/business (in the south). Lapologang village lies to the south of West Mine. The Mzipha village lies south east of the southern mine rights boundary whereas Elandsdrift/Mamba lies east of the mine.

1.3 Scope of Study

The air quality impact assessment for the developments at Tharisa Minerals will form part of the Environmental Impact Assessment (EIA) undertaken by SLR Africa. The Tharisa Mine will undergo three phases, namely:

1. A construction phase
2. An operational phase
3. A decommissioning phase, and
4. Closure

The decommissioning phase of the mine represents a phase during which the infrastructure at the mine will be removed. This means that the decommissioning phase will be the reverse of the construction phase. The same air quality impacts associated with the construction phase can be expected for this phase.

As emissions during the closure phase of the mine will be negligible compared to the construction, operational and decommissioning phases and as the emissions associated with the construction phase and decommissioning phase will be the same, this air quality study will only focus on the construction and operational phases.

In order to determine the possible impacts from the changes at Tharisa Minerals on the surrounding environment and human health, a study was done on the current operations (before the commencement of the construction phase), the construction phase and the future operational phase.

The characterisation of the current air quality included:

- The assessment of regional climate and site-specific atmospheric dispersion potential;
- The identification of potential sensitive receptors in the vicinity of the site;
- The preparation of hourly average meteorological data for dispersion modelling purposes;
- The identification of existing sources of emissions and the characterisation of ambient air quality and dustfall levels in the area based on data recorded to date; and
- A description of the legislative and regulatory context, including emission limits and guidelines, ambient air quality guidelines and dustfall classifications with specific reference to the new legislation.

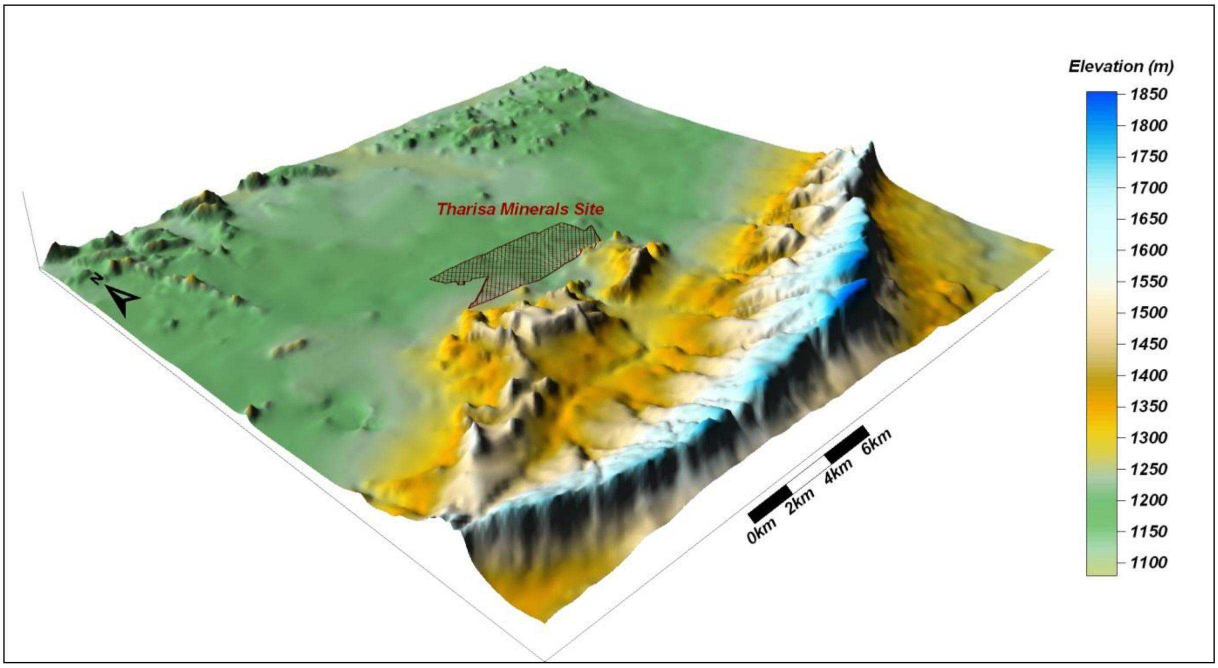

Figure 1-1: Topography of study area.

The air quality impact study included (for the construction and operational phases of the mine):

- The compilation of an emissions inventory, comprising the identification and quantification of potential routine sources of emission that included:
    - Open pit operations - drilling, excavation of ore and waste rock and vehicle activity;
    - Crushing and screening
    - Vehicle entrainment of dust from unpaved haul roads
    - Windblown dust from exposed areas such as the tailings facilities; and
    - Materials handling fugitive emissions;
    - Particulate and gaseous emissions from the chrome ore dryer plant stacks
- The compilation of an emissions inventory, comprising the identification and quantification of potential upset (unplanned, unmitigated) sources of emission that included:
    - Open pit operations;
    - Blasting and drilling

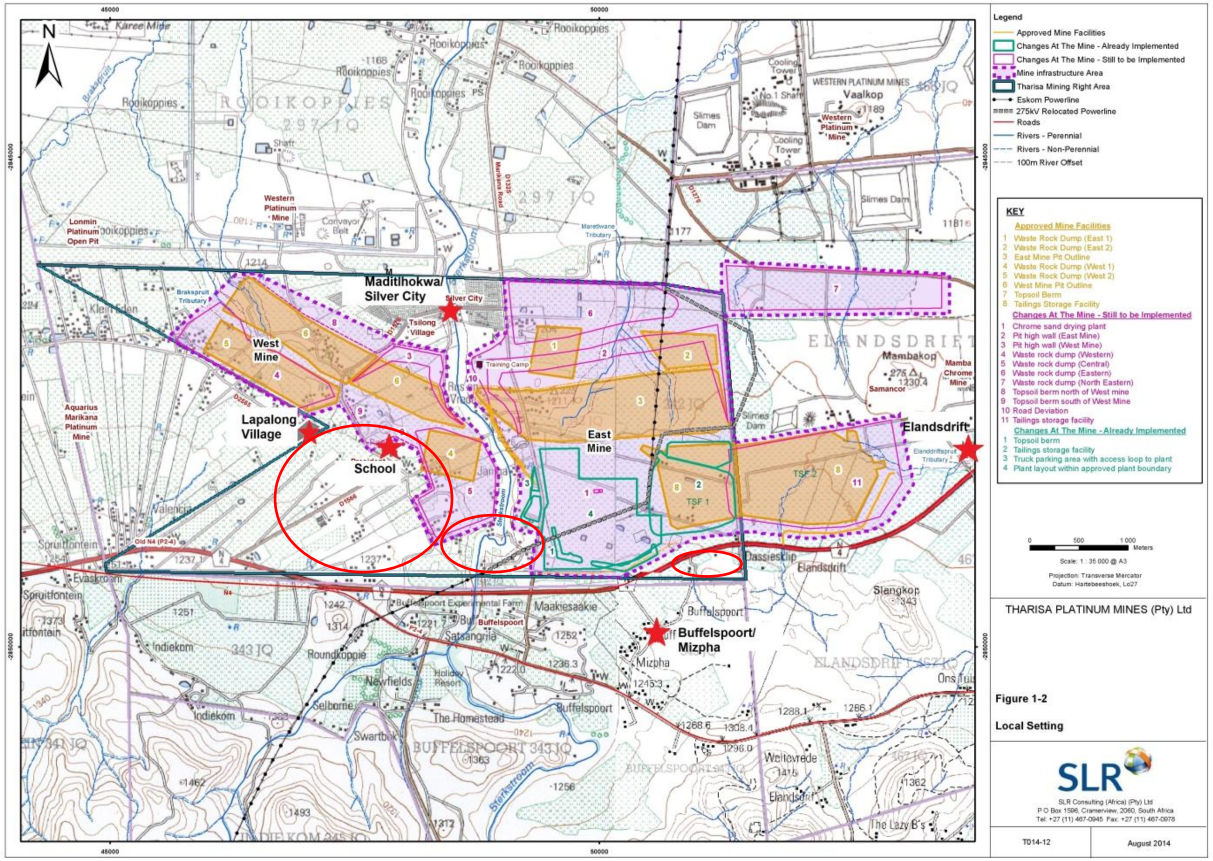

Figure 1-2: The nearest sensitive receptors within and outside the Tharisa Minerals boundary.

1.4 Air Quality Impact Assessment Methodology

The establishment of a comprehensive emission inventory formed the basis for the assessment of the impacts from of the proposed operations' emissions on the receiving environment. The establishment of an emissions inventory comprises the identification of sources of emission, and the quantification of each source's contribution to ambient air pollution concentrations.

Fugitive dust emissions occur as a result of vehicle-entrained dust from unpaved haul roads, wind erosion from open areas, material handling operations, drilling, blasting, and crushing and screening operations. In assessing the impact of fugitive dust emissions a distinction needs to be made between Total Suspended Particulates (TSP) and respirable particulates. Although TSP may be defined as all particulates with an aerodynamic diameter of less than 100 µm, an effective upper limit of 30 µm aerodynamic diameter is frequently assigned. Respirable particulates are generally defined as particulate matter with an aerodynamic diameter of less than 10 µm (PM_{10}) and particulate matter with an aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$). PM_{10} and $PM_{2.5}$ has health implications since it represents particles of a size that would be deposited in, and damaging to the lungs.

In the quantification of fugitive dust emissions use was made of emission factors which associate the quantity of a pollutant to the activity associated with the release of that pollutant. Due to the absence of locally generated emission factors, use was made of the comprehensive set of emission factors published by the US Environmental Protection Agency (US EPA) in its AP-42 document Compilation of Air Pollution Emission Factors as well as the Australian NPI emission estimation documents. The US EPA AP-42 emission factors are of the most widely used in the field of air pollution. Empirically derived predictive emission factor equations are available for vehicle-entrained dust from roadways, Aeolian erosion from open areas, material handling operations, drilling, blasting, crushing and screening operations. Predictive equations explain much of the observed variance in measured emission by relating emissions to parameters, which characterise the source (EPA, 1995). Such parameters may be grouped into three classes:

- Measures of source activity or energy expended (e.g. the speed and weight of a vehicle on an unpaved road);
- Properties of the material being disturbed (e.g. the content of suspended fines in the surface material on an unpaved road); and
- Climatic parameters (e.g. number of precipitation free days per year, when a maximum of emissions occur).

In the estimation of emissions and the simulation of patterns of dispersion, a distinction was made between Total Suspended Particulates (TSP) and inhalable particulates (PM_{10} and $PM_{2.5}$, particulate matter with an aerodynamic diameter of less than 10 µm and 2.5 µm, respectively). Whereas TSP is of interest due to its implications in terms of nuisance dust impacts, the PM_{10} and $PM_{2.5}$ fractions are taken into account to determine the potential for human health risks.

Gaseous pollutants including NO_x, SO_2, CO and VOC's (Volatile Organic Compound) are of possible concern at the study site, as the proposed sand dryer will make use of coal as fuel for the boiler. Emissions factors associated with boilers were obtained from the NPI, 2011.

In characterising the dispersion potential of the site, reference was made to hourly average meteorological data modelled by SAWS (unified model) for the period January 2009 to December 2011. The data were generated by the model at a coordinate set within the Tharisa Minerals boundary.

PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, VOC concentrations and dustfall rates were simulated for the proposed operations. The simulation of ambient air pollutant concentrations and dust deposition due to the proposed mine and concentrator plant emissions were undertaken through the application of the US-EPA AERMOD (version 5). The US EPA (EPA, 1986) considers the range of uncertainty to be -50% to 200%. The accuracy of the model improves with fairly strong wind speeds and during neutral atmospheric conditions.

1.5 Assumptions and Limitations

Due to data limitations some assumptions had to be made during the assessment. These were:

- No onsite meteorological data were available for use in the current study and use was made of unified modelled data from SAWS.
- In all cases where data or information for the project was limited, use was made of data from similar projects and operations in the area.
- The dispersion model cannot compute real-time mining processes; average mining throughputs were therefore used. Operational locations and periods were selected to reflect the worst case scenarios.
- Gaseous pollutants included in this study include all those related to the fuel consumption of the dryer plant, other gaseous pollutants i.e. haul truck exhaust fumes were not included as the impacts of these compounds are generally low.
- It is important to note that dispersion modelling done for this study represents the predicted impacts from the Tharisa Minerals mine only. There was not enough information available to do a cumulative assessment of air quality in the area. As the area in which Tharisa is situated is an area where many platinum mines are found (it falls under the Waterberg-Bonjanala Priority Area), air quality is already low and therefore the impacts predicted in this study will most probably be higher than predicted in this report.

1.6 Report Outline

The report is structured as follows:

Section 2	Overview of the relevant ambient air quality guidelines and dustfall limits.
Section 3	Characterisation of the regional climate and the atmospheric dispersion potential of the proposed mine and concentrator plant.
Section 4	Characterisation of current air quality
Section 5	Air quality impact assessment
Section 6	Conclusions
Section 7	Air quality management measures and recommendations
Section 8	References
Appendix A	Project specific management measures
Appendix B	Particulate matter background information

2 REGULATORY CONTEXT

The air quality standards presented below are applicable to all areas where the general public has access to, as well as all off-site areas viz. all areas outside the property boundary. These standards are not applicable on site. On site concentrations to which workers are an occupational health and safety concern and are not regulated by the National Environmental Management Air Quality Act. Evaluation of on-site air pollutant concentrations does not form part of the scope of this study.

2.1 National Emission Standards for Listed Activities Proposed at Tharisa Minerals.

South Africa's air quality is regulated by the National Environmental Management: Air Quality Act (Act no.39 of 2004) (AQA) which came into effect on the 11th of September 2005 as published in the Government Gazette on the 9th of September 2005 (DEA 2004). National Ambient Air Quality Standards (NAAQS) were published on the 24 December 2009 (DEA 2009) to regulate South Africa's ambient air concentration, while emission standards to regulate release of pollutants into the atmosphere was published on the 31 March 2010 (DEA 2010). The revised standards were published on 22 November 2013 (Government Gazette No. 37054).

Standards applicable to the chrome ore dryer plant operations (listed activity) are included in Table 2-1**Error! Reference source not found.**.

Table 2-1: Subcategory 4.1 Drying and Calcining.

Description	Drying and calcining of mineral solids including ore		
Application	Facilities with a production capacity of more than 100 tons/month product		
Substance or mixture of substances		**Plant status**	**mg/Nm³ under normal conditions of 273 kelvin and 101.3 kPa**
Common name	**Chemical symbol**		
Particulate matter	N/A	New	50
		Existing	100
Sulphur dioxide	SO_2	New	1000
		Existing	1000
Oxides of nitrogen	NOx expressed as NO_2	New	500
		Existing	1200

2.2 Ambient Air Quality Standards for Criteria Pollutants

Criteria pollutants are considered those pollutants most commonly found in the atmosphere, that have proven detrimental health effects when inhaled and are regulated by ambient air quality criteria. These generally include CO, NO_2, PM_{10}, $PM_{2.5}$, ground level ozone (O_3) and SO_2.The South African Bureau of Standards (SABS) was engaged to assist DEA in the facilitation of the development of ambient air quality standards. This included the establishment of a technical committee to oversee the development of standards. Standards were determined based on international best practice for PM_{10}, dust fall, SO_2, NO_2, O_3, CO, lead (Pb) and benzene (C_6H_6). These standards were published for comment in the Government Gazette on 9 June 2007. The proposed revised national ambient standards were published for comment in the Government Gazette on the 13th of March 2009. The final national ambient standards, as published in the Government Gazette on the 24th of December 2009, are listed in Table 2-2.

Table 2-2: National ambient air quality standards.

Pollutant	Averaging Period	Limit Value (µg/m³)	Limit Value (ppb)	Frequency of Exceedance	Compliance Date
C_6H_6	1 year	10	3.2	0	Immediate – 31 Dec 2014
	1 year	5	1.6	0	1 Jan 2015
CO	1 hour	30000	26000	88	Immediate
	8 hour[1]	10000	8700	11	Immediate
Pb	1 year	0.5	-	0	Immediate
NO_2	1 hour	200	106	88	Immediate
	1 year	40	21	0	Immediate
O_3	8 hour[2]	120	61	11	Immediate
PM_{10}	24 hour	120	-	4	Immediate – 31 Dec 2014
	24 hour	75	-	4	1 Jan 2015
	1 year	50	-	0	Immediate – 31 Dec 2014
	1 year	40	-	0	1 Jan 2015
SO_2	10 minutes	500	191	526	Immediate
	1 hour	350	134	88	Immediate

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[1] Calculated on 1 hour averages

[2] Running average

Pollutant	Averaging Period	Limit Value (µg/m³)	Limit Value (ppb)	Frequency of Exceedance	Compliance Date
	24 hour	125	48	4	Immediate
	1 year	50	19	0	Immediate

In June 2012 the National Ambient Air quality Standard (NAAQS) for $PM_{2.5}$ matter was approved and published in the Government Gazzete No. 486. The proposed standards are depicted in Table 2-3..

Table 2-3: South African standards for $PM_{2.5}$

Averaging Period	Concentration	Frequency of Exceedance	Compliance Date
24 Hours	65	4	Immediate – 31 Dec 2015
24 Hours	40	4	1 Jan 2016 – 31 Dec 2029
24 Hours	25	4	1 Jan 2030
1 Year	25	0	Immediate – 31 Dec 2015
1 Year	20	0	1 Jan 2016 – 31 Dec 2029
1 Year	15	0	1 Jan 2016 – 31 Dec 2029

2.3 Dust Fallout Regulations

Dustfall is assessed for nuisance impact and not for inhalation health impact. National Dust Control Regulations were published on the 27th of May 2011 with the National Dust Control Regulations (NDCR) published on 1 November 2013 (Government Gazette No. 36974). The purpose of the regulations is to prescribe general measures for the control of dust in all areas including residential and light commercial areas.

The acceptable dustfall rates as measured (using ASTM D1739:1970 or equivalent) at and beyond the boundary of the premises where dust originates are given in Table 2-4.

In addition to the dustfall limits, the National Dust Control Regulations (NDCR) prescribe monitoring procedures and reporting requirements..

Table 2-4: National dust control regulations

Level	Dust fallout rate, *D* ($mg \cdot m^{-2} \cdot day^{-1}$, 30-d average)	Permitted frequency of exceeding dust fallout rate
Residential area	$D < 600$	Two within a year, not sequential months
Non-residential area	$600 < D < 1\ 200$	Two within a year, not sequential months

2.4 Waterberg-Bojanala Priority Area

Under the National Environmental Management: Air Quality Act, (Act No. 39 of 2004) airshed priority areas can be declared where there is concern of elevated atmospheric pollutant concentrations within the area. The DEA identified the potential of an airshed priority area (as in the vicinity of the Waterberg District Municipality (Government Gazette, Number 33600; 8 October 2010). This was later expanded to include the Bojanala Platinum District Municipality, North-West Province (Government Gazette, Number 34631; 30 September 2011) and the Waterberg Bojanala Priority Area was officially declared on 15th June 2012 (Government Gazette, Number 35435). The AQMP for the Waterberg Bojanala Priority Area is currently under way. Tharisa Minerals falls in this priority area.

2.5 Diesel Exhaust Gas as a Carcinogen

According to the World Health Organisation’s (WHO) International Agency for Research on Cancer (IARC), large populations are exposed to diesel exhaust fumes in everyday, whether through their occupation or through the ambient air. People are exposed not only to motor vehicle exhausts but also to exhausts from other diesel engines, including from other modes of transport (e.g. diesel trains and ships) and from power generators and diesel fuel boilers (WHO, 2012).

After a week-long meeting of international experts, the IARC classified diesel engine exhaust as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer (WHO, 2012).

3 ATMOSPHERIC DISPERSION POTENTIAL

In the assessment of the possible impacts from air pollutants on the surrounding environment and human health, a good understanding of the regional climate (as described in Appendix A) and local air dispersion potential of a site is essential. Meteorological characteristics of a site govern the dispersion, transformation and eventual removal of pollutants from the atmosphere (Pasquill and Smith, 1983; Godish, 1990). The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal and mechanical turbulence within the earth's boundary layer. Dispersion comprises vertical and horizontal components of motion. The vertical component is defined by the stability of the atmosphere and the depth of the surface mixing layer. The horizontal dispersion of pollution in the boundary layer is primarily a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of plume 'stretching'. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness. The wind direction and the variability in wind direction, determine the general path pollutants will follow, and the extent of cross-wind spreading (Shaw and Munn, 1971; Pasquill and Smith, 1983; Oke, 1990).

Pollution concentration levels fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth, and to shifts in the wind field. Spatial variations, and diurnal and seasonal changes, in the wind field and stability regime are functions of atmospheric processes operating at various temporal and spatial scales (Goldreich and Tyson, 1988). Atmospheric processes at macro- and meso-scales need therefore be taken into account in order to accurately parameterise the atmospheric dispersion potential of a particular area.

In characterising the dispersion potential of the site, reference was made to hourly average meteorological data modelled by SAWS (unified model) for the period January 2009 to December 2011. The data was generated by the model at a coordinate set within the Tharisa Minerals boundary.

Meteorological data recorded at Anglo Platinum's Klipfontein meteorological station for the period January to December 2007 are also included in this report.

Parameters that need to be taken into account in the characterisation of meso-scale ventilation potentials include wind speed, wind direction, extent of atmospheric turbulence, ambient air temperature and mixing depth.

3.1 Local Wind Field

3.1.1 Klipfontein Meteorological Station

Dispersion comprises vertical and horizontal components of motion. The wind field largely determines the horizontal dispersion of pollution in the atmospheric boundary layer. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of plume 'stretching'. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness. The wind direction and the variability in wind direction, determine the general path pollutants will follow, and the extent of cross-wind spreading (Shaw and Munn, 1971; Pasquill and Smith, 1983; Oke, 1990).

In characterising the dispersion potential of the site reference was made to hourly average meteorological data recorded at Anglo Platinum's Klipfontein ambient monitoring station for the period January to December 2007. This weather station is situated ~ 13km to the west of the proposed mine and concentrator plant.

Wind roses comprise 16 spokes, which represent the directions from which winds blew during the period. The colours used in the wind roses below, reflect the different categories of wind speeds; the grey area, for example, representing winds of 1 m/s to 1.5 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. For the current wind roses, each dotted circle represents a 3% frequency of occurrence. The value given in the centre of the circle described the frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s.

Klipfontein ambient monitoring station is regarded as representative of the local meteorology. Period average, day-time, night-time and seasonal wind roses (January 2007 to December 2007) measured at Klipfontein are depicted in Figure 3-1. The spatial and diurnal variability in the wind field is clearly evident in this figure. The dominant wind direction is south-south-westerly (~9% frequency of occurrence) to a southerly (~8% frequency of occurrence). Frequent air flow also occurs from the east (~7%) and east-southeast (~6% of the time). However, this dominant wind field consists of relatively low wind speeds of approximately 1-2 m/s not effectively dispersing pollutants. Wind speeds in excess of 4 m/s are evident from the southerly and south-south-easterly sector occurring infrequently (< 5% of the total period). Calm conditions (wind speeds < 1 m/s) occur for 32% of the time at the Klipfontein station.

Airflow for the Rustenburg region is characterised mainly by a variation in north-westerly and south-westerly winds, with more frequent southerly to easterly winds in the Brits area. The Lonmin area indicates predominantly north-westerly and east-south-easterly winds (Liebenberg-Enslin & Burger, 2003).

Diurnal airflow for the region is characterised mainly by a variation in north-westerly and easterly winds, with the strongest winds recorded from the south North-easterly and north-westerly wind flow dominates day-time conditions with north-north-westerly winds occurring for 10% of the time and northerly winds for 9% of the time. Infrequent but strong southerly winds are evident with calm conditions occurring for 27% of the time. During night-time there is dramatic decrease in frequency of occurrence of the wind from the northerly sector with a strong increase of winds from the south to southwest (for 28% of the time combined) and east-southeast (17% of the time). As is typical from night-time conditions, an increase in the number of calms to 36% of the time is evident. The seasonal variation in wind flow at Klipfontein is considerable, with strong southerly winds dominant throughout the year. During the summer months, the strongest winds are from the easterly to east-south-easterly sector. In autumn the general wind speed decreases with more frequent winds from the south and south-southwest. A similar wind flow pattern is evident during the winter months with an increase in frequent winds from the south-southwest, northwest and east-southeast. During spring time the wind flow shifts to reflect similar patterns than during the summer months with prevailing winds from the easterly sector and from the northwest.

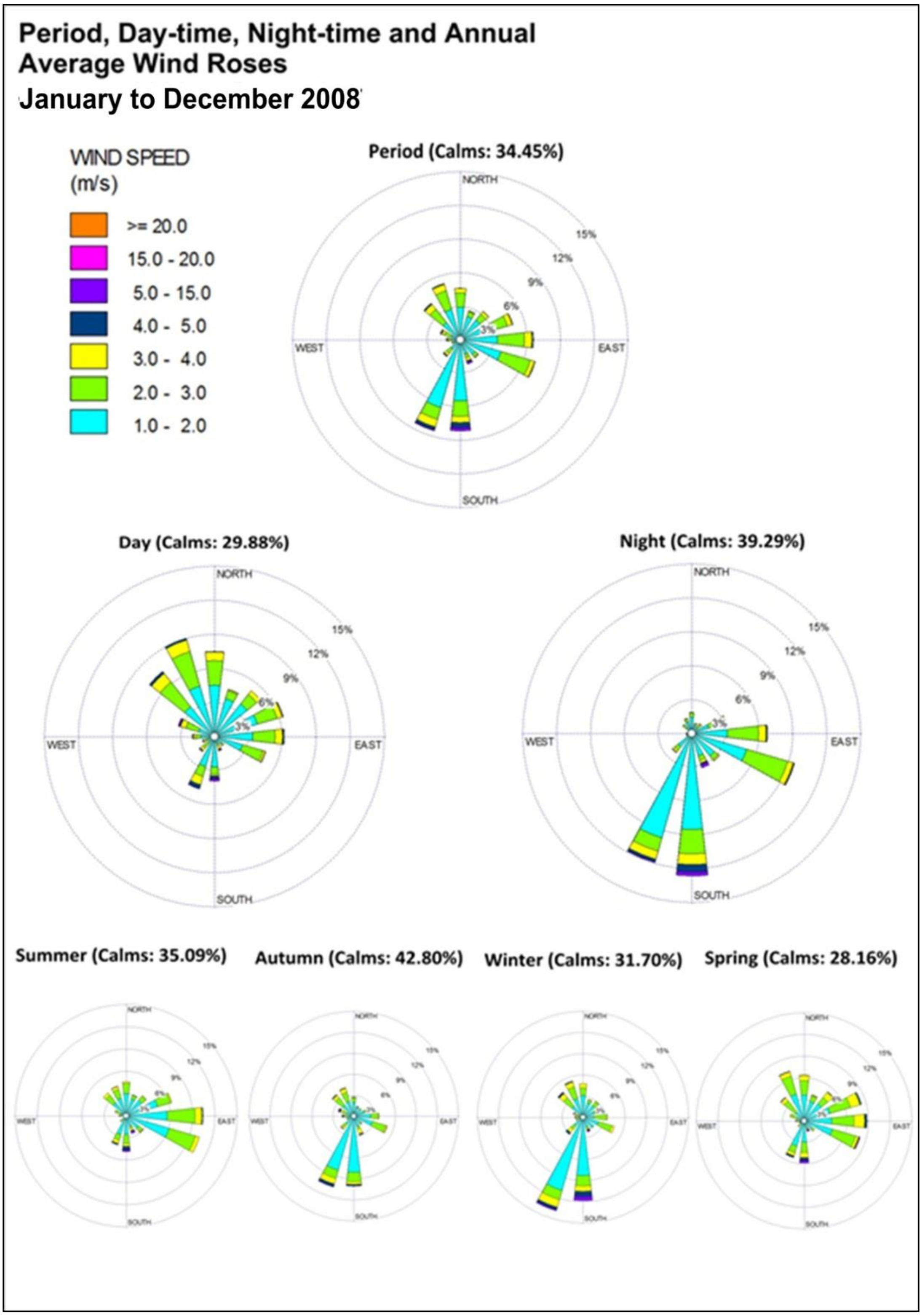

Figure 3-1: Period, day and night time and seasonal wind roses for the Klipfontein station for the period Jan to Dec 2008.

3.1.2 *SAWS Unified Model*

The unified model generated wind data is illustrated in the figures below. Figure 3-2: Periodic, daytime, night-time and annual wind roses for Unified Model data for a point located within the property shows the periodic, day-time, night-time and annual wind roses for the period January 2009 to December 2011. It is clear from the periodical wind rose that the dominant wind direction modelled by the Unified model is North West. Winds from the south west sector are the least common. Wind speeds hardly reach speeds higher than 5 m/s. day-time and night-time wind roses differ significantly with day-times dominated by winds from the north-west and north north-west whereas night times are dominated by winds from the opposite direction and the south. Annual wind roses resemble the periodic wind rose.

Figure 3-3 depicts seasonal wind roses. Summer, spring and autumn winds are dominantly from the north-west, while winter winds are prevailingly from the south. The highest wind speeds are associated with spring time.

3.1.3 *Agreement between Klipfontein and Unified model*

There is a sufficient agreement between the measured Klipfontein and Unified Model modelled data and therefore use was made of the more recent modelled data that was available for a longer period. The modelled data was therefore decided to be valid for model input.

It is important to note that there exist a discrepancy between the calm conditions for the measured data at the Klipfontein station (which averages around 30%) and the modelled data with an average of around 8%. The dispersion model used for the purpose of this study, Aermod, cannot evaluate dispersion potential for calm conditions and thus disregards hours with calm wind conditions. As the measured Klipfontein meteorological data was only available for a period of one year, this means that a third of the one year data would be disregarded by the model. Using Klipfontein modelled data would thus not supply one with enough data to run the model for the required time (minimum of 3 years) for the purpose of an impact assessment study.

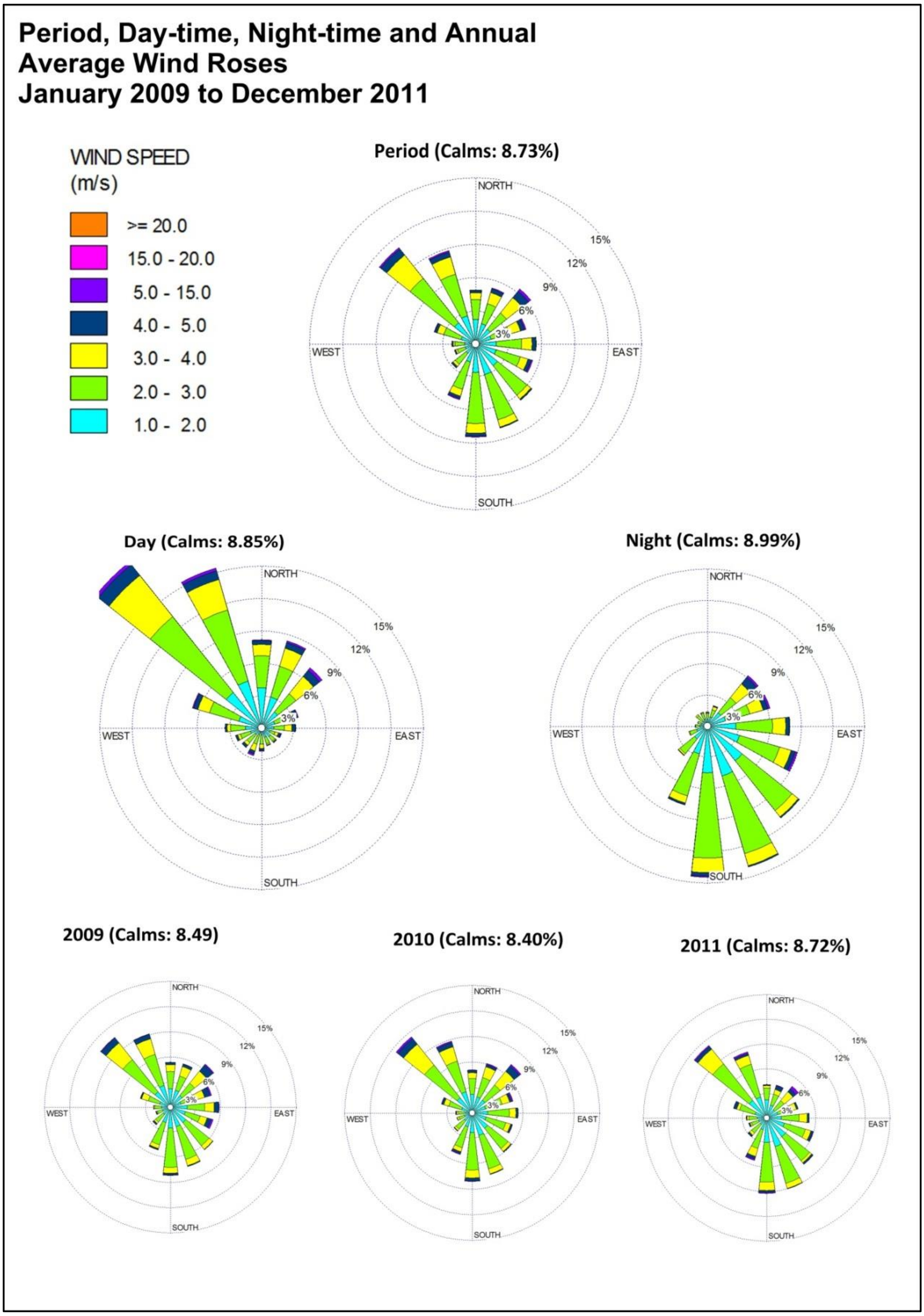

Figure 3-2: Periodic, daytime, night-time and annual wind roses for Unified Model data for a point located within the property (Jan 2009 to Dec 2011).

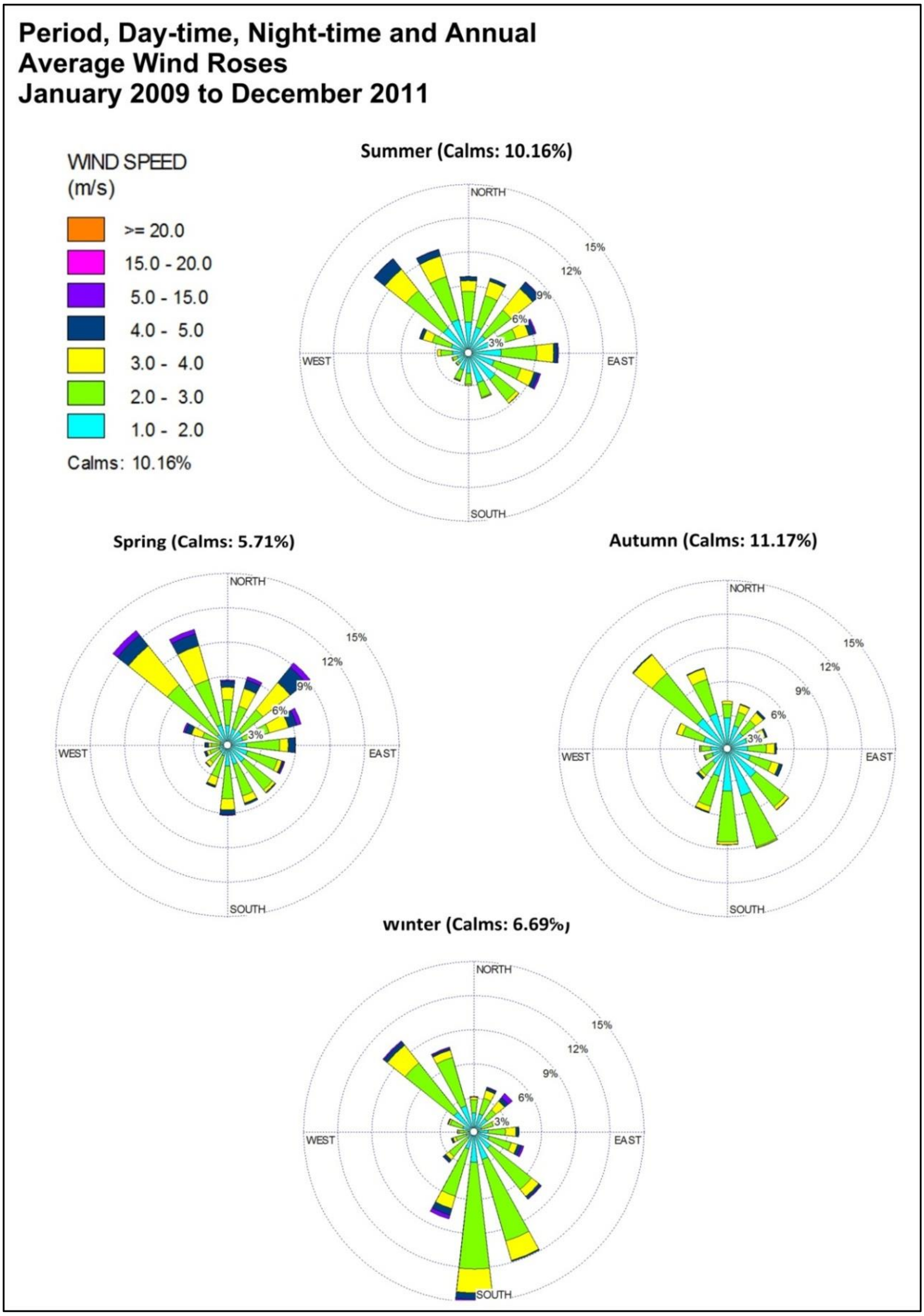

Figure 3-3: Seasonal wind roses for Unified model data for a point located within the property of Tharisa Minerals (Jan 2009 to Dec 2011).

3.2 Temperature

3.2.1 Klipfontein Meteorological Station

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume is able to rise), and determining the development of the mixing and inversion layers. Monthly trends for the year 2007 in ambient temperature recorded at the Klipfontein station is illustrated in Figure 3-3.

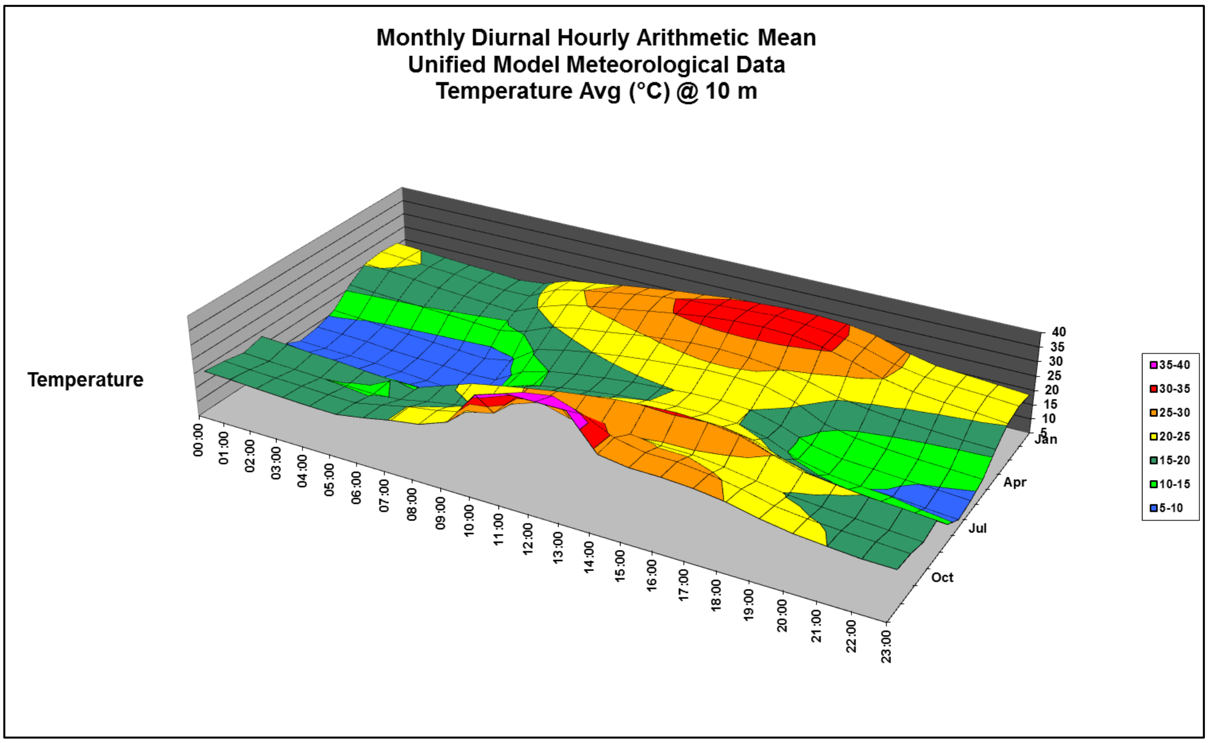

Figure 3-4: Monthly diurnal temperature profile for Klipfontein (2007).

3.2.2 SAWS Unified Model

A temperature profile of the unified model temperature data is shown in Figure 3-5. From the figure it can be seen that December is the warmest month with temperatures reaching values of around 28 ° C at noon. June and July are the coldest months with minimum temperatures of around 2.5 ° C before sunrise.

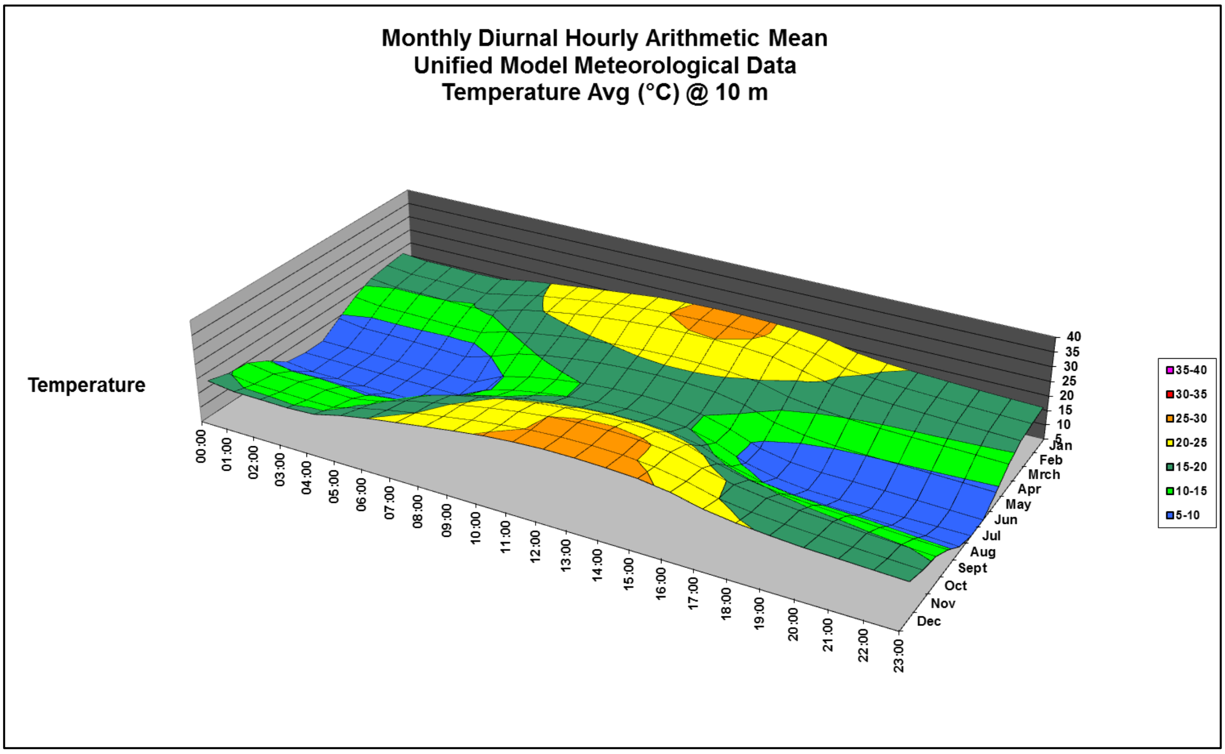

Figure 3-5: Unified Model temperature profile (2009 - 2011).

3.3 Rainfall and Precipitation

3.3.1 Klipfontein Meteorological Station

Precipitation is important to air pollution studies since it represents an effective removal mechanism of atmospheric pollutants. Long-term monthly average rainfall figures for various stations within the Rustenburg-Brits region are given in Table 3-1 and depicted in Figure 3-4. Long-term average total annual rainfall is in the range of 630 mm to 740 mm. The study area falls within a summer rainfall region, with over 70% of the annual rainfall occurring during the October to February period.

Table 3-1: **Long-term monthly rainfall figures (mm) for the Rustenburg-Brits region**

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Ann
Donkerhoek (1914 - 1975)	138	107	99	48	19	10	8	9	16	54	97	132	738
Rustenburg (1928 - 1989)	120	92	85	51	16	10	5	8	19	49	91	114	659
Kroondal (1949 - 1992)	126	92	77	56	15	10	4	6	20	56	90	109	660
Waterkloof (1917 - 2000)	125	102	94	47	19	7	5	8	21	54	115	140	737
Klipfontein (1928 - 2001)	116	91	78	45	17	8	4	5	16	53	82	115	631
Brits (1951-1984)	121	82	62	52	19	5	4	5	14	59	101	97	621

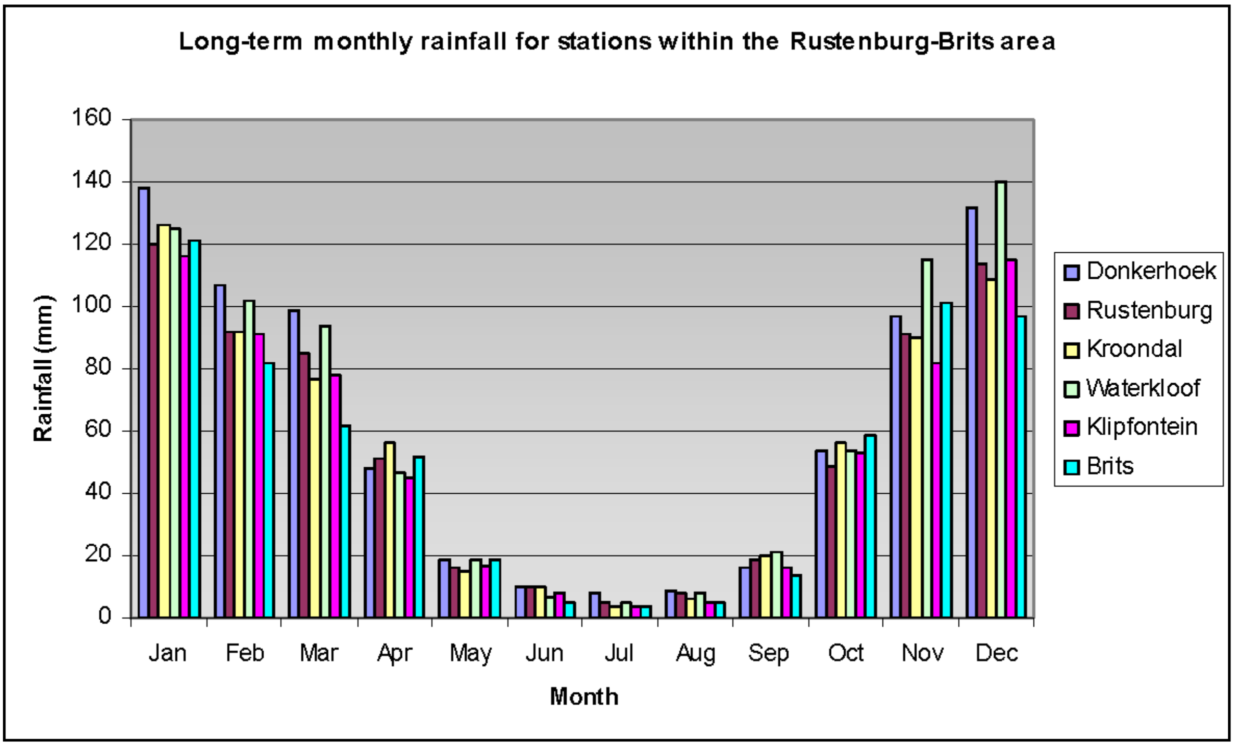

Figure 3-6: **Long-term monthly rainfall for stations within the Rustenburg-Brits region.**

3.3.2 SAWS Unified Model

Rainfall data generated by the Unified model was not available.

3.4 Mixing Height and Atmospheric Stability

The vertical component of dispersion is a function of the extent of thermal turbulence and the depth of the surface mixing layer. Unfortunately, the mixing layer is not easily measured, and must therefore often be estimated using prognostic models that derive the depth from some of the other parameters that are routinely measured, e.g. solar radiation and temperature. During the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth’s surface and the extension of the *mixing layer* to the lowest elevated inversion. Radiative flux divergence during the night usually results in the establishment of ground based inversions and the erosion of the mixing layer. Day-time mixing heights were calculated with the prognostic equations of Batchvarova and Gryning (1990), while night-time boundary layer heights were calculated from various diagnostic approaches for stable and neutral conditions. The mixing layer at the proposed sites ranges in depth from 0 metres (i.e. only a stable or neutral layer exists) during night-times to the base of the lowest-level elevated inversion during unstable, day-time conditions.

Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table 3-1. The hourly standard deviation of wind direction, wind speed and solar radiation were used to determine hourly-average stability classes (STAR method).

Table 3-2: Atmospheric Stability Classes

A	very unstable	calm wind, clear skies, hot daytime conditions
B	moderately unstable	clear skies, daytime conditions
C	unstable	moderate wind, slightly overcast daytime conditions
D	neutral	high winds or cloudy days and nights
E	stable	moderate wind, slightly overcast night-time conditions
F	very stable	low winds, clear skies, cold night-time conditions

The atmospheric boundary layer is normally unstable during the day as a result of the turbulence due to the sun's heating effect on the earth's surface. The thickness of this mixing layer depends predominantly on the extent of solar radiation, growing gradually from sunrise to reach a maximum at about 5-6 hours after sunrise. This situation is more pronounced during the winter months due to strong night-time inversions and a slower developing mixing layer. During the night a stable layer, with limited vertical mixing, exists. During windy and/or cloudy conditions, the atmosphere is normally neutral.

For elevated releases, the highest ground level concentrations would occur during unstable, daytime conditions. The wind speed resulting in the highest ground level concentration depends on the plume buoyancy. If the plume is considerably buoyant (high exit gas velocity and temperature) together with a low wind, the plume will reach the ground relatively far downwind. With stronger wind speeds, on the other hand, the plume may reach the ground closer, but due to the increased ventilation, it would be more diluted. A wind speed between these extremes would therefore be responsible for the highest ground level concentrations. The highest concentrations for low level releases would occur during weak wind speeds and stable (night-time) atmospheric conditions. Air pollution episodes are characterised by calm winds and stable conditions.

4 CURRENT AIR QUALITY

The Rustenburg Local Municipality developed an Air Quality Management Plan for the municipal area in 2005. According to the main findings from the plan, major air pollution sources within Rustenburg-Brits area include emissions from manufacturing and mining industries, townships and informal settlements and vehicular activity. Primary atmospheric emissions released from these sources include sulphur dioxide (SO_2) nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter ($PM_{2.5}$ and PM_{10}) and Volatile Organic Compounds (VOCs). Secondary pollutants such as ozone (O_3) are formed in the atmosphere through the chemical transformation of precursors such as VOCs and NO_x. Heavy metals such as lead (Pb), chromium (Cr) and nickel (Ni) occur in the Rustenburg area due to mining and smelting activities.

4.1 Identification of Existing Sources of Emission within the Rustenburg-Brits Area

The contribution of various sources of emission to ambient particulate and gaseous concentrations within the Rustenburg region is of interest given the elevated concentrations having been recorded. The most significant sources located within the Rustenburg-Brits region include:

- Stack, vent and fugitive emissions from *industrial* operations - industrial emissions include various criteria pollutants (as SO_2, NO_x, CO and particulates), greenhouse gases (CO_2 and CH_4), volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), various heavy metals and other toxins such as dioxins and furans. Industries in the region include three platinum smelter operations, viz.: Anglo Platinum Smelter Operation (Waterval Smelter), Impala Platinum and Lonmin (Western Platinum). Sources of emission at these operations typically include stack emissions, including main stack releases which comprise furnace and converter off-gases, acid plant stack emissions and releases from flash dryer stacks. The furnace and converter operations are also associated with significant fugitive emissions. Aside from the two ferro-chrome industries situated in the region, viz. the Xstrata (Rustenburg) and Xstrata (Wonderkop) operations, Merafe Ferrochrome is situated to the north west of Rustenburg and IFM ~30 km east of Rustenburg. Furnace stack emissions, furnace fugitives and baghouse stack releases represent the main sources at these operations. The induction furnaces at Joerg Foundry (Trek Engineering) represent a smaller source of industry-related emissions.

- Stack emissions from *boiler* operations - boiler stack emissions include particulates, NO_x, SO_2, CO, VOCs and CO_2. In addition to various smelter plants, boiler operations are also undertaken at Rainbow Chickens, Rustenburg Abattoir, MKTV Tobacco Limited, Rustenburg Provincial Hospital, British American Tobacco Products, Mageu Number One and Anglo Platinum Base Metals Refinery (BMR).

- Stack emissions from *incineration* operations - emissions include criteria gases (SO_2, NO_x, CO, lead and particulates), acid gases (hydrogen chloride, hydrogen bromide, hydrogen fluoride), metal gases (chromium, arsenic, cadmium, mercury, manganese, etc.) and dioxins and furans. Incineration operations are undertaken at Anglo Platinum Precious Metals Refinery (PMR), with medical waste incineration occurring at Ferncrest Hospital.

- Fugitive emissions from *quarrying* and *mining* operations - comprising mainly dust releases, with small amounts of NO_x, CO, SO_2, methane, CO_2 being released during blasting operations.

- Fugitive dust emissions from *tailings impoundments* which are associated with Anglo, Impala and Lonmin mineral processing operations. Anglo Platinum tailings dams in the region currently include Phases 1-3 (i.e. Paardekraal tailings), Waterval West, Waterval East, and Klipfontein. Lonmin's tailings include Western Platinum - North, - East, - South and - West, Karee Mine and Eastern Platinum. Impala Platinum has one large tailings dam.

- *Vehicle tailpipe emissions* - significant primary pollutants emitted by motor vehicles include CO_2, CO, hydrocarbons (HCs), SO_2, NO_x, particulate matter and lead.

- *Household fuel combustion* (coal, wood) - coal burning emits a large amount of gaseous and particulate pollutants including SO_2, heavy metals, total and respirable particulates including heavy metals and inorganic ash, CO, polycyclic aromatic hydrocarbons (PAHs), NO_2 and various toxins such as benzo(a)pyrene. Pollutants from wood burning include respirable particulates, NO_2, CO, PAHs, particulate benzo(a)pyrene and formaldehyde. Particulate emissions from wood burning have been found to contain about 50% elemental carbon and about 50% condensed hydrocarbons.

- *Biomass burning* - major pollutants from veld fires are particulates, CO and VOCs. The extent of NO_x emissions depend on combustion temperatures, with minor sulphur oxides being released.

- Various miscellaneous *fugitive dust sources*, including: agricultural activities, wind erosion of open areas, vehicle-entrainment of dust along paved and unpaved roads.

- Ambient air pollutant concentrations within the Rustenburg region occur not only due to local source but also as a result of emissions from various remote sources. Regionally- transported air masses comprising well mixed concentrations of 'aged' (secondary) pollutants are known to represent a significant component of ambient fine particulate concentrations within the South African interior. Such air masses contain pollutants released from various remote sources including elevated releases from distant industrial operations and power generation facilities and large scale biomass burning in neighbouring countries. Typical pollutants which circulate within such regionally-transported polluted air masses include nitrates, ammonium nitrate and sulphates.

The quantification of background particulate concentration, which is of particular importance given the nature of the proposed development, is complicated due to the large number of sources of this pollutant. Sources of particulates also include a significant proportion of fugitive emissions from diffuse sources (e.g. vehicle-entrained dust from roadways, wind-blown dust from stockpiles and open areas, dust generated by materials handling) which are more difficult to quantify than are emissions from point sources.

4.1.1 Ambient Air Quality Data

4.1.2 Dust fallout Results

A dust fallout monitoring network was established in April 2009 and data up to February 2011 was included in this report. The various dust fallout monitoring sites are shown in the figures below (Figure 4-1 and Figure 4-2).

Figure 4-1: Dust fallout monitoring stations surrounding Tharisa Minerals.

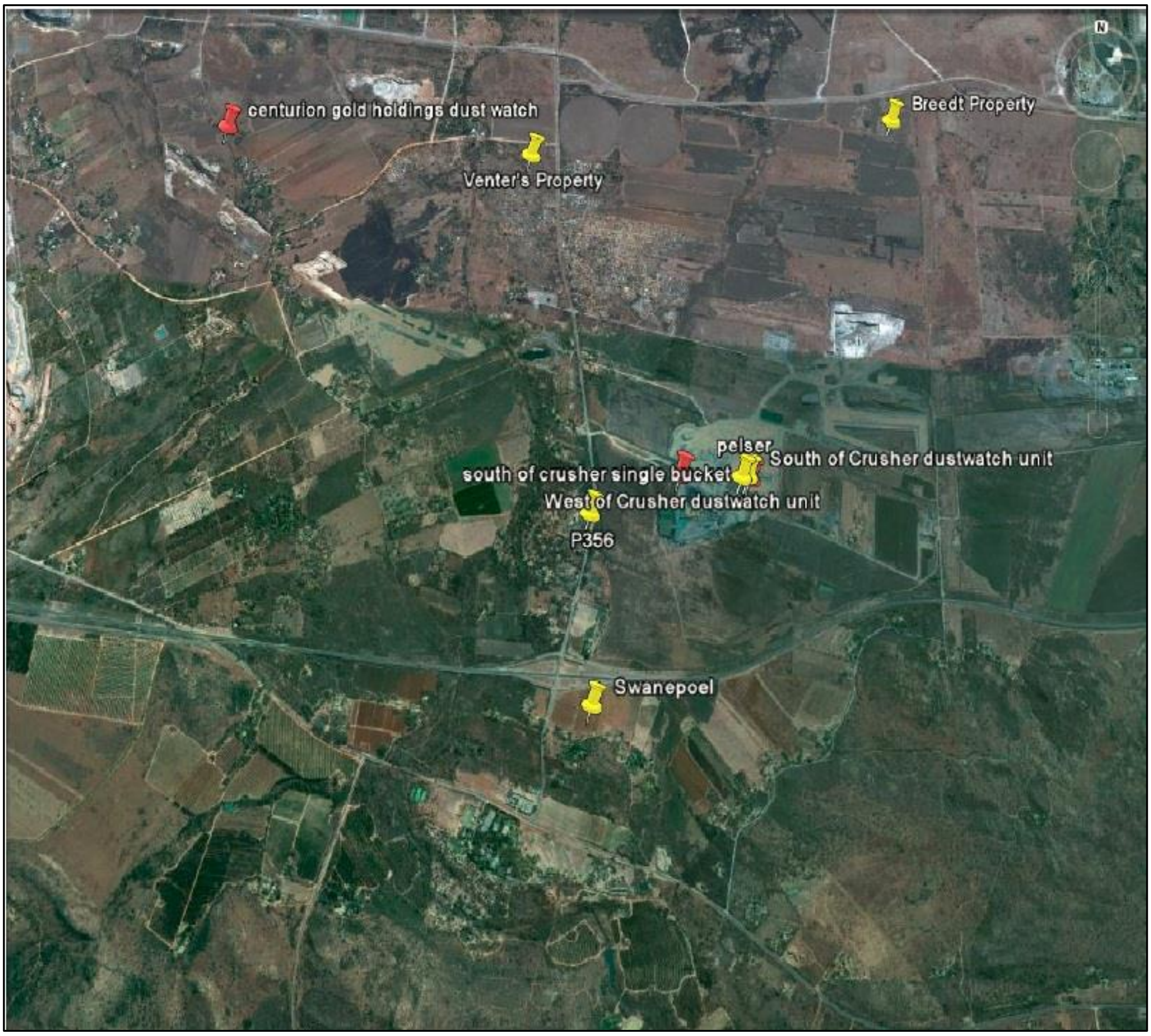

Figure 4-2: Dust fallout monitoring stations surrounding Tharisa Minerals.

Dust deposition rates were evaluated based on the NDCRs (Table 2-4), providing a residential limit of 600 mg/m²/day and a non-residential limit of 1 200 mg/m²/day, not to be exceeded for more than two times within a year or two sequential months.

The sites used in the monitoring study were either residential or non-residential sites. The table below (Table 4-1) lists the monitoring station locations and their site classifications.

Table 4-1: Site classification of some dustfall monitor station locations.

Site	Site Classification
P356	Non-Residential
Venter's Property	Residential
Swanepoel	Residential
Breedt Property	Residential
South of Crusher	Residential
Pelser	Non-Residential
Centurion Gold	Non-Residential
South of Crusher	Non-Residential
West of Crusher	Non-Residential

The following tables (Table 4-2, Table 4-3, Table 4-4, Table 4-5, and Table 4-6) summarise the dust fallout monitoring results. Those sites that are within the various limits are shown in green, with the ones exceeding the NDCR residential threshold level highlighted in orange and the sites exceeding the non-residential threshold level highlighted in red.

Table 4-2: Dust fallout monitoring results for the period April 2009 to May 2009.

Date	Igloo Houses	Eskom Wires	H. van Rensburg	Flat Roof House	Mountain Reservoir	Marikana Chrome	Silver Workshop	Quarry	De Beers	Gravel Road
Apr-09	303	ND	142	48	104	ND	135	241	305	168
May-09	25	ND	95	100	93	ND	61	ND	72	201

Table 4-3: Dust fallout monitoring results for the period June 2009 to August 2009.

Date	Pit Outcrop East	P356	Venters Property	Swanepoel	Geldenhuys Guest House	Breedt Property	Silver Workshop	Centurion Holdings	Spruitfontein
Jun-09	ND	62	55	26	77	42	51	140	146
Jul-09	87	61	104	60	92	107	97	81	209
Aug-09	60	51	92	188	52	192	ND	81	ND

Table 4-4: Dust fallout monitoring results for the period September 2009 to November 2009.

Date	Pit Outcrop East	P356	Venters Property	Swanepoel	Breedt Property	East of Crusher	Centurion Holdings	South of Crusher	West of Crusher
Sep-09	ND	282	242	258	320	458	341	822	827
Oct-09	383	304	337	282	529	NA	378	2117	1080
Nov-09	352	169	228	333	86	381	312	1060	1416

Table 4-5: Dust fallout monitoring results for the period December 2009 to January 2010.

Date	Igloo Houses	Eskom Wires	H. van Rensburg	Flat Roof House	Mountain Reservoir	Marikana Chrome	Centurion Holdings	South of Crusher	West of Crusher
Dec-09	ND	122	55	62	42	876	195	2762	380
Jan-10	ND	86	42	22	28	756	103	ND	353

Table 4-6: Dust fallout monitoring results for the period February 2010 to February 2011.

Date	Pit Outcrop East	P356	Venters Property	Swanepoel	Breedt Property	East of Crusher	Centurion Holdings	South of Crusher	West of Crusher
Feb-10	ND	79	103	90	75	123	50	859	159
Mar-10	ND	50	196	104	25	2709	ND	2281	1875
Apr-10	ND	16	26	26	103	475	ND	509	87
May-10	ND	14	24	5	21	3391	ND	136	71
Jun-10	ND	62	56	147	62	ND	ND	8509	140
Jul-10	ND	94	105	26	46	ND	ND	2392	140
Aug-10	ND	ND	202	180	43	ND	ND	1609	339
Sep-10	ND	216	212	187	188	ND	ND	652	348
Oct-10	ND	188	387	203	370	ND	ND	1070	807
Nov-10	ND	155	69	90	274	ND	ND	2687	433
Dec-10	ND	56	82	120	68	ND	ND	3004	1088
Jan-11	ND	233	27	27	140	ND	135	1080	359
Feb-11	ND	34	71	ND	33	ND	387	528	34

4.2 Baseline Modelled Results

An impact assessment was done for Tharisa Minerals during 2007.This study represents mining operations at Tharisa mine before expansion. The results from the 2007 study can thus be seen as baseline (current air quality) air quality at the mine. Meteorological data from Anglo American's Klipfontein meteorological station were used for the impact assessment. As Unified Model data were used for this study, the 2007 scenario was run using Unified Model meteorological data.

It is important to note that dispersion modelling done for this study represents the predicted impacts from the Tharisa Minerals mine only. There was not enough information available to do a cumulative assessment of air quality in the area. As the area in which Tharisa is situated is an area where many mines are found (it falls under the Waterberg-Bonjanala Priority Area), air quality is already is already potentially poor and therefore the impacts predicted in this study will most probably be higher than predicted in this report.

4.2.1 PM$_{10}$

Figure 4-3 and Figure 4-4 show the baseline annual average PM$_{10}$ concentrations and daily frequency of exceedance values. From the figures it can be seen that annual average exceedances take place outside the northern and eastern mine boundaries. Daily exceedances occur over a large area outside the mine boundary.

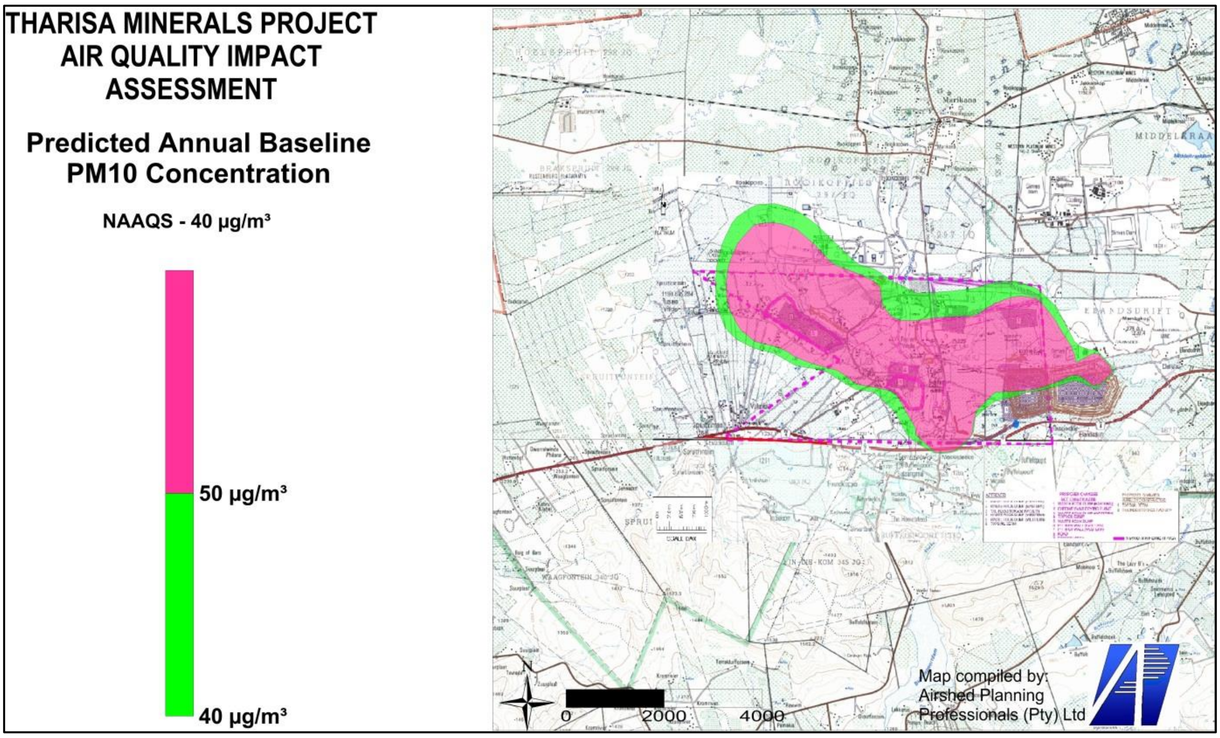

Figure 4-3: Baseline annual average PM$_{10}$ concentrations at Tharisa Minerals.

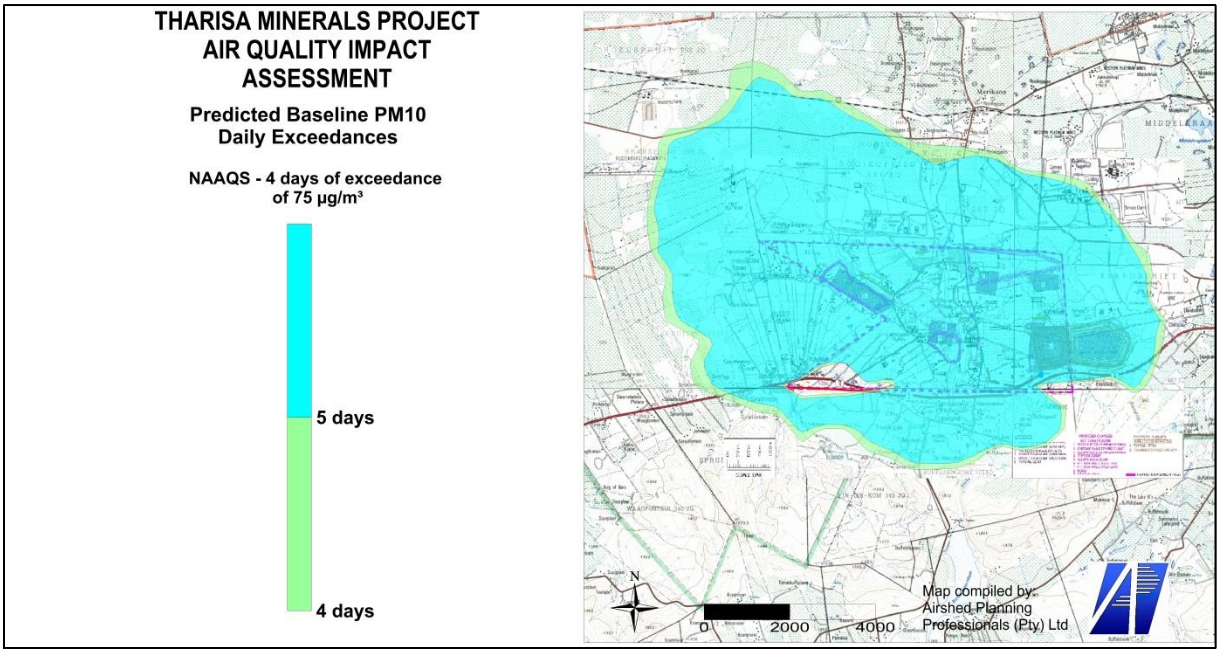

Figure 4-4: Daily frequency of exceedance of the PM_{10} NAAQ limit value at Tharisa Minerals.

4.2.2 $PM_{2.5}$

Annual average baseline $PM_{2.5}$ concentrations and daily frequencies of exceedance of the NAAQ $PM_{2.5}$ limit values can be seen in Figure 4-5 and Figure 4-6 respectively. In both cases exceedances occur up to a distance of 4km outside the mine boundary.

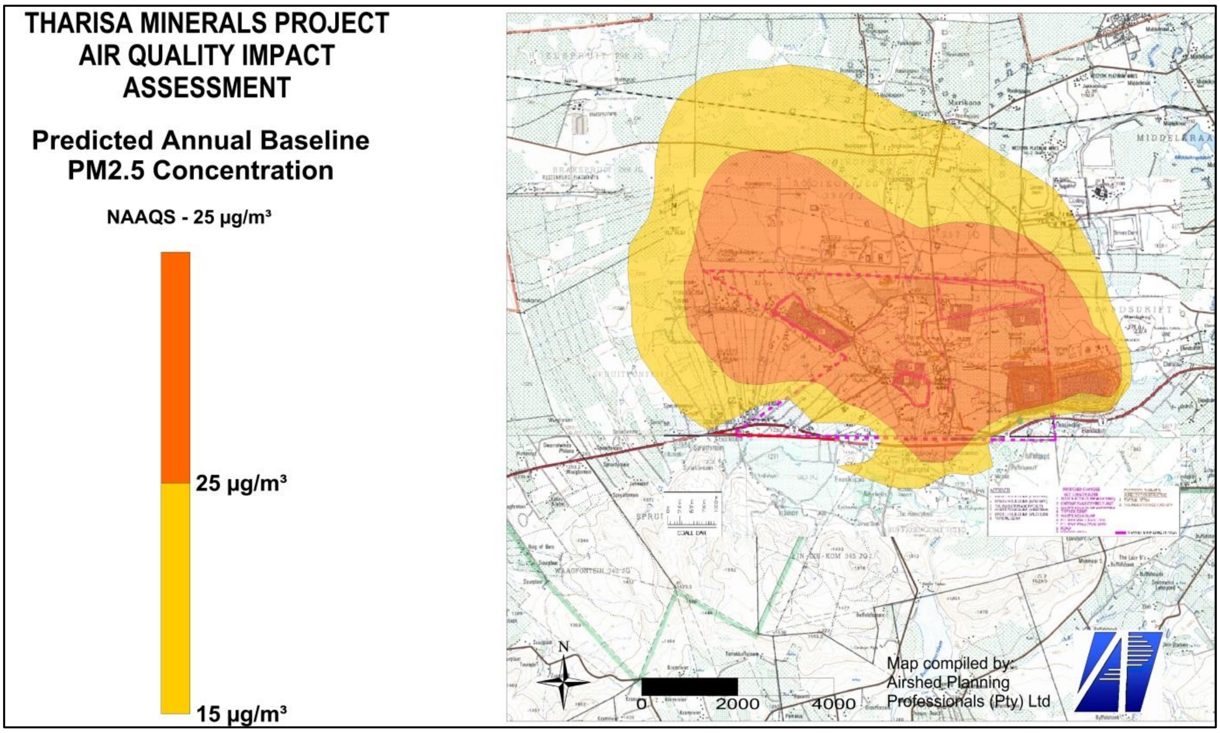

Figure 4-5: Baseline annual average $PM_{2.5}$ concentrations at Tharisa Minerals.

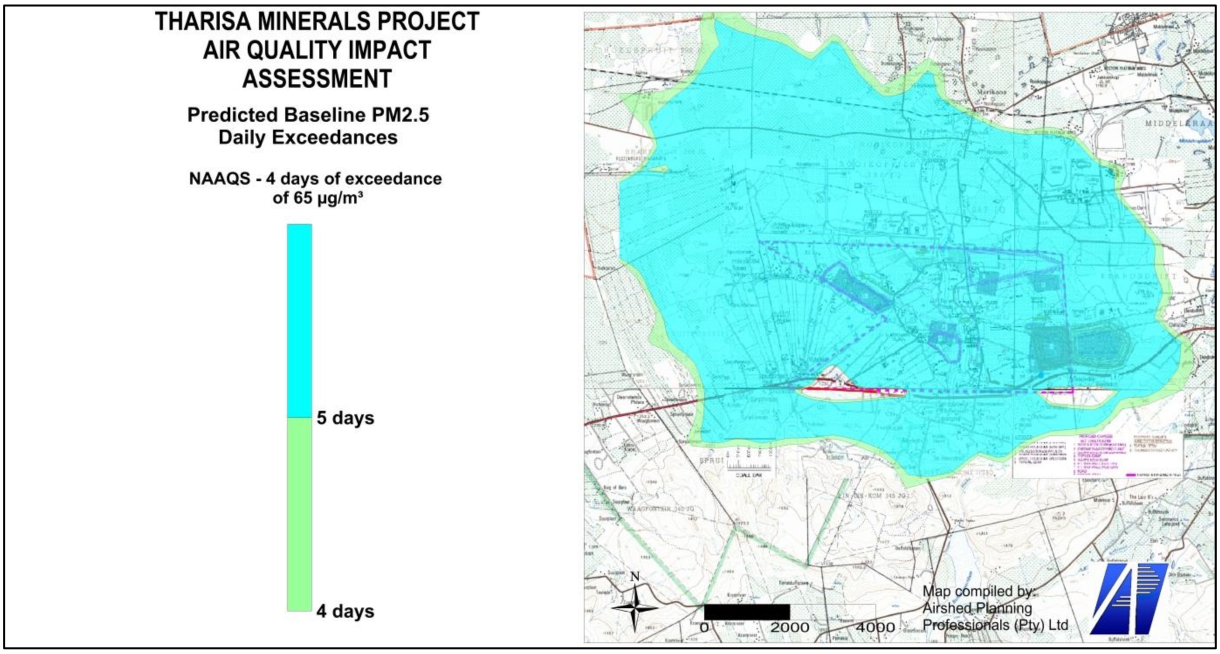

Figure 4-6: Daily frequency of exceedance of the $PM_{2.5}$ NAAQ limit value at Tharisa Minerals.

4.2.3 Dustfall

Daily baseline dust fallout rates are shown in Figure 4-7. Dust fallout residential exceedances (> 600 mg/m²/day) occur outside the mine boundary whereas the non-residential limit of 1 200 mg/m²/day are exceeded inside the mine boundary and at sensitive receptors within the mine boundary.

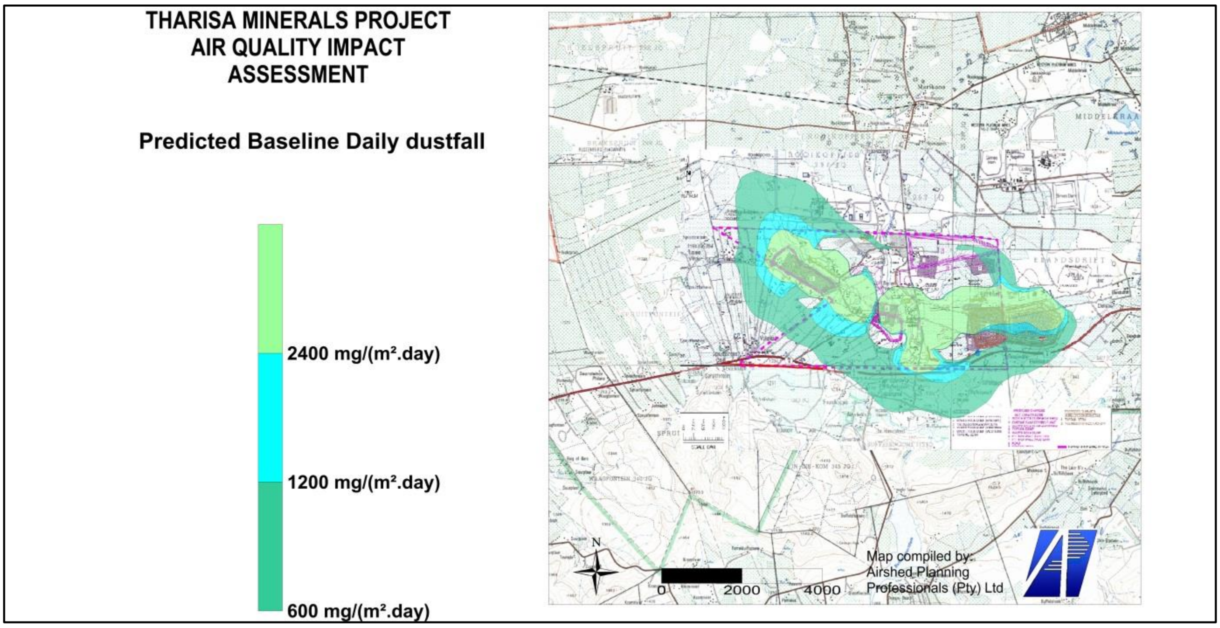

Figure 4-7: Daily baseline dust fallout rates at Tharisa Minerals.

5 AIR QUALITY IMPACT ASSESSMENT

5.1 Emissions Inventory

Emissions were quantified for the expansion operations at Tharisa Mine as discussed under Section 1.1.

In the quantification of TSP, PM_{10} and $PM_{2.5}$ emissions, use was made of emission factors published by the US Environmental Protection Agency (US EPA) in its AP-42 document Compilation of Air Pollution Emission Factors as well as the Australian National Pollutant Inventory (NPI) document.

Three phases of operation (from which emissions to the air will occur) were identified at Tharisa Minerals, namely a construction phase an operational phase and a decommissioning phase. The decommissioning phase will have similar impacts as the construction phase. The construction phase would primarily cover the construction of the chrome sand dryer plant and will be temporary in nature. The following production rates (Table 5-1) were used for the emissions calculations in this study.

Table 5-1: Mining production rates (tons per annum)

Material	Tpa (tons per annum)
Ore mined from open pits	5 500 000.00
Waste rock from open pits	16 666 666.67
Topsoil from Open Pits	5 000 000.00
Chrome Concentrate Produced	1 463 000.00
PGM Concentrate Produced	131 000.00

5.2 Construction Phase

The construction phase normally comprises a series of different operations including land clearing, topsoil removal, road grading, material loading and hauling, stockpiling, compaction, etc. Each of these operations has their own duration and potential for dust generation.

The construction operations associated with the changes to the mining and processing operations at Tharisa Mine will include the construction of the chrome sand dryer plant. The other changes – extending the east and west open pits with increases in waste rock dumps and the TSF – would fall under the operational phase of the mine. The construction activities at the chrome sand dryer plant will be temporary and occur concurrently with the mining activities, the construction phase emissions were therefore not determined.

5.3 Operational Phase

The following sources of pollutants have been included in the operational phase of this study:

- Drilling & blasting in the east and west open pits;
- Materials handling, including truck and shovel mining of ore and waste rock in both pits;
- Dozing of material at the tailings expansion;
- Vehicle entrainment from unpaved haul roads
- Crushing and screening of ore;
- Concentrator plant emissions;
- Chrome Dryer Plant emissions; and
- Wind erosion of the tailings facilities, stockpiles and topsoil berm.

The operational phase was modelled for two scenarios, a partially mitigated scenario and a mitigated scenario. The partially mitigated scenario included only the mitigation that is currently in use at the Tharisa Minerals mine, whereas the mitigated scenario includes a more involved system of mitigation. The following table (Table 5-2) summarises the mitigation methods included for each scenario.

The management measures used for mitigation are discussed in more detail in Appendix A.

Table 5-2: Mitigation methods modelled for the partially mitigated and mitigated scenarios, respectively.

Source	Partially Mitigated	Mitigated
Drilling	No Mitigation	70% by means of effective water sprays
Blasting	No Mitigation	No Mitigation
Materials handling	50% mitigated (by means of water sprays) only for selected materials handling points at the processing plant.	70% mitigated by means of water sprays for material transfer points and enclosure for conveyor loading and off-loading points
Vehicle entrainment from unpaved roads	75% Mitigated by means of watering	90% Mitigation by means of chemical dust palliatives
Crushing and screening	50% Mitigated by means of water sprays.	98% Mitigated by means of enclosure.

5.3.1 Drilling

During the operational phase of Tharisa Minerals drilling will take place in both the eastern and western pits. PM_{10} and TSP emissions due to the in-pit drilling operations at the mine were quantified using the Australian NPI single valued emission factors for mining (Table 5-3). $PM_{2.5}$ emissions were quantified by using the emission factor for $PM_{2.5}$ published by the Canada National Pollutant Release Inventory (NPRI, 2009). Source specific information that was used in the calculation of drilling emissions is presented in Table 5-4 with the total estimated emissions from drilling presented in Table 5-5. No mitigation was applied to drilling operations.

Table 5-3: Australian NPI emission factors for drilling operations

Source	PM_{10} (kg PM_{10} / hole drilled)	$PM_{2.5}$ (kg $PM_{2.5}$ / hole drilled)	TSP (kg TSP / hole drilled)
Drilling	0.31	0.31	0.59

Table 5-4: Drilling source specific information

Days/ week that Drilling will take place	5
Area Drilled (m^2)	2000
Number of Rows	7
Hole Spacing (m)	4.5
Hole Size (m)	0.2
Hole Depth (m)	4.5

The table below (Table 5-5) gives the emission rates modelled for drilling during the operational phase.

Table 5-5: Predicted annual emission rates for drilling during the operational phase.

Partially Mitigated Emission Rate (tpa)			Mitigated Emission Rate (tpa)		
PM_{10}	$PM_{2.5}$	TSP	PM_{10}	$PM_{2.5}$	TSP
15.5	15.5	29.5	4.65	4.65	8.85

5.3.2 Blasting

During the operational phase of Tharisa Minerals blasting will take place in both the eastern and western pits. During the construction phase blasting only takes place in the eastern pit. PM_{10} and TSP emissions due to blasting at the mine were quantified using the Australian NPI predictive emission factor equation for mining (Equation 1). Source specific information that was used in the calculation of blasting emissions is presented in Table 5-6 . No mitigation was applied to blasting operations. $PM_{2.5}$ emissions were quantified by using the emission factor for $PM_{2.5}$ published by the Canada National Pollutant Release Inventory (NPRI, 2009).

$$EF = k \cdot 344 \cdot \frac{A^{0.8}}{M^{1.9} \cdot D^{1.8}} \tag{1}$$

where;

E = *emission factor (kg dust / blast)*

k = *particle size multiplier* ($k_{PM10} = 0.52$; $k_{TSP} = 1$)

A = *blast area* (m^2)

M = *material moisture content (%)*

D = *hole diameter (m)*

Table 5-6: Blasting source specific information

Blasts per Day	1
Blasts per Week	5
Area Blasted per Pit (m^2)	2000
Moisture Content (%)	5
Hole Size (m)	0.2

The table below (Table 5-7) gives the emission rates modelled for blasting during the operational phase.

Table 5-7: Predicted annual emission rates for blasting during the operational phase.

Partially Mitigated Emission Rate (tpa)			Mitigated Emission Rate (tpa)		
PM_{10}	$PM_{2.5}$	TSP	PM_{10}	$PM_{2.5}$	TSP
100.2	6.0	192.7	100.2	6.0	192.7

5.3.3 Materials Handling

Materials handling points at the mine and chrome sand drying plant include truck and shovel mining operations, materials handling by front-end loaders and tipping of material from trucks and conveyor transfer points.

The quantity of dust that will be generated from materials handling operations will depend on various climatic parameters, such as wind speed and precipitation, in addition to non-climatic parameters such as the nature and volume of the material handled. Fine particulates are most readily disaggregated and released to the atmosphere during the material transfer process, as a result of exposure to strong winds. Increases in the moisture content of the material being transferred would decrease the potential for dust emission, since moisture promotes the aggregation and cementation of fines to the surfaces of larger particles. The following US EPA AP42 predictive equation was used to estimate PM_{10} and TSP emissions from material transfer operations:

$$E = k \cdot 0.0016 \left(\frac{U}{2.3} \right)^{1.3} \cdot \left(\frac{M}{2} \right)^{-1.4} \qquad (2)$$

where,

E = *TSP emission factor (kg dust / tons of material transferred)*

U = *mean wind speed (m/s)*

M = *material moisture content (%)*

k = *particle size multiplier* ($k_{PM10} = 0.35$; $k_{TSP} = 0.74$)

The material moisture content, material throughput rates and assumed control efficiencies used in the calculation of emissions for each point are presented in Table 5-8. A control efficiency of 50%, achievable with water sprays, was applied to selected conveyor transfer/ stockpiling points at the concentrator plant. Emissions from materials handling points were calculated using the hourly average wind speed of 1.78 m/s.

$PM_{2.5}$ was assumed to contribute to 15% of PM_{10} emissions (US EPA, Generalised Particle Size Distributions, 1995; NPRI, 2009).

The material moisture content, material throughput rates and assumed control efficiencies used in the calculation of emissions for each point are presented in Table 5-9). The annual emission rates for materials handling is shown in Table 5-28.

Table 5-8: Materials handling source specific information

2012 Operational and Construction	Handling Rate (tons/hour)	Moisture Content (%)
Loading of ore, topsoil and waste rock at east pit	1937.6	1.0
IN-PIT East truck & shovel	1937.6	1.8
Tipping of waste rock at east waste rock dump	1019.8	1.0
Tipping of topsoil at east topsoil berm	437.1	1.0
Tipping of ore at ore stockpile at plant	480.8	1.0
Tipping and loading of ore, waste rock and topsoil at stockpile next to west pit	1937.6	1.0
Tipping of topsoil at west topsoil berm	437.1	1.0
IN-PIT West Truck & Shovel	1937.6	1.8
Tipping of waste rock at east waste rock dump	1019.8	1.0
Tipping of ore at plant stockpile	480.8	1.0
Loading material onto conveyor to primary crushing	961.5	4.3
Tipping of material from conveyor at primary crushing	961.5	4.3
Loading material onto conveyor to secondary crushing	961.5	4.3
Tipping of material from conveyor at tersiary crushing	961.5	4.3
Loading material onto conveyor to tersiary crushing	961.5	4.3
Tipping of material from conveyor at tersiary crushing	961.5	4.3
Loading of material on conveyor to stockpile	961.5	4.3
Tipping of material on stockpile	961.5	4.3
Stockpiling Chrome Concentrate Product at Bunkers	174.2	9.9
StockpilingPlatinum Concentrate Product at Bunkers	0.0	9.9
Reclaiming & Loading Chrome Concentrate Product from Bunkers and to Trucks	174.2	9.9
Reclaiming & Loading Platinum Concentrate Product from Bunkers and to Trucks	0.0	9.9

Table 5-9: Annual emission rates for materials handling operations during the operational phase at Tharisa minerals.

Partially Mitigated Emission Rate (tpa)			Mitigated Emission Rate (tpa)		
PM_{10}	$PM_{2.5}$	TSP	PM_{10}	$PM_{2.5}$	TSP

67.0	10.0	131.3	3.6	24.4	53.7

5.3.4 Vehicle Entrainment from Unpaved Haul Roads

Vehicle-entrained dust emissions have been found to account for a great portion of fugitive dust emissions from open pit mining operations. The force of the wheels of vehicles travelling on unpaved haul roads causes the pulverisation of surface material. Particles are lifted and dropped from the rotating wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed. The quantity of dust emissions from unpaved roads varies linearly with the volume of traffic.

The unpaved road size-specific emission factor equation of the US EPA, used in the quantification of emissions, is given as follows:

$$E = k\left(\frac{s}{12}\right)^{a} \cdot \left(\frac{W}{3}\right)^{b} \cdot 281.9 \tag{3}$$

Where,

E = *emissions in grams of particulates per vehicle kilometre travelled (g/VKT)*

K = *particle size multiplier (dimensionless);*

S = *silt content of road surface material (%);*

W = *mean vehicle weight (tons)*

The particle size multiplier in the equation (k) varies with aerodynamic particle size range and is given as 1.5 for PM_{10} and 4.9 for total suspended particulates (TSP). The constants a and b are given as 0.9 and 0.45 respectively for PM_{10} and as 0.7 and 0.45 respectively for TSP. A mean silt loading of 6% were used as input in the emission estimations due to the absence of data on-site specific road silt loading. (The road silt loading range for coal mining haul roads is given by the US-EPA as 2.8% to 18%). The mean vehicle weight of the ore and waste-carrying haul trucks was taken as 215 tons (180 ton capacity).

Fugitive dust emissions from unpaved roads were calculated assuming haulage of the material as volumes given in Table 5-1. A control efficiency of 63% was applied to all the haul roads included in the construction phase of this study. This percentage was obtained by using the watering rate of unpaved roads at Tharisa Minerals in the following equation (equation 4) in order to deduce the control efficiency of the watering rate at the Tharisa Minerals area. Error! Reference source not found. gives a ummary of the watering rates of unpaved roads at Tharisa Minerals whereas **Error! Reference source not found.** gives the parameters used in equation 4. Estimated particulate emissions from unpaved roads are listed in **Error! Reference source not found.**. It was assumed that $PM_{2.5}$ missions equals PM_{10} emissions as is recommended by the Canadian NPIR (2009), however according to the US-EPA (1995) $PM_{2.5}$ account for only 15% of PM_{10} emissions on unpaved roads and therefore it can be assumed that $PM_{2.5}$ emissions from unpaved roads will be somewhere between 100% and 10% of PM_{10} emissions.

$$c=100-(0.8pdt/I) \qquad (4)$$

Where

c = average control efficiency (%)

p = potential average daytime evaporation rate (mm/hr)

d = average hourly daytime traffic rate (traffic per hour)

t = time between applications

I = application intensity (litres per m^2)

Table 5-10: Watering rates at Tharisa Minerals.

Watering of Roads at Tharisa Minerals	
Litres per day	192000
Litres per truck (5 trucks) per day	38400
Total road area	176541
Litres per square metre every 2 hours	0.22

Table 5-11: Parameters used in Equation 4.

Parameter	Values
p	0.43 (Maximum evaporation rate during December)
d	20
t	2 hours
I	0.22

The following haulage activities were included in the study:

- In-pit haul roads;
- Waste haulage from open-pits to berm and tailings wall for construction purposes;
- Ore haulage from the west open pit to the western primary crusher; and
- Ore haulage from the east open pit to the primary crusher at the concentrator plant.

The following table (Table 5-12) summarises the annual emission rates modelled for unpaved roads during the operational phase at Tharisa Minerals.

Table 5-12: Annual emission rates of unpaved roads during the operational phase.

Partially Mitigated Emission Rate (tpa)			Mitigated Emission Rate (tpa)		
PM_{10}	**$PM_{2.5}$**	**TSP**	**PM_{10}**	**$PM_{2.5}$**	**TSP**
528.0	52.8	752.2	52.8	5.3	75.2

5.3.5 Dozing

The formulas for calculating the emission factors (EF) in kg/h/vehicle for in pit dozing for TSP and PM_{10} respectively is given below (equations 5 and 6) (NPI, 2012).

$$EF_{TSP} = 2.6 \times s^{1.2} \times M^{-1.3} \quad (5)$$

$$EF_{PM10} = 0.34 \times s^{1.2} \times M^{-1.3} \quad (6)$$

Where:

s: Silt content of material

M: moisture content of material

A silt content of 6% was used as published in the US EPA (1995) for metaliferous plant roads. The table below (**Error! Reference source not found.**) lists the estimated particulate emissions from ozing. $PM_{2.5}$ was assumed to make up 10% of all PM_{10} emissions, (US EPA 1995).

Table 5-13: Estimated particulate emissions from dozing.

Emission Rate (tpa)		
PM_{10}	**$PM_{2.5}$**	**TSP**
28.4	2.8	126.8

5.3.6 Crushing and Screening

Crushing and screening plants represent significant dust-generating sources if uncontrolled. Dust fallout in the vicinity of crushers also give rise to the potential for the re-entrained of dust emitted by vehicles or by the wind at a later date. The large percentage of fines in this deposited material enhances the potential for it to become airborne. Fugitive dust emissions due to the crushing and screening operations for the proposed mine and concentrator plant were quantified using NPI, 2012 single valued emission factors for such operations (Table 5-14). These emission factors include emissions from the loading of crusher hoppers and screening. It was assumed that crushing will be mitigated at a control efficiency of 50% by the use of water sprays. It was further assumed that 15% of PM_{10} emissions consist of $PM_{2.5}$ (EPA, 1995).

Table 5-14: NPI emission factors for crushing of high moisture ore

Source	PM_{10} (kg PM10 / t ore processed)	$PM_{2.5}$ (kg PM10 / t ore processed)	TSP (kg TSP / t ore processed)

Primary crushing	0.004	0.0006	0.01
Secondary crushing	0.012	0.0018	0.03

The following table (Table 5-15) summarises the annual emission rates modelled for crushing and screening during the operational phase at Tharisa Minerals.

Table 5-15: Annual emission rates for crushing and screening during the operational phase.

Partially Mitigated Emission Rate (tpa)			Mitigated Emission Rate (tpa)		
PM_{10}	**$PM_{2.5}$**	**TSP**	**PM_{10}**	**$PM_{2.5}$**	**TSP**
323	48.5	3230	6.46	0.97	64.6

5.3.7 Wind Erosion

Wind erosion emissions arise due to the mechanical disturbance of granular material from open areas and storage piles. Parameters which have the potential to impact on the rate of emission of fugitive dust include the extent of surface compaction, moisture content, ground cover, the shape of the storage pile, particle size distribution, wind speed and precipitation. Any factor that binds the erodible material, or otherwise reduces the availability of erodible material on the surface, decreases the erosion potential of the fugitive source. High moisture content, whether due to precipitation or deliberate wetting, promotes the aggregation and cementation of fines to the surfaces of larger particles, thus decreasing the potential for dust emissions. Surface compaction and ground cover similarly reduces the potential for dust generation. The shape of a storage pile or disposal dump influences the potential for dust emissions through the alteration of the airflow field. The particle size distribution of the material on the disposal site is important since it determines the rate of entrainment of material from the surface, the nature of dispersion of the dust plume, and the rate of deposition (Burger, 2010).

The tailings impoundments, topsoil berms and stockpiles were identified as potential sources of particulate matter emissions through the process of wind erosion.

The calculation of an emission rate for every hour of the simulation period was carried out using the ADDAS model. This model is based on the dust emission model proposed by (Marticorena & Bergametti, 1995). The model attempts to account for the variability in source erodibility through the parameterisation of the erosion threshold (based on the particle size distribution of the source) and the roughness length of the surface..

In the quantification of wind erosion emissions, the model incorporates the calculation of two important parameters, viz. the threshold friction velocity of each particle size, and the vertically integrated horizontal dust flux, in the quantification of the vertical dust flux (i.e. the emission rate). The equations used are as follows:

$$E_i = G_i 10^{(0.134C-6)} \tag{7}$$

where,

$$G_i = 0.261 \frac{\rho_a}{g} U_*^3 (1 + R_i)(1 - R_i^{\ 2}) \tag{8}$$

$$R_i = \frac{U_{t*i}}{U_*}$$

and,

E_i = Emission rate (size category i)

C = clay content (%)

ρ_a = air density

g = gravitational acceleration

U_* = frictional velocity

U_{t*i} = threshold frictional velocity (size category i)

Dust mobilisation occurs only for wind velocities higher than a threshold value, and is not linearly dependent on the wind friction and velocity. The threshold friction velocity, defined as the minimum friction velocity required initiating particle motion, is dependent on the size of the erodible particles and the effect of the wind shear stress on the surface. The threshold friction velocity decreases with a decrease in the particle diameter, for particles with diameters >60 µm. Particles with a diameter <60 µm result in increasingly high threshold friction velocities, due to the increasingly strong cohesion forces linking such particles to each other (Marticorena and Bergametti, 1995). The relationship between particle sizes ranging between 1 µm and 500 µm and threshold friction velocities (0.24 m/s to 3.5 m/s), estimated based on the equations proposed by Marticorena and Bergametti (1995), is illustrated in **Error! Reference source not found.**.

The logarithmic wind speed profile may be used to estimate friction velocities from wind speed data recorded at a reference anemometer height of 10 m (EPA, 1996):

$$U^* = 0.053 U_{10}^+ \tag{9}$$

(This equation assumes a typical roughness height of 0.5 cm for open terrain, and is restricted to large relatively flat piles or exposed areas with little penetration into the surface layer.)

The wind speed variation over the dump was based on the work of (Cowhert, Muleski, & Kinsey, 1988). With the aid of physical modelling, the US-EPA has shown that the frontal face of an elevated pile (i.e. windward side) is exposed to wind speeds of the same order as the approach wind speed at the top of the pile. The ratios of surface wind speed (u_s) to approach wind speed (u_r), derived from wind tunnel studies for two representative pile shapes, are indicated in **Error! Reference source not ound.**(viz. a conical pile, and an oval pile with a flat top and 37° side slope. The contours of normalised surface wind speeds are indicated for the oval, flat top pile for various pile orientations to the prevailing direction of airflow. It is interesting to note that the higher the ratio of surface wind speed (u_s) to approach wind speed (u_r) the greater the wind exposure potential.

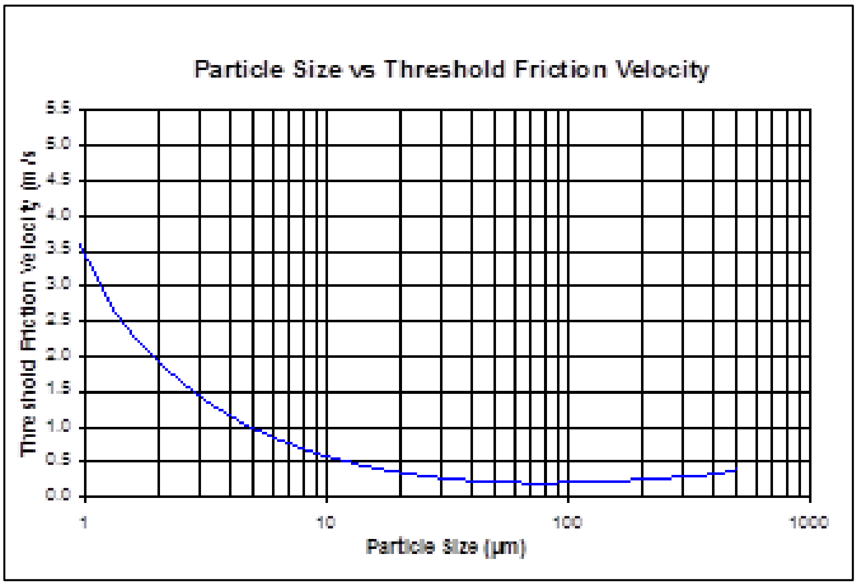

Figure 5-1: Relationship between particle sizes and threshold friction velocities using the calculation methods proposed by Marticorena and Bergametti (1995).

The ADDAS model was run for all the potential wind erosion sources and for different moisture contents of the material potentially being eroded. For the three years ADDAS model was run, emissions above zero were only predicted for five years at a moisture content of 0.1 (the lowest moisture content the model can run).The predicted tons per annum of particulates predicted to be emitted from wind erosion is tabulated in Table 5-16.

Table 5-16: Predicted annual emission rate for wind erosion.

Emission Rate (tpa)		
$PM_{2.5}$	**PM_{10}**	**TSP**
0.00	0.01	0.01

It is clear from the table above that predicted tonnages from wind erosion is negligibly small compared to the other sources inventoried. Therefore wind erosion was not included as a source during the modelling phase of this study.

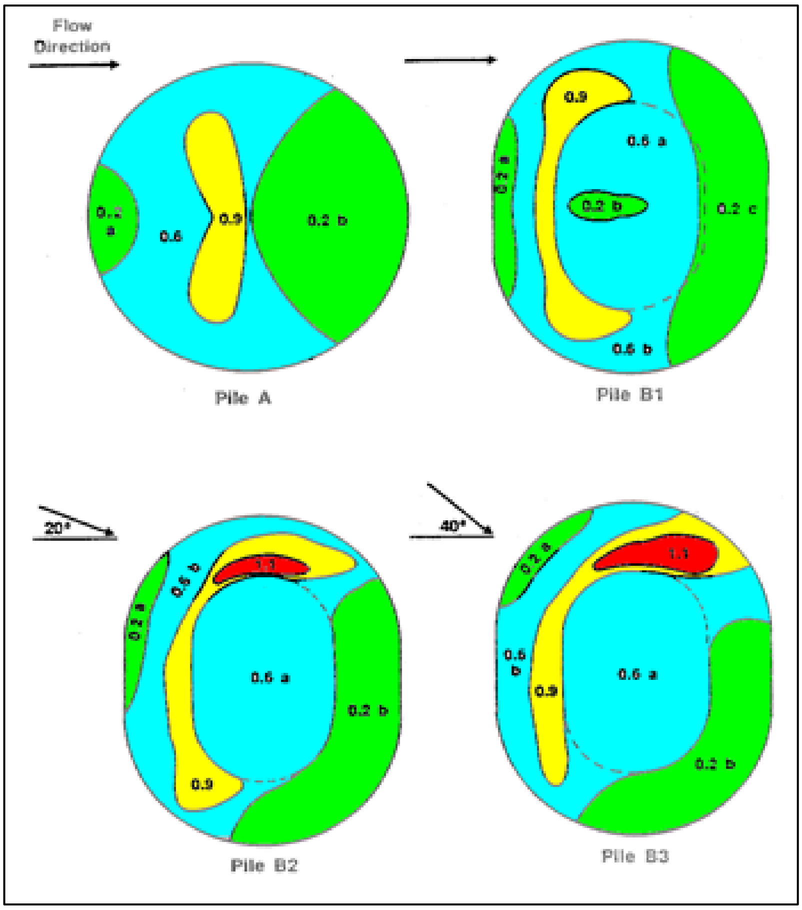

Figure 5-2: Contours of normalised surface wind speeds (i.e. surface wind speed / approach wind speed) (After EPA, 1996).

5.3.8 Chrome Dryer Plant

The chrome dryer plant will be fuelled by either Diesel, Pea Coal or Heavy Fuel Oil. The CO, NOx, SO_2 $PM_{2.5}$, PM_{10} and TSP emission rates for all three fuel types were quantified and discussed in the sections below. However, the chrome dryer plant was modelled as being fuelled by diesel as this will give in general the most conservative results. The table below (Table 5-17) summarises all the dryer plant stack parameters that were used for modelling purposes in this study.

The $PM_{2.5}$, PM_{10} and TSP emissions were calculated by making use of the baghouse efficiency. Thus some of the particulate matter will be retained by the baghouse filter (fabric filter) and only some of the particulate matter emissions will escape.

Table 5-17: Chrome dryer plant stack parameters.

Stack Parameters:		Unit
Flow rate	4.4	m$^{3/}$s
	16000	Am^3/hr
Baghouse Efficiency	20	mg/Nm^3
Exit Temperature	110	C
Stack Height	15	m
Stack diameter	0.55	m

5.3.8.1 Diesel

The chrome dryer plant was modelled as using 640 kg of diesel fuel per hour. The emission factors used for the quantifications of emissions were obtained from the (NPI, 2011) for Diesel boilers with a capacity of less than 30 MW are listed in Table 5 18. The predicted emission rate per annum for each of the modelled pollutants is given in Table 5 19.

Table 5-18: NPI Emission factors for diesel boilers (<30 MW)

Emission Factor (kg/t)			
CO	**NOx**	**SO_2**	**VOC**
0.68	2.72	0.019	0.027

Table 5-19: Predicted annual emission rate for the chrome dryer plant fuelled by diesel.

Emission rate (tpa)					
CO	**NOx**	**SO_2**	**VOC**	**PM_{10}**	**$PM_{2.5}$**
3.66	14.6	0.104	0.146	2	2

5.3.8.2 Pea coal (Bituminous Coal)

The emission factors for a spreader stoker (NPI, 2011) were used in the calculations of emissions from the dryer plant when fuelled by pea coal (Table 5-20). The predicted emission rates per annum for each of the modelled pollutants are given in Table 5-21.

Table 5-20: NPI Emission factors for a coal spreader stoker.

Emission Factor (kg/t)			
CO	NOx	SO_2	VOC
2.5	5.5	1.5.2	0.03

Table 5-21: Predicted annual emission rates for the chrome dryer plant fuelled by pea coal.

Emission Rate (tpa)					
CO	NOx	SO_2	VOC	PM_{10}	$PM_{2.5}$
6.2	13.5	37.4	0.1	2	2

5.3.8.3 Heavy Fuel Oil

The emission factors for a residual oil boiler with a capacity of less than 30 MW (NPI, 2011) were used in the calculations of emissions from the dryer plant when fuelled by heavy fuel oil (Table 5-22). The predicted emission rates per annum for each of the modelled pollutants are given in **Error! Reference ource not found.**.

Table 5-22: NPI Emission factors for a residual oil boiler.

Emission Factor (kg/t)			
CO	NOx	SO_2	VOC
6.70E-01	7.32E+00	2.09E-02	4.00E-02

Table 5-23: Predicted annual emission rate for the chrome dryer plant fuelled by heavy fuel oil.

Emission Rate (tpa)					
CO	NOx	SO_2	VOC	PM_{10}	$PM_{2.5}$
0.401109	4.382262	0.012512	0.023947	2	2

5.4 Synopsis of Estimated Particulate Emissions

A synopsis of the estimated particulate emissions from the proposed operations mine and concentrator plant are presented in the following section. Emissions from activities within the open pits such as in pit roads and truck and shovel activities have been grouped together as open pit sources.

5.4.1 Construction Phase

Dispersion modelling was regarded not representative of the actual activities that will result in dust emissions during the construction phase. It is anticipated that the various construction activities would not result in higher off-site impacts than the operational phase mining activities. The temporary nature of the construction activities, and the likelihood that these would occur concurrently with the mining activities would reduce the significance of the potential impacts of the construction phase. These emissions are expected to be masked by the Tharisa mining operations.

Mitigation measures to consider during the construction phase include water sprays on all cleared and graded areas; ensure the distances between the topsoil removal and topsoil stockpiles are kept at a minimum and topsoil piles vegetated.

5.4.2 Operational Phase (Partially Mitigated)

Table 5-24 summarises the contribution of each source to annual PM_{10}, $PM_{2.5}$ and dustfall (TSP) emissions during the operational phase (partially mitigated scenario), whereas Figure 5-3 shows this results graphically. The source distribution during the operational phase is very similar to that of the construction phase. Again, the most significant contributor to PM_{10} and $PM_{2.5}$ emissions are unpaved roads whereas crushing stays the main contributor to TSP emissions.

Table 5-24: Source contributions to annual PM_{10}, $PM_{2.5}$ and TSP emissions for the partially mitigated scenario at Tharisa Minerals.

Operational Phase						
Source	**PM_{10} (tpa)**	**PM_{10} (%)**	**$PM_{2.5}$ (tpa)**	**$PM_{2.5}$ (%)**	**TSP (tpa)**	**TSP(%)**
Materials handling	67	6%	10	2%	131	2%
Unpaved Roads	528	49%	528	80%	1981	35%
Drilling	15	1%	15	2%	29	1%
Blasting	100	9%	6	1%	193	3%
Crushing and Screening	323	30%	48	7%	3231	56%
Dryer Plant	0	0%	0	0%	0	0%
Open Pit Sources	49	5%	49	7%	166	3%
Total	1083		657		5731	

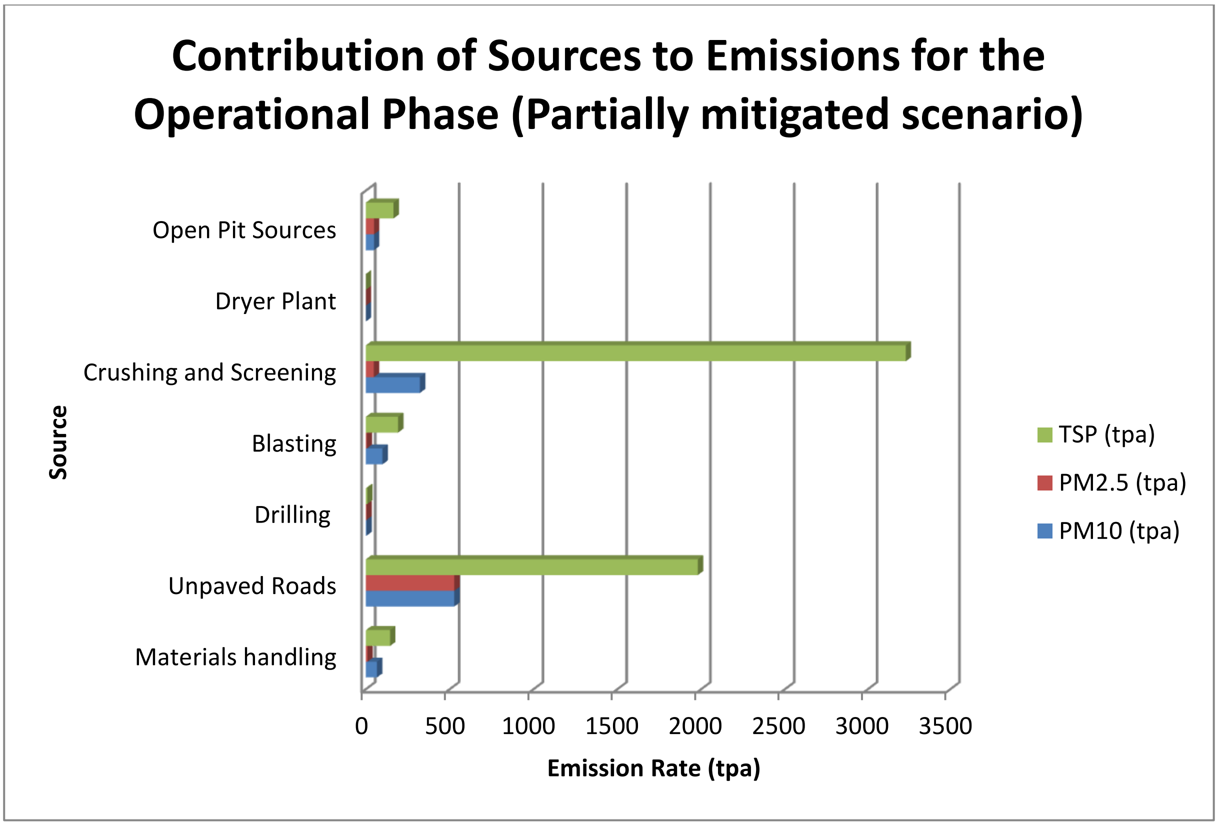

Figure 5-3: Source contributions to annual PM_{10}, $PM_{2.5}$ and TSP emissions for the partially mitigated scenario at Tharisa Minerals.

5.4.3 Operational Phase (Mitigated)

Table 5-25 summarises the contribution of each source to annual PM_{10}, $PM_{2.5}$ and dustfall (TSP) emissions during the operational phase (mitigated scenario), whereas Figure 5-5 shows this results graphically. It is clear that emissions reduce significantly with mitigation.

Table 5-25: Source contributions to annual PM_{10}, $PM_{2.5}$ and TSP emissions for he mitigated scenario at Tharisa Minerals.

Operational Phase (Mitigated Scenario)						
Source	**PM_{10} (tpa)**	**PM_{10} (%)**	**$PM_{2.5}$ (tpa)**	**$PM_{2.5}$ (%)**	**TSP (tpa)**	**TSP(%)**
Materials handling	24	10%	4	6%	54	8%
Unpaved Roads	53	23%	5	8%	198	29%
Drilling	1	1%	1	2%	3	0%
Blasting	100	43%	6	9%	193	28%
Crushing and Screening	6	3%	1	1%	65	10%
Dryer Plant	0	0%	0	0%	0	0%
Open Pit Sources	49	21%	49	74%	166	24%
Total	234		66		678	

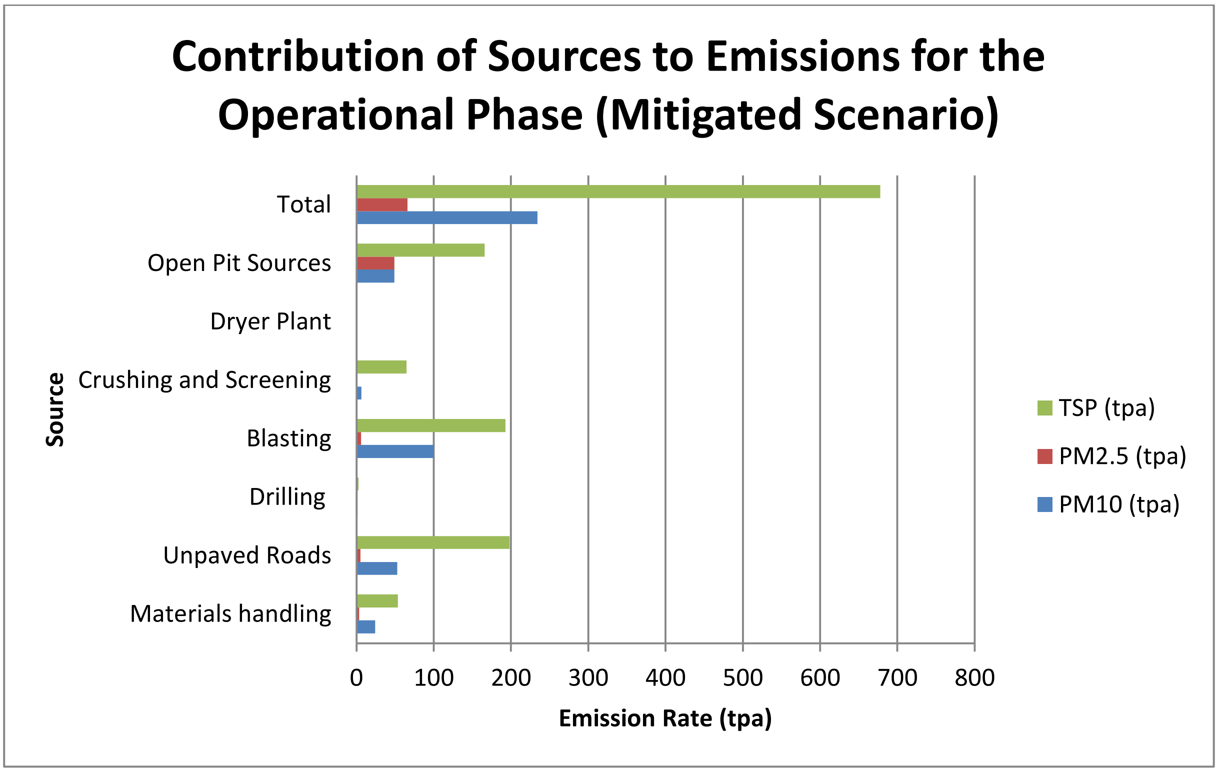

Figure 5-4: Source contributions to annual PM_{10}, $PM_{2.5}$ and TSP emissions for the mitigated scenario at Tharisa Minerals.

5.5 Dispersion Modelling

5.5.1 Dispersion Model Selection and Data Requirements

Dispersion models compute ambient concentrations as a function of source configurations, emission strengths and meteorological characteristics, thus providing a useful tool to ascertain the spatial and temporal patterns in the ground level concentrations arising from the emissions of various sources. Increasing reliance has been placed on concentration estimates from models as the primary basis for environmental and health impact assessments, risk assessments and emission control requirements. It is therefore important to carefully select a dispersion model for the purpose.

It was decided to employ the most recent US Environmental Protection Agency (US EPA) approved regulatory model. The most widely used US EPA model is the new generation AERMET/AERMOD suite of models. AERMOD is a Gaussian plume model, which was developed under the support of the AMS/EPA Regulatory Model Improvement Committee (AERMIC), whose objective has been to include state-of the-art science in regulatory models (Hanna et al., 1999). AERMOD is a dispersion modelling system with three components, namely: AERMOD (AERMIC Dispersion Model), AERMAP (AERMOD terrain pre-processor), and AERMET (AERMOD meteorological pre-processor).

- AERMOD is an advanced new-generation model. It is designed to predict pollution concentrations from continuous point, flare, area, line, and volume sources. AERMOD offers new and potentially improved algorithms for plume rise and buoyancy, and the computation of vertical profiles of wind, turbulence and temperature however retains the single straight line trajectory limitation of ISCST3 (Hanna *et al,* 1999).

- The AERMET is a meteorological pre-processor for the AERMOD. Input data can come from hourly cloud cover observations, surface meteorological observations and twice-a-day upper air soundings. Output includes surface meteorological observations and parameters and vertical profiles of several atmospheric parameters.

- The AERMAP is a terrain pre-processor designed to simplify and standardize the input of terrain data for the AERMOD. Input data includes receptor terrain elevation data. The terrain data may be in the form of digital terrain data. The output includes, for each receptor, location and height scale, which are elevations used for the computation of air flow around hills.

- The stochastic uncertainty includes all errors or uncertainties in data such as source variability, observed concentrations, and meteorological data. Even if the field instrument accuracy is excellent, there can still be large uncertainties due to unrepresentative placement of the instrument (or taking of a sample for analysis). Model evaluation studies suggest that the data input error term is often a major contributor to total uncertainty. Even in the best tracer studies, the source emissions are known only with an accuracy of ±5 %, which translates directly into a minimum error of that magnitude in the model predictions. It is also well known that wind direction errors are the major cause of poor agreement, especially for relatively short-term predictions (minutes to hourly) and long downwind distances. All of the above factors contribute to the inaccuracies not even associated with the mathematical models themselves.

Input data types required for the AERMOD model include: source data, meteorological data (pre-processed by the AERMET model), terrain data and information on the nature of the receptor grid.

5.5.2 Meteorological Data Requirements

AERMOD requires two specific input files generated by the AERMET pre-processor. AERMET is designed to be run as a three-stage processor and operates on three types of data (upper air data, on-site measurements, and the national meteorological database).

For the purpose of the current study use was made of the SAWS Unified Model meteorological data for the period January 2009 to December 2011. The parameters required in the calculation of the AERMET files together with the data availability are presented in Table 5-26.

Table 5-26: Parameters and data availability from the Klipfontein station

Data Period	**2009/01/01– 2011/12/31**	
Parameters	**Measured/Calculated**	**Data Availability**
Wind Direction	Measured	94 %
Wind Speed	Measured	94 %
Standard Deviation	Calculated (a)	0 %
Ambient Temperature	Measured	94 %
Relative Humidity	Measured	94 %
Pressure	Measured	94 %
Solar Radiation	Measured	94 %
Cloud Cover	Calculated (b)	0 %
Ceiling Height	Calculated	0 %

Notes:

(a) Standard deviation calculation based on measured wind directions and solar radiation.

(b) Cloud cover calculated based on ratio of measured solar radiation to calculated solar radiation.

5.5.3 Source Data Requirements

The AERMOD model is able to model point, flare, area, pit, line and volume sources. The sources at Tharisa Minerals mine and concentrator plant were grouped and modelled as follows:

- Open pit mining (incl. roads and trucks and shovels within the pit) – modelled as open pit sources;
- Unpaved roads – modelled as area sources;

- Materials handling operations – modelled as volume sources;
- Crushing and screening operations – modelled as volume sources;
- Dozing – modelled as area sources.
- Chrome dryer plant stack - modelled as a point source

5.5.4 Modelling Domain

The dispersion of pollutants expected to arise from the operations was modelled for an area covering 30 km (east-west) by 30 km (north-south). The area was divided into a grid matrix with a resolution of 400 m by 400 m, with the site located approximately in the centre of the receptor area. The nearby sensitive receptors identified (Figure 1-3) were included as discrete receptor points. AERMOD simulates ground-level concentrations for each of the receptor grid points. Topography was included in the model setup (Figure1-2).

5.6 Dispersion Modelling Results

Dispersion modelling was undertaken to determine highest hourly, highest daily, highest monthly and annual average ground level concentrations for each pollutant for the operational phase only. These averaging periods were selected to facilitate the comparison of predicted pollutant concentrations with relevant air quality standards and dustfall limits.

It should be noted that the ground level concentration isopleths depicted present interpolated values from the concentrations predicted by AERMOD for each of the receptor grid points specified. Plots reflecting daily averaging periods contain only the highest predicted ground level concentrations, for those averaging periods, over the entire period for which simulations were undertaken. It is therefore possible that even though a high daily average concentration is predicted to occur at certain locations, that this may only be true for one day of the year.

5.6.1.1 Operational Phase (Mitigated Scenario)

Figure 5-5 shows the annual average PM_{10} concentrations for the mitigated scenario of the operational phase at Tharisa Minerals. From the figure it can be seen that the mitigation measures reduced PM_{10} impacts significantly. The NAAQS is not predicted to exceed outside the mine boundary but exceedances still occur at sensitive receptors inside the mine boundary. The frequency of exceedance of the daily NAAQS is shown in Figure 5-6. Exceedances of the daily NAAQS occur slightly outside the northern and western mine boundaries. Again exceedances occur at the locations of sensitive receptors within the mine boundaries.

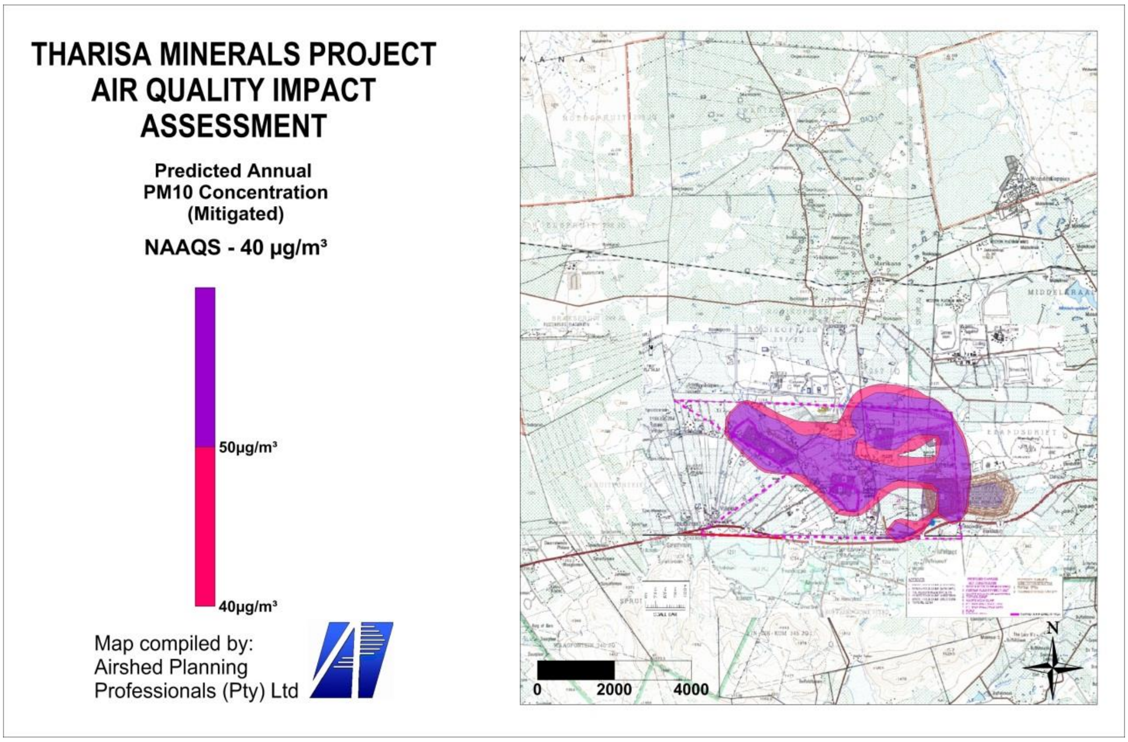

Figure 5-5: Predicted annual average PM$_{10}$ concentrations for the for the operational phase (mitigated scenario) at Tharisa Minerals.

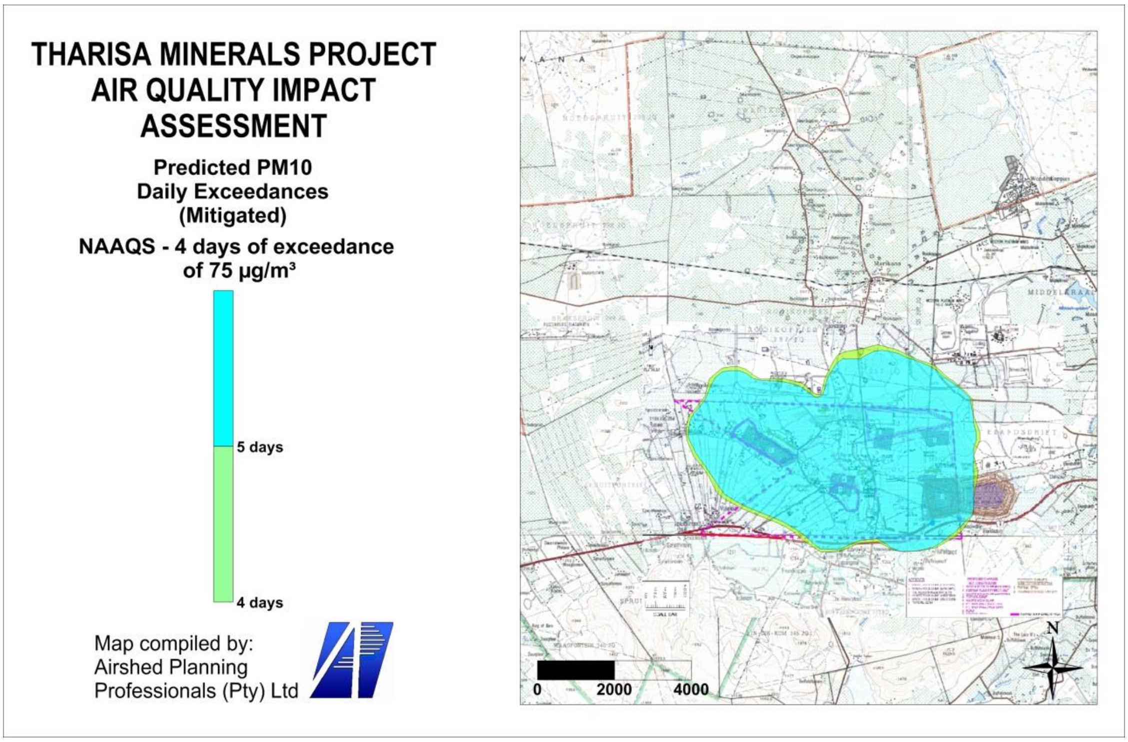

Figure 5-6: Predicted PM$_{10}$ daily exceedance plot for the operational phase (mitigated scenario) at Tharisa Minerals.

5.6.2 PM$_{2.5}$

5.6.2.1 Construction Phase

Figure 5-7 shows the annual average PM$_{2.5}$ concentration plot for the construction phase at Tharisa Minerals. From the figure it can be seen that exceedances of the NAAQS exist at a maximum distance of approximately 3 km from the northern boundary of the mine. Figure 5-8 indicates the daily frequency of exceedance plot and yet again exceedances are predicted to exist at a maximum distance of around 5 to 6 km from the northern mine boundary. Unpaved roads and crushing and screening are the main contributors.

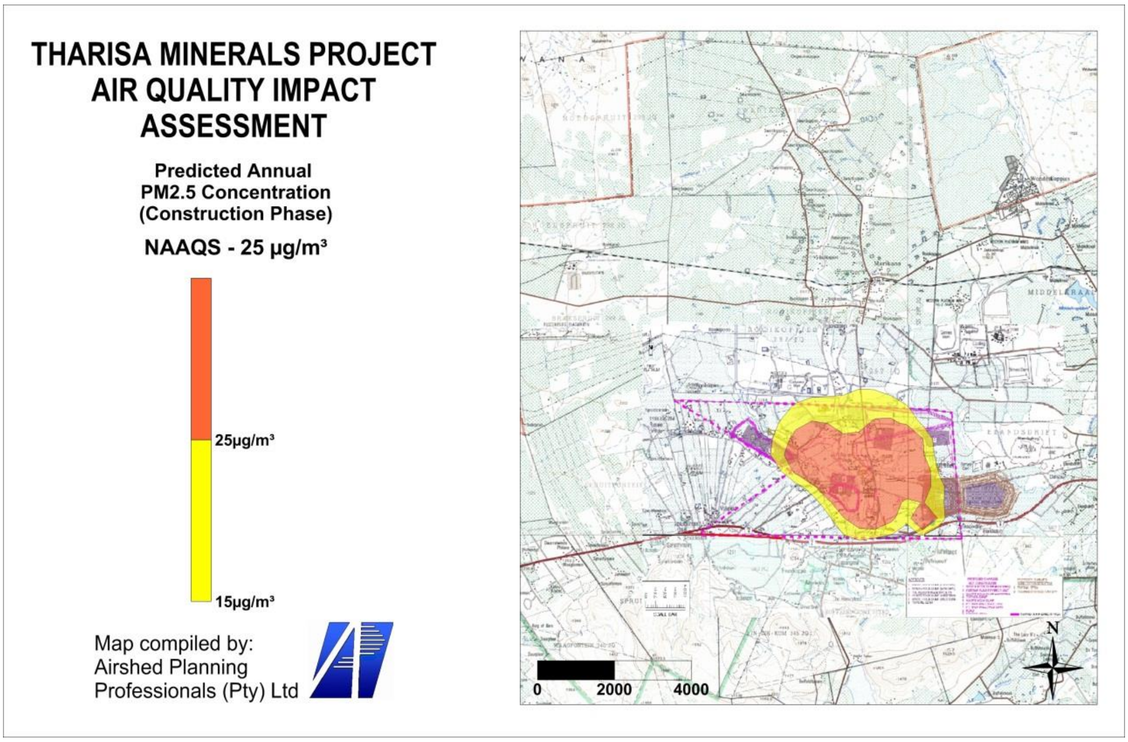

Figure 5-7: Predicted annual average PM$_{2.5}$ impacts a result of operations during the construction phase at Tharisa Minerals.

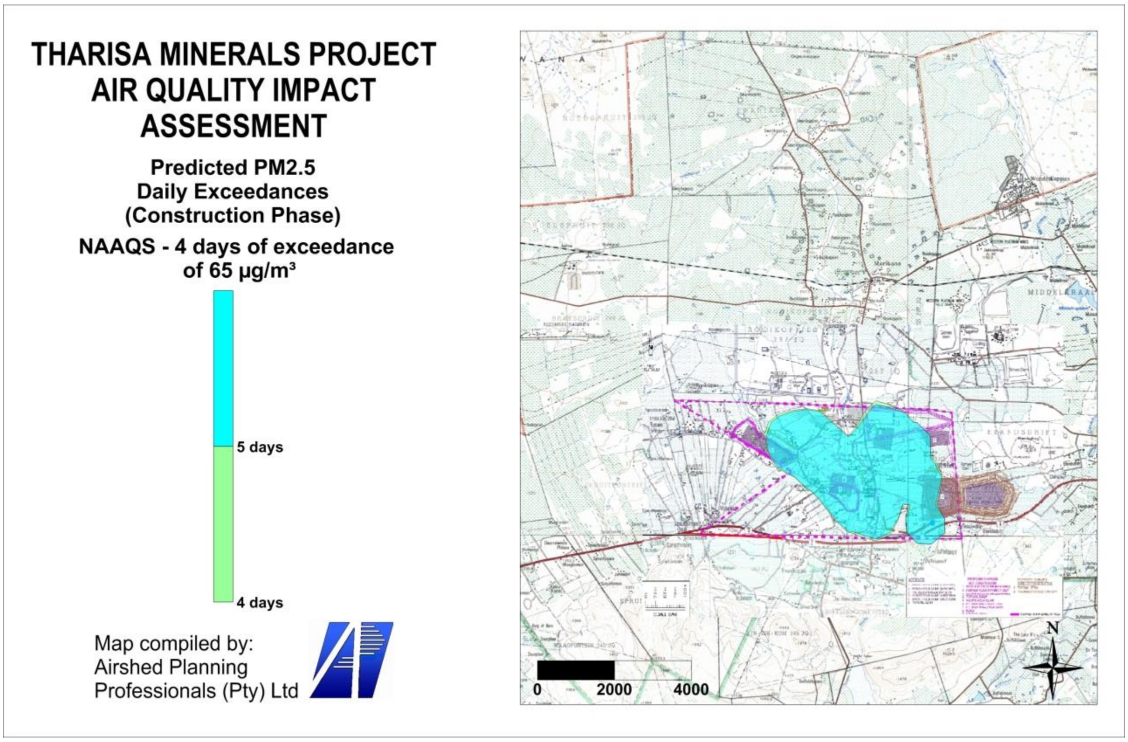

Figure 5-8: Predicted daily frequency of exceedance of the NAAQ $PM_{2.5}$ limit as a result of operations during the construction phase at Tharisa Minerals.

5.6.2.2 Operational Phase (Partially Mitigated Scenario)

The predicted annual average $PM_{2.5}$ plot for the operational phase at Tharisa Minerals is shown in Figure 5-9.The concentration distribution ids very similar to that of the construction phase and annual average exceedances are predicted to occur up to a maximum distance of around 4 km from the northern mine boundary. Figure 5-10 shows the predicted daily frequency of exceedance plot. Exceedances are predicted over a wide area at a maximum distance of 5 to 6 km from the northern mine boundary.

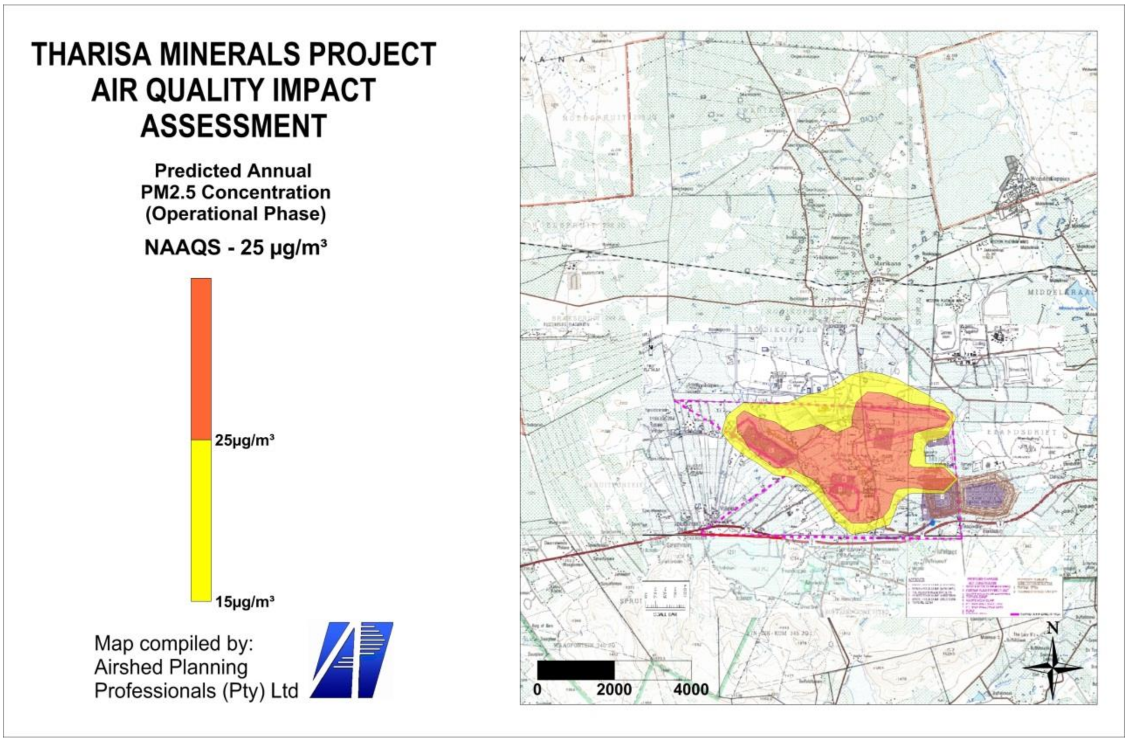

Figure 5-9: Predicted annual average $PM_{2.5}$ impacts a result of operations during the operational phase (partially mitigated scenario) at Tharisa Minerals.

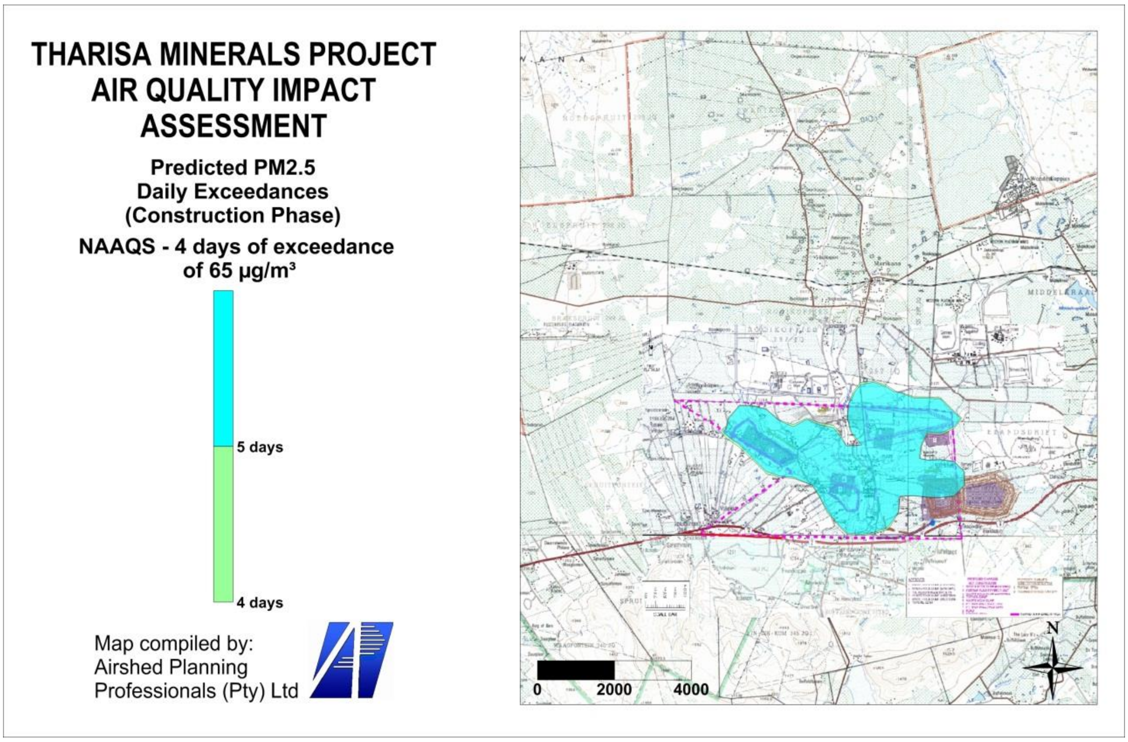

Figure 5-10: Predicted daily frequency of exceedance of the NAAQ $PM_{2.5}$ limit as a result of operations during the operational phase (partially mitigated scenario) at Tharisa Minerals.

5.6.2.3 *Operational Phase (Mitigated Scenario)*

Figure 5-11 shows the predicted annual average $PM_{2.5}$ concentrations for the mitigated scenario of the operational phase. From the figure it can be seen that exceedances of the NAAQS are contained within the mine boundary. It is however possible that exceedances may still occur at sensitive receptors within the mine boundary. No daily exceedances were predicted for this scenario.

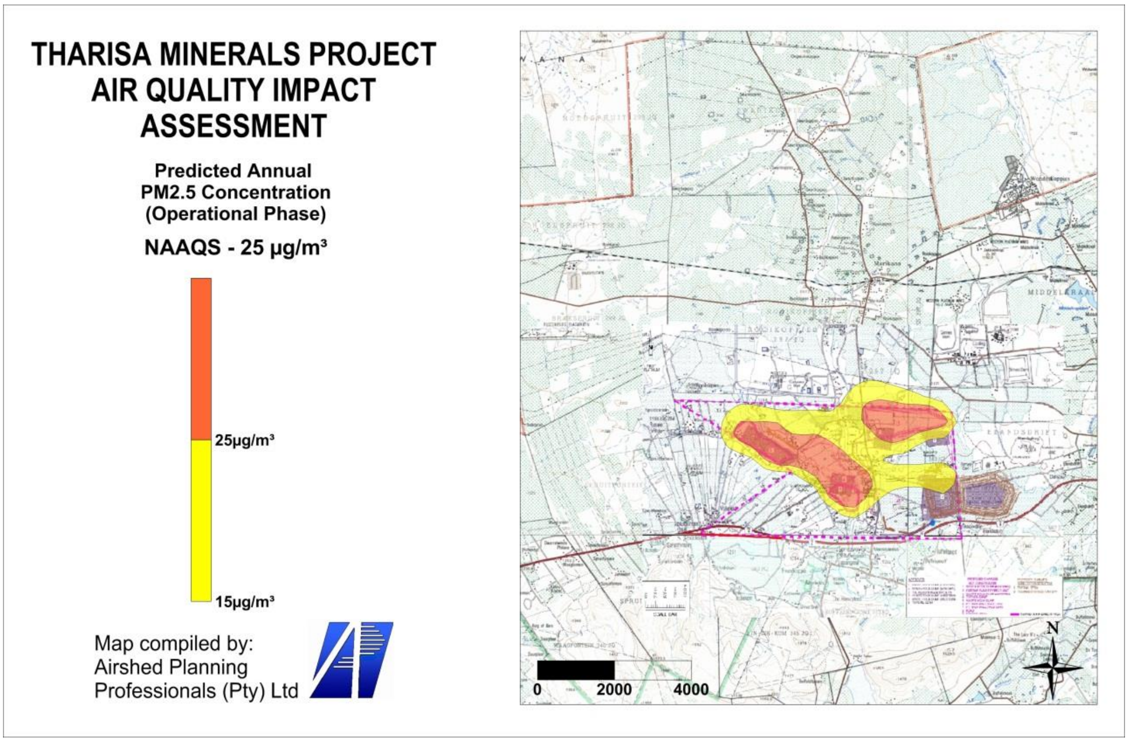

Figure 5-11: Predicted daily frequency of exceedance of the NAAQ $PM_{2.5}$ limit as a result of operations during the operational phase (mitigated scenario) at Tharisa Minerals.

5.6.3 Dustfall

5.6.3.1 *Construction Phase*

Figure 5-12 shows the predicted daily dustfall at Tharisa Minerals during the construction phase. From the figure it is clear that the NDCR residential (600 mg/m²/day) and non-residential (1 200 mg/m²/day) limits are only exceeded within the mine boundary.

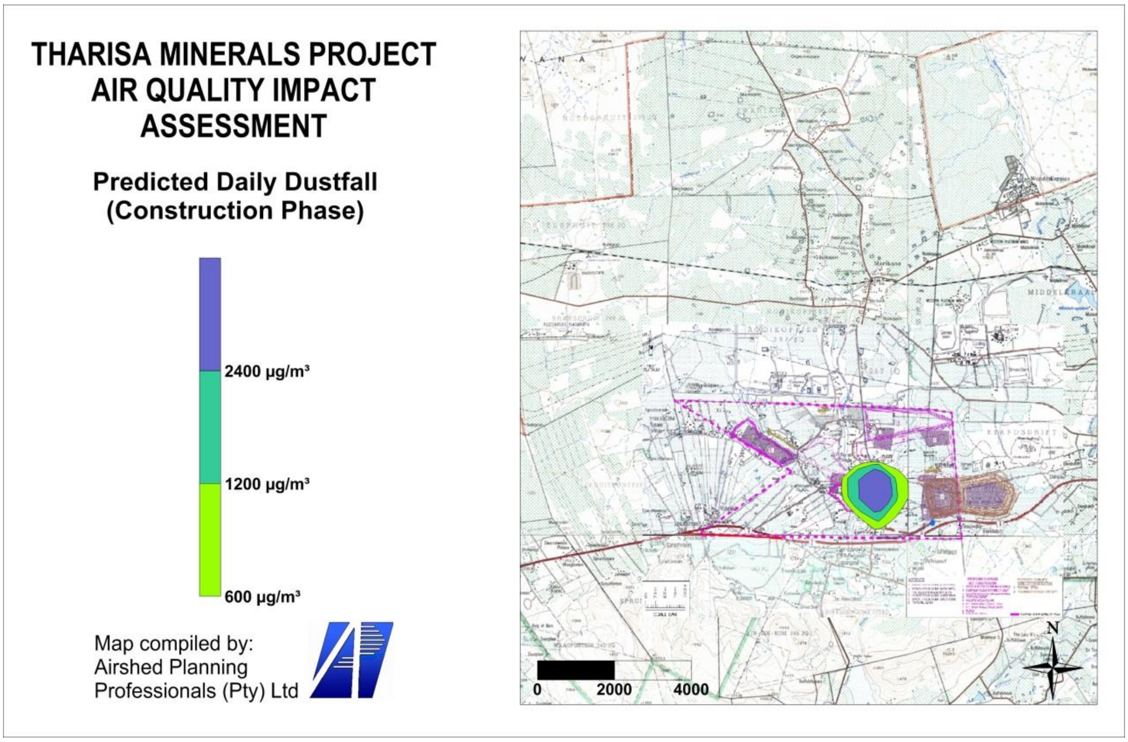

Figure 5-12: Predicted daily dustfall rate during the construction phase at Tharisa Minerals

5.6.3.2 Operational Phase (Partially Mitigated Scenario)

Figure 5-13 shows the predicted daily dustfall at Tharisa Minerals during the operational phase. From the figure it can be seen that the NDCR residential (600 mg/m²/day) and non-residential (1 200 mg/m²/day) limits are again only exceeded within the mine boundary.

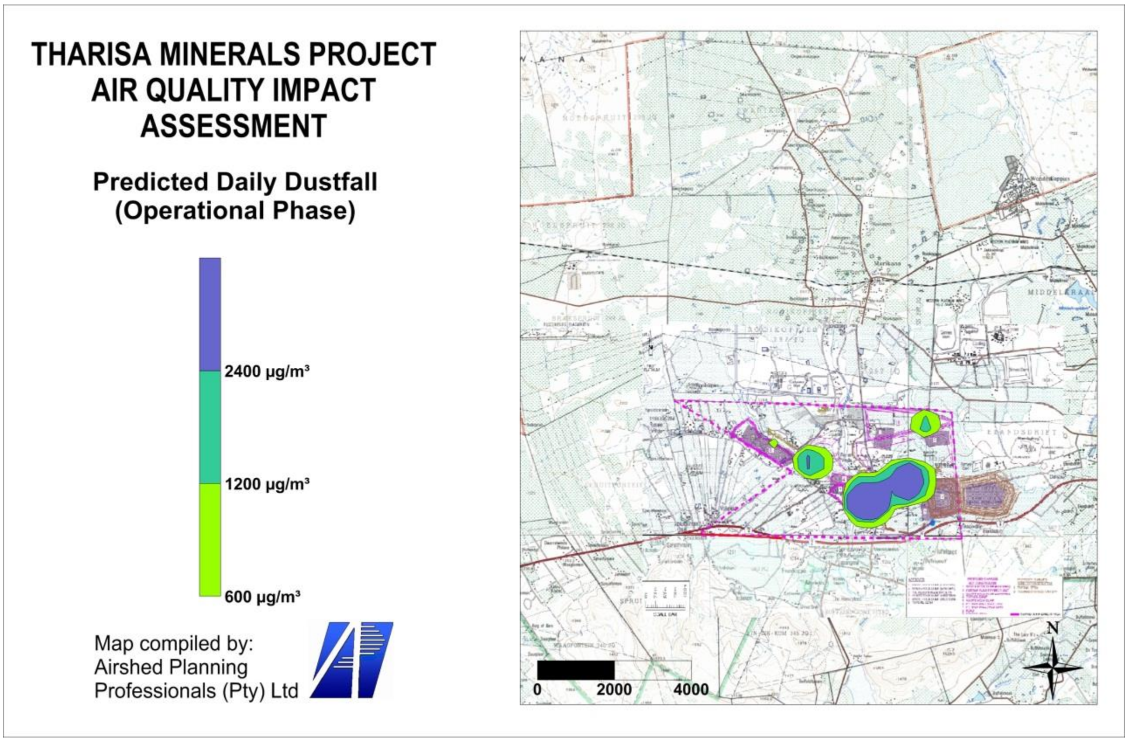

Figure 5-13: Predicted daily dustfall rate during the operational phase (partially mitigated scenario) at Tharisa Minerals.

5.6.3.3 Operational Phase (Mitigated scenario)

Dustfall rates for the mitigated operational phase scenario are shown in Figure 5-14. From the figure it can be seen that mitigation contained the dustfall to below the NDCR residential limit.

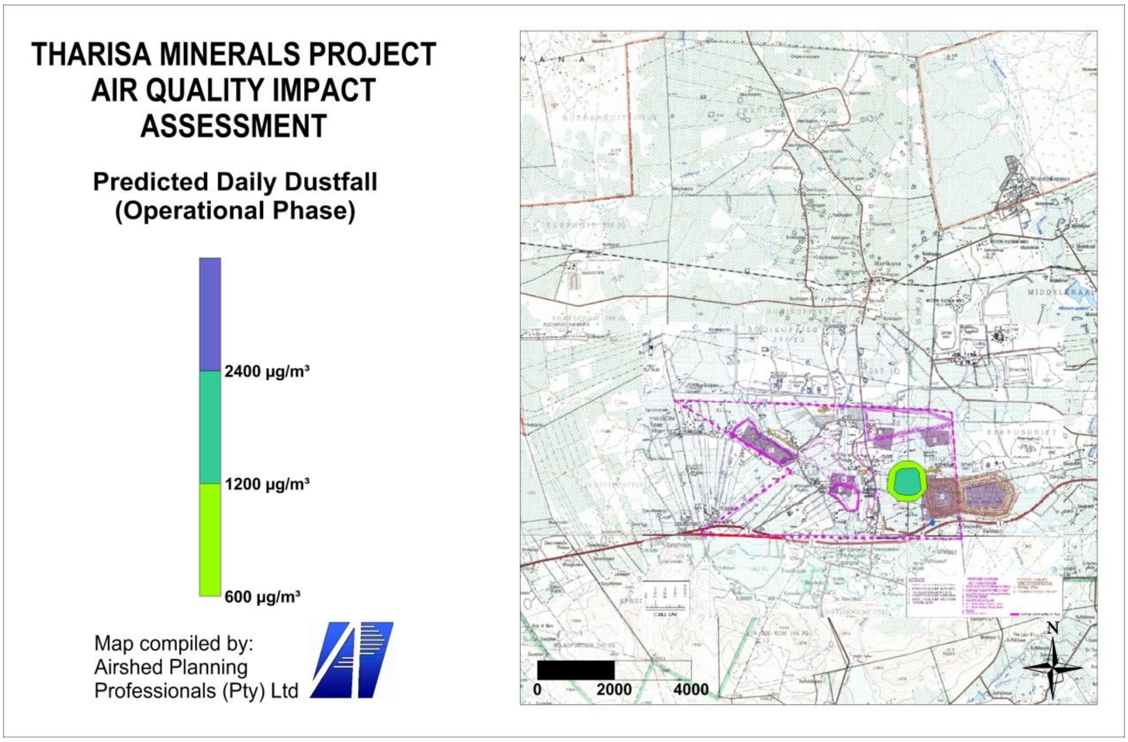

Figure 5-14: Predicted daily dustfall rate during the operational phase (mitigated scenario) at Tharisa Minerals.

5.6.4 CO

Figure 5-15 and Figure 5-16 shows the predicted highest one-hourly and highest eight-hourly CO concentrations, respectively, caused by the chrome sand dryer plant. Neither of the two cases exceeds the NAAQS.

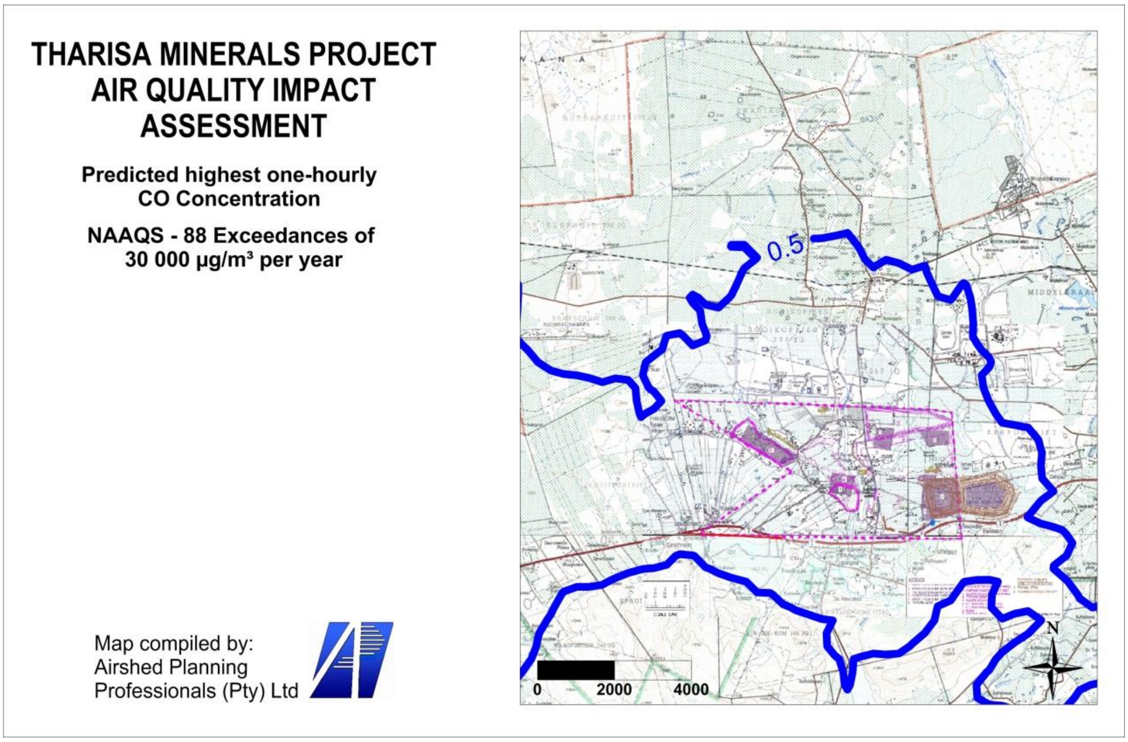

Figure 5-15: Predicted highest one-hourly CO concentrations at Tharisa Minerals caused by the chrome sand dryer plant.

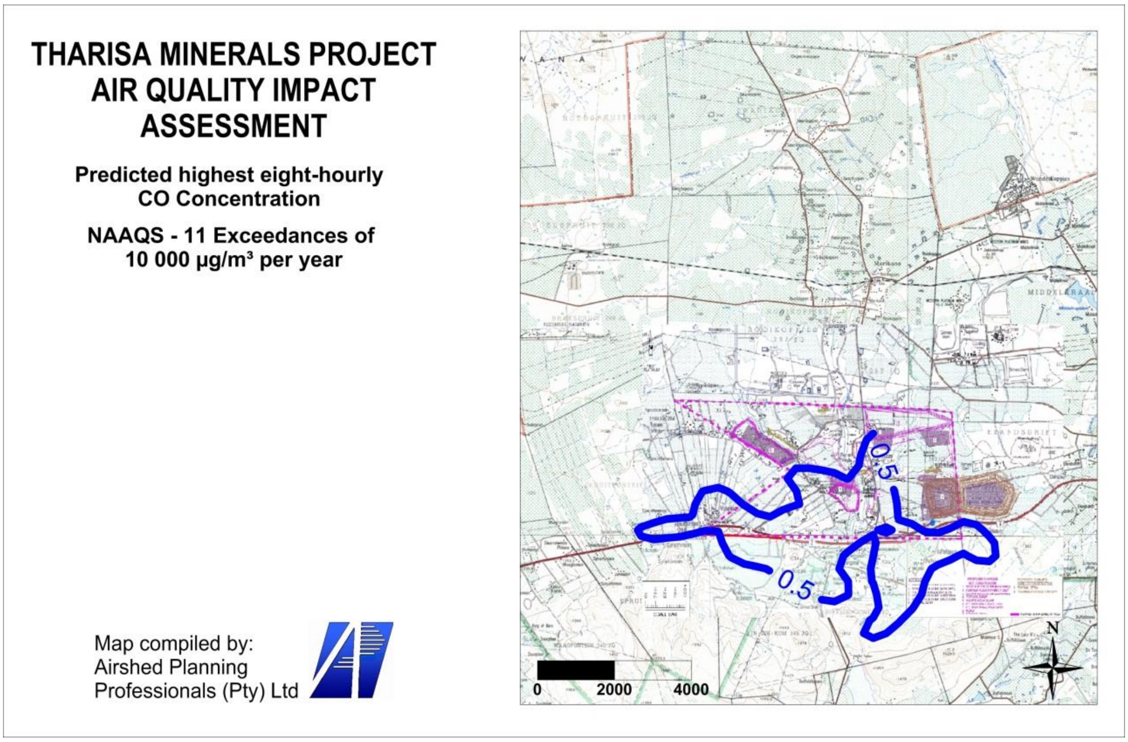

Figure 5-16: predicted highest eight-hourly CO concentrations at Tharisa Minerals caused by the chrome sand dryer plant.

5.6.5 NOx

Figure 5-17 shows the predicted highest hourly NOx concentrations. Again the emissions are quite low and the NAAQS is not exceeded. The predicted annual average concentrations were very low and were thus not reported.

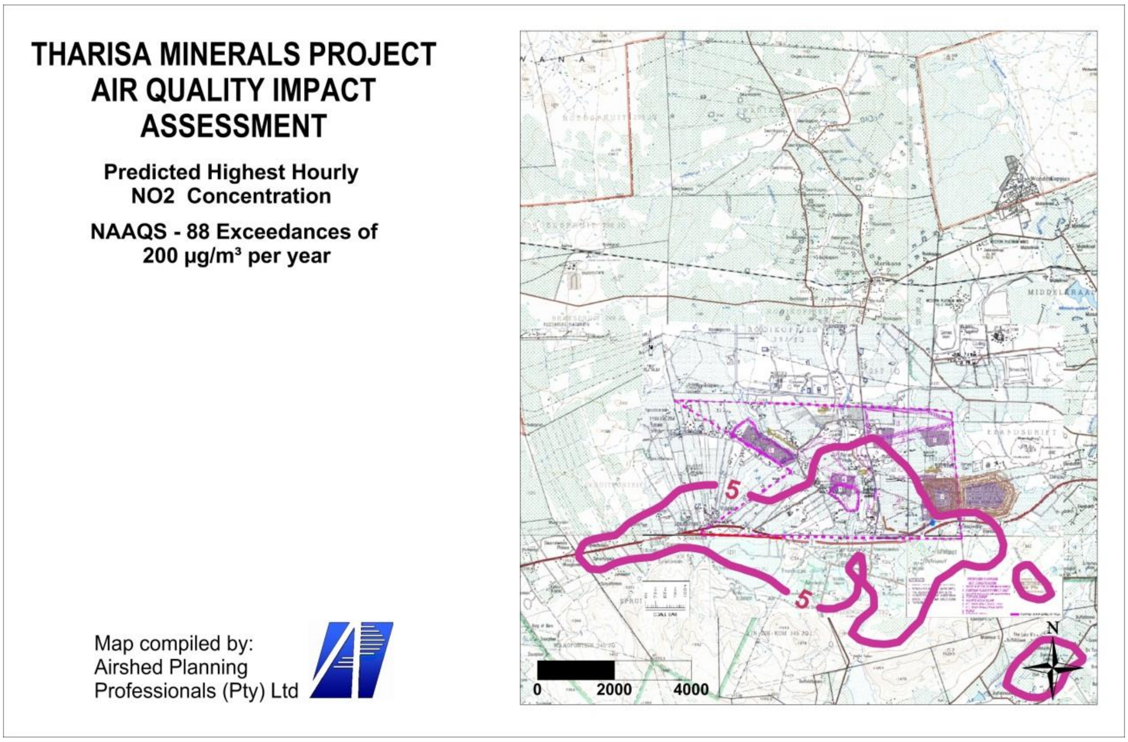

Figure 5-17: Predicted highest one-hourly NOx concentration at Tharisa Minerals caused by the chrome sand dryer plant.

5.6.6 SO_2

Figure 5-18 shows the predicted highest hourly SO_2 values whereas Figure 5-19 indicates the predicted highest daily concentrations. Emissions are low and the NAAQ standards were not exceeded in either of the cases. Again annual average concentrations were very low and were not reported.

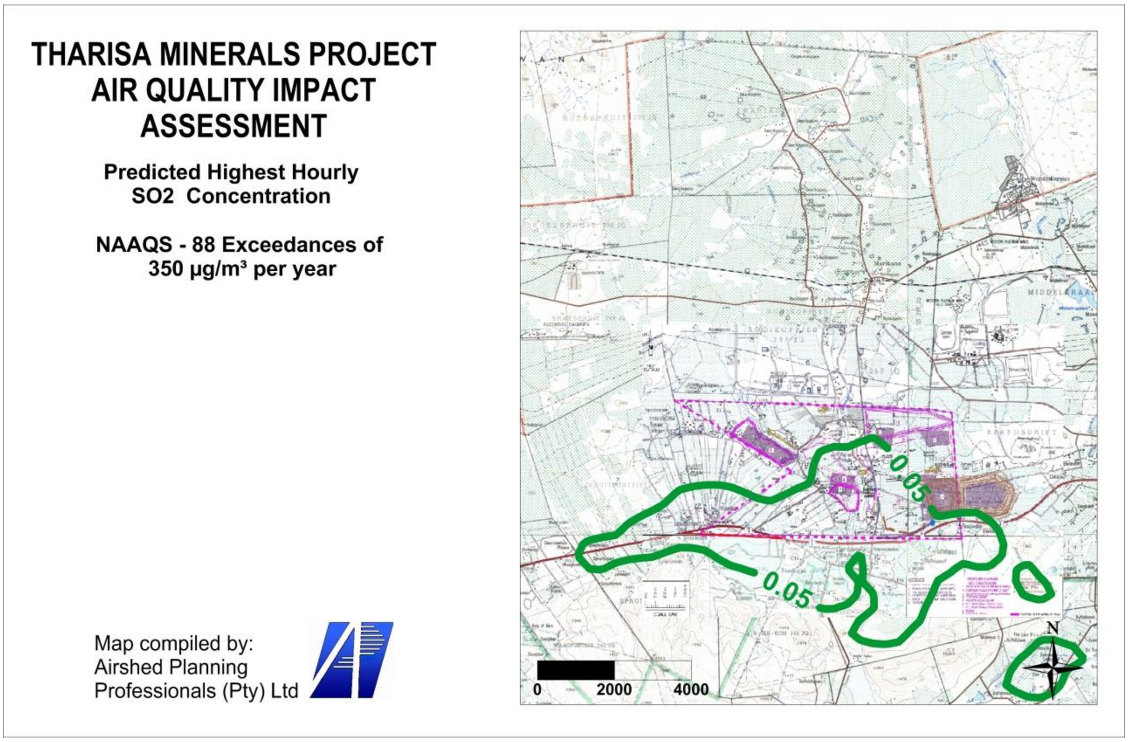

Figure 5-18: Predicted highest one-hourly SO_2 concentration at Tharisa Minerals caused by the chrome sand dryer plant.

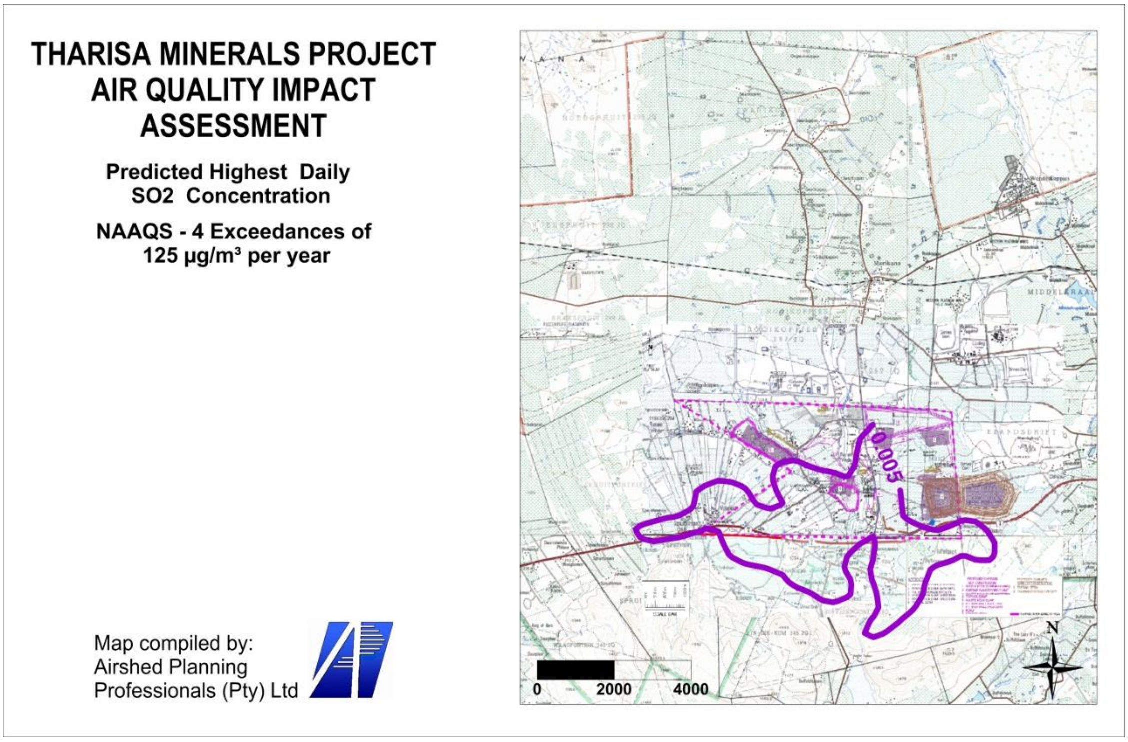

Figure 5-19: Predicted highest daily SO_2 concentration at Tharisa Minerals caused by the chrome sand dryer plant.

5.6.7 VOC

The annual average VOC concentrations caused by the chrome sand dryer plant were negligibly low.

5.7 Compliance Assessment

5.7.1 PM_{10} Impacts

Table 5-27 and Table 5-28 give the incremental PM_{10} annual average ground level concentrations predicted to occur at the various sensitive receptors due to emissions from the operational phases (both partially mitigated and mitigated). Where exceedances of the NAAQS occur the concentration is highlighted in red. From the tables it is clear that unpaved roads, and crushing and screening operations are the main contributors to impacts at sensitive receptors.

Table 5-27: Incremental PM_{10} annual average concentrations at sensitive receptors during the operational phase (partially mitigated scenario) at Tharisa Minerals.

Source	Silver City 1	Silver City 2	Silver City 3	School	Lepologang Village	Buffels-poort	Village	Elands-drift	Boundary
Materials handling	17	14	10	18	11	0	1	1	2
Unpaved Roads	**80**	**152**	**84**	**157**	**101**	2	6	5	**40**
Drilling	0	0	0	0	0	0	0	0	0
Blasting	0	0	0	0	0	0	0	0	0
Crushing and Screening	35	32	23	**66**	**48**	1	3	2	8
Dryer Plant	0	0	0	0	0	0	0	0	0
Open Pit Sources	7	7	6	3	3	0	0	0	1
All Sources	**139**	**204**	**123**	**244**	**163**	3	10	8	51

Table 5-28: Incremental PM_{10} annual average concentrations at sensitive receptors during the operational phase (mitigated scenario) at Tharisa Minerals.

Source	Silver City1	Silver City 2	Silver City 3	School	Lepologang Village	Buffels-poort	village	Elands-drift	Boundary
Materials handling	5	4	3	6	4	0	0	0	1
Unpaved Roads	31	**59**	32	**63**	**41**	1	2	2	19
Drilling	0	0	0	0	0	0	0	0	0
Blasting	0	0	0	0	0	0	0	0	0
Crushing and Screening	1	1	0	1	1	0	0	0	0
Dryer Plant	0	0	0	0	0	0	0	0	2
Open Pit Sources	7	6	6	3	3	0	0	0	2
All Sources	**43**	**70**	**41**	**73**	**49**	1	2	2	24

5.7.2 $PM_{2.5}$ Impacts

Table 5-29 and Table 5-30 give the incremental $PM_{2.5}$ annual average ground level concentrations predicted to occur at the various sensitive receptors due to emissions from the operational phase (both scenarios). Where exceedances of the NAAQS occur the concentration is highlighted in red. From the tables it is clear that unpaved roads, and crushing and screening operations are the main contributors to impacts at sensitive receptors.

Table 5-29: Incremental $PM_{2.5}$ annual average concentrations at sensitive receptors during the operational phase (partially mitigated scenario) at Tharisa Minerals.

Source	Silver City 1	Silver City 2	Silver City 3	School	Lepologang Village	Buffels-poort	Village	Elands-drift	Boundary
Materials handling	3	2	1	2	1	0	0	0	0
Unpaved Roads	**80**	**152**	**84**	**157**	**101**	2	6	5	**43**
Drilling	0	0	0	0	0	0	0	0	0
Blasting	0	0	0	0	0	0	0	0	0
Crushing and Screening	5	5	3	10	7	0	0	0	1
Dryer Plant	0	0	0	0	0	0	0	0	0
Open Pit Sources	7	7	6	3	3	0	0	0	1
All Sources	**95**	**166**	**94**	**172**	**112**	2	6	5	45

Table 5-30: Incremental $PM_{2.5}$ annual average concentrations at sensitive receptors during the operational phase (mitigated scenario) at Tharisa Minerals.

Source	Silver City 1	Silver City 2	Silver City 3	School	Lepologang Village	Buffels-poort	Village	Elands-drift	Boundary
Materials handling	1	1	0	1	0	0	0	0	0
Unpaved Roads	9	16	9	19	12	0	1	1	1
Drilling	0	0	0	0	0	0	0	0	0
Blasting	0	0	0	0	0	0	0	0	0
Crushing and Screening	0	0	0	0	0	0	0	0	0
Dryer Plant	0	0	0	0	0	0	0	0	0
Open Pit Sources	7	7	6	3	3	0	0	0	1
Total	17	24	15	23	15	0	1	1	2

5.7.3 Dustfall Impacts

Table 5-31 and Table 5-32 give the incremental daily dustfall rates predicted to occur at the various sensitive receptors due to emissions from the operational phase at Tharisa Minerals. Exceedances of the NDCRs were not predicted to occur at any of the sensitive receptors for any of the scenarios. Again it is evident that unpaved roads and crushing and screening operations are the main contributors to impacts at sensitive receptors.

Table 5-31: Incremental daily dustfall rates at sensitive receptors during the operational phase (partially mitigated scenario) at Tharisa Minerals.

Source	Silver City 1	Silver City 2	Silver City 3	School	Lepologang Village	Buffels-poort	Village	Elands-drift	Boundary
Materials handling	4	2	0	2	0	1	0	0	4
Unpaved Roads	61	52	4	84	5	29	36	59	16
Drilling and Blasting	1	1	0	0	0	0	0	0	4
Crushing and Screening	46	36	2	17	4	19	8	9	19
Dryer Plant	0	0	0	0	0	0	0	0	3
Open Pit Sources	1	1	0	2	0	1	0	0	1
All Sources	113	92	6	105	9	50	44	68	47

Table 5-32: Incremental daily dustfall rates at sensitive receptors during the operational phase (mitigated scenario) at Tharisa Minerals.

Source	Silver City 1	Silver City 2	Silver City 3	School	Lepologang Village	Buffels-poort	Village	Elands-drift	Boundary
Materials handling	1	1	1	1	1	1	0	0	0
Unpaved Roads	6	16	6	24	20	7	2	1	11
Drilling	0	0	0	0	0	0	0	0	0
Blasting	0	0	0	0	0	0	0	0	0
Crushing and Screening	1	1	1	2	1	2	0	0	0
Dryer Plant	0	0	0	0	0	0	0	0	1
Open Pit Sources	0	0	0	0	0	0	0	0	1
All Sources	8	18	8	27	22	10	2	1	13

5.8 Source Impact Rating

Ranking source contributions to predicted ground level concentrations can provide valuable insight regarding sources of atmospheric that need to be focussed and can feed into an air quality management plan. Source impacts are ranked based on each source group’s contribution to the impacts at the various sensitive receptors.

5.8.1 PM$_{10}$

Figures 5-20 and Figure 5-21 show the contribution of each source group to predicted maximum annual average ground level PM$_{10}$ concentrations at the various sensitive receptors as a result of activities during the operational phase of the mine respectively.

From Figure 5-20 it can be seen that during the operational phase concentrations are predicted to be the highest at the school within the mining rights boundary, followed by the Lepologang Village and the Madithlokwa/Silver City. The main contributor to impacts at sensitive receptors during the operational phase is unpaved roads followed by crushing operations.

For the mitigated operational phase scenario it is clear that impacts reduce significantly relative to the partially mitigated scenario. Impacts are still the highest at the school and at sections of the Madithlokwa/Silver City. The annual average NAAQS is predicted to be exceeded at the school, Silver City and Lepologang village even after mitigation measures were applied.

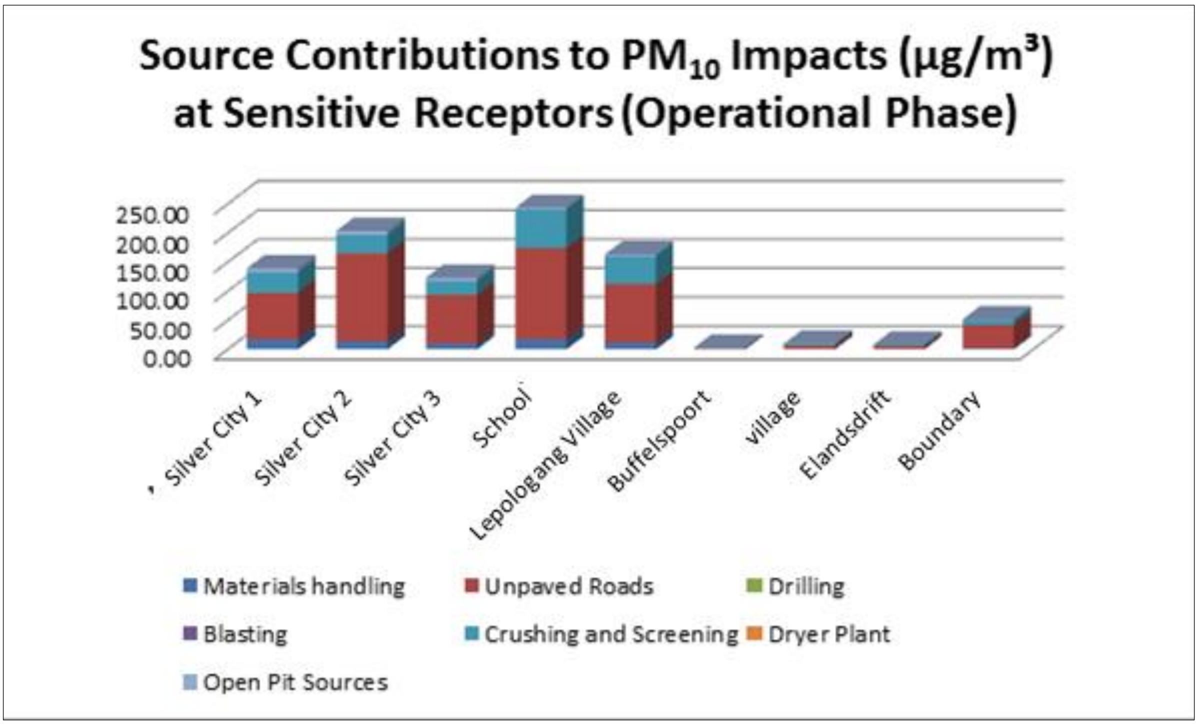

Figure 5-20: Source contributions to PM$_{10}$ impacts at various sensitive receptors during the operational phase (partially mitigated scenario) of the mine.

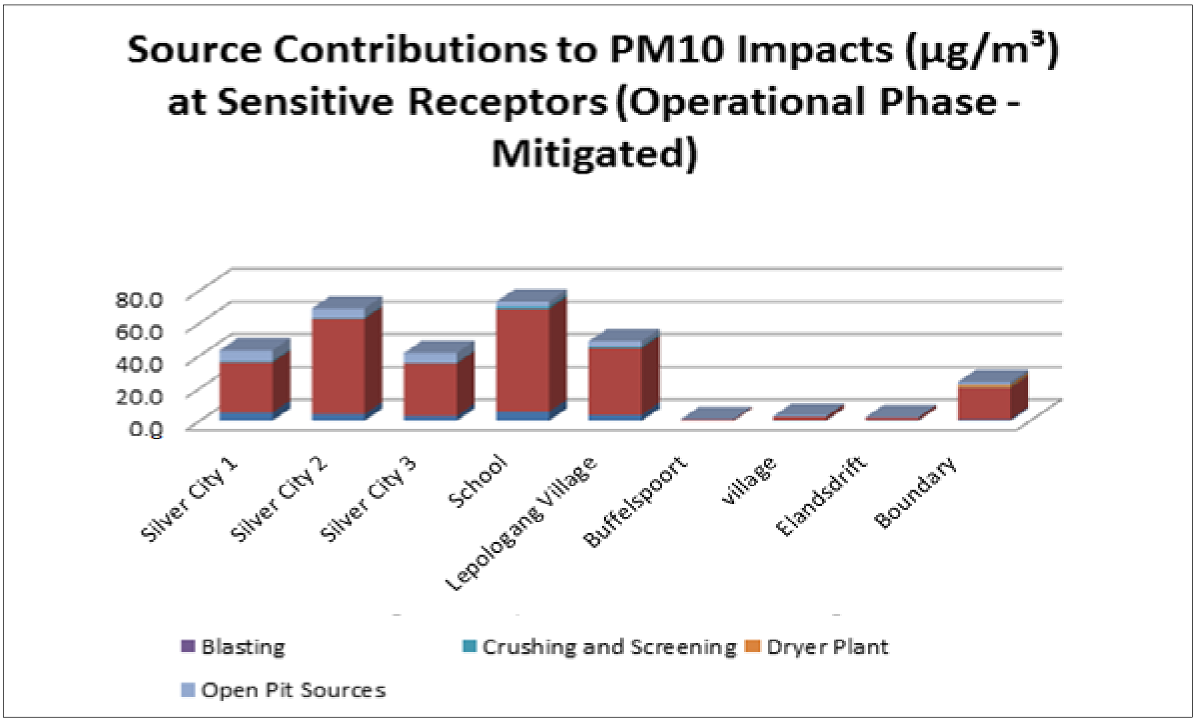

Figure 5-21: Source contributions to PM$_{10}$ impacts at various sensitive receptors during the operational phase (mitigated scenario) of the mine.

5.8.2 $PM_{2.5}$

Figures 5-22 and Figure 5-23 shows the contribution of each source group to predicted maximum annual average ground level $PM_{2.5}$ concentrations at the various sensitive receptors as a result of activities during the construction and operational phases of the mine respectively.

$PM_{2.5}$ impact distributions are similar to that of PM_{10}. Again the main source contributors to emissions are predicted to be unpaved roads and crushing. Exceedances of the annual average NAAQS are predicted at the school and the Madithlokwa/Silver City for the operational phase (and for both the mitigated and unmitigated scenarios for the operational phase).

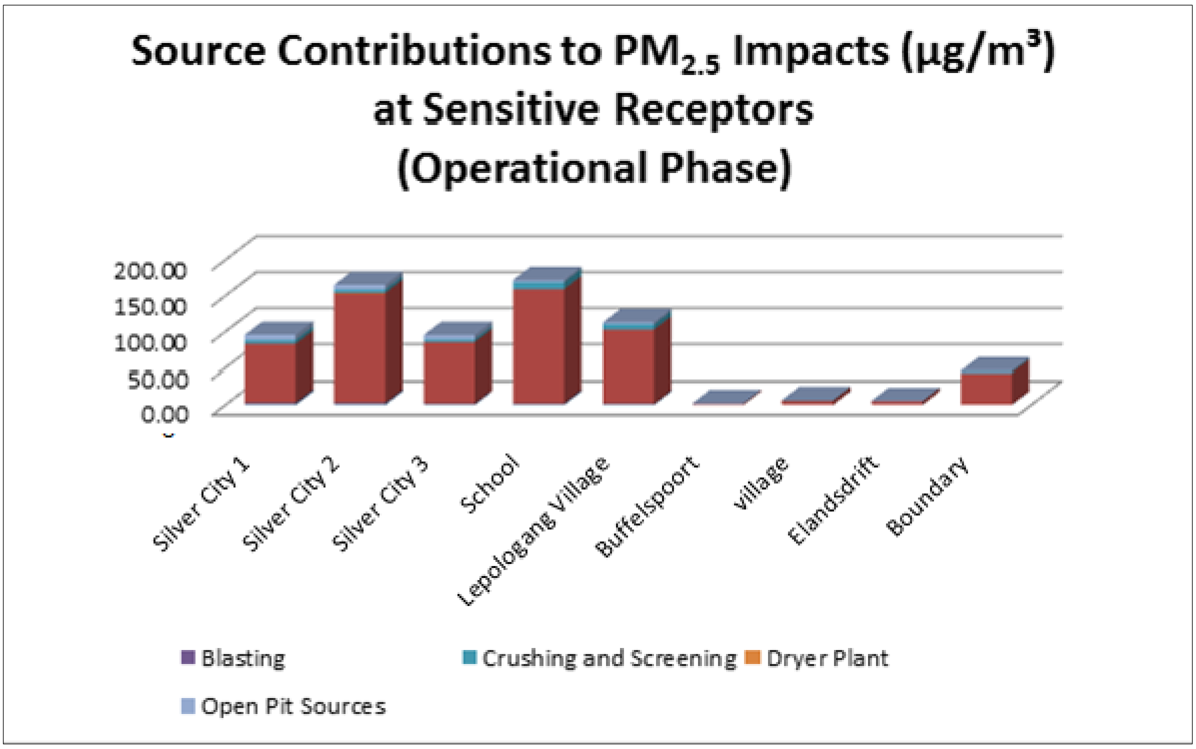

Figure 5-22: Source contributions to $PM_{2.5}$ impacts at various sensitive receptors during the operational phase (partially mitigated scenario) of the mine.

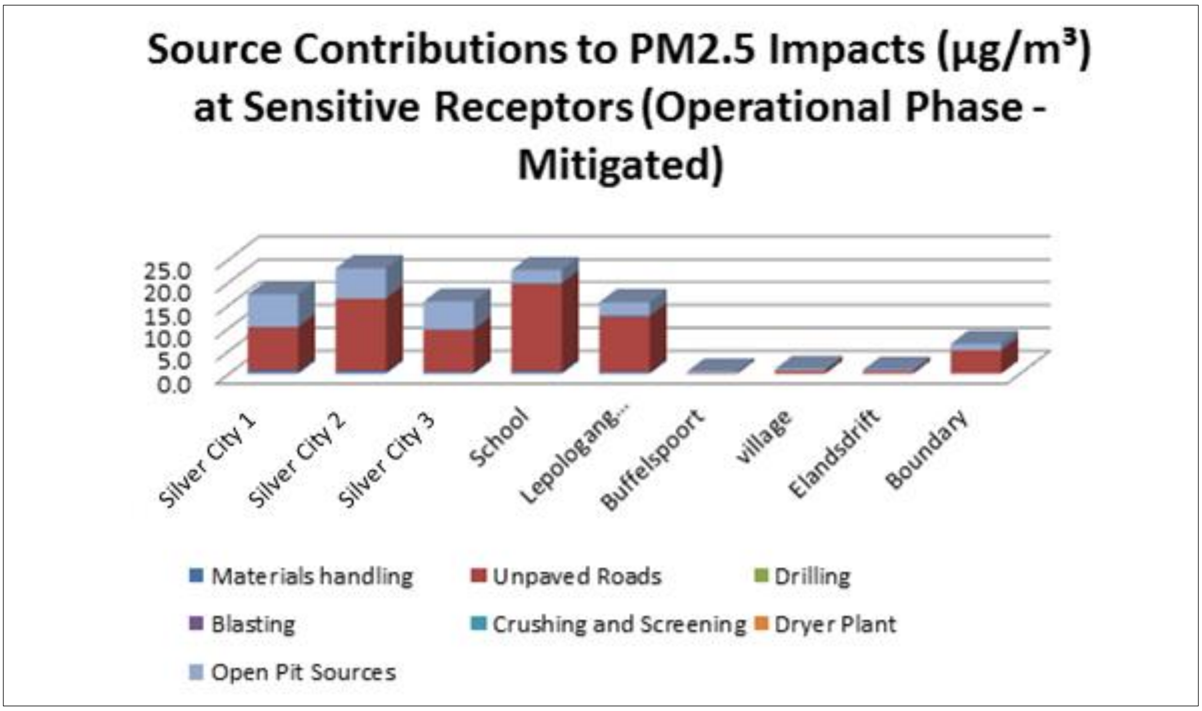

Figure 5-23: Source contributions to $PM_{2.5}$ impacts at various sensitive receptors during the operational phase (mitigated scenario) of the mine.

5.8.3 Dustfall

Figures 5-24 to Figure 5-25 shows the contribution of each source group to predicted daily dustfall rates at the various sensitive receptors as a result of activities during the operational phase of the mine respectively. Dustfall rates are predicted to be quite low all sensitive receptors and fall below the NDCR residential limit.

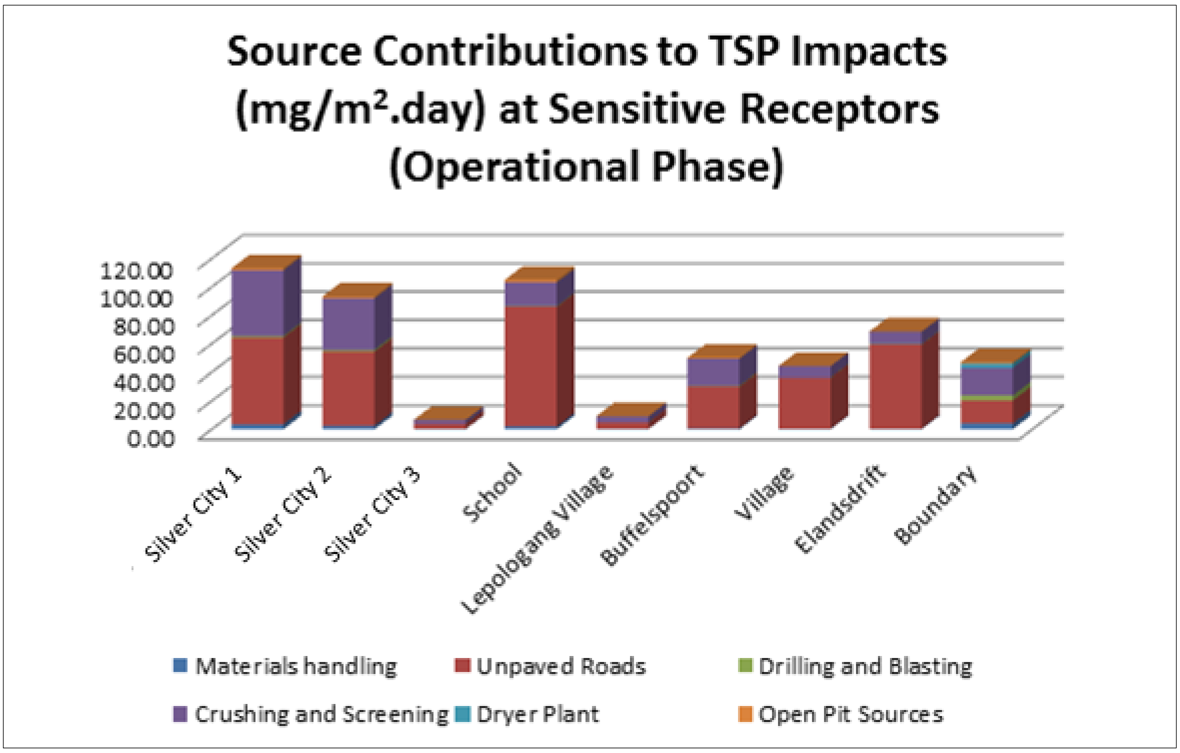

Figure 5-24: Source contributions to daily dustfall impacts at various sensitive receptors during the operational phase (partially mitigated scenario) of the mine.

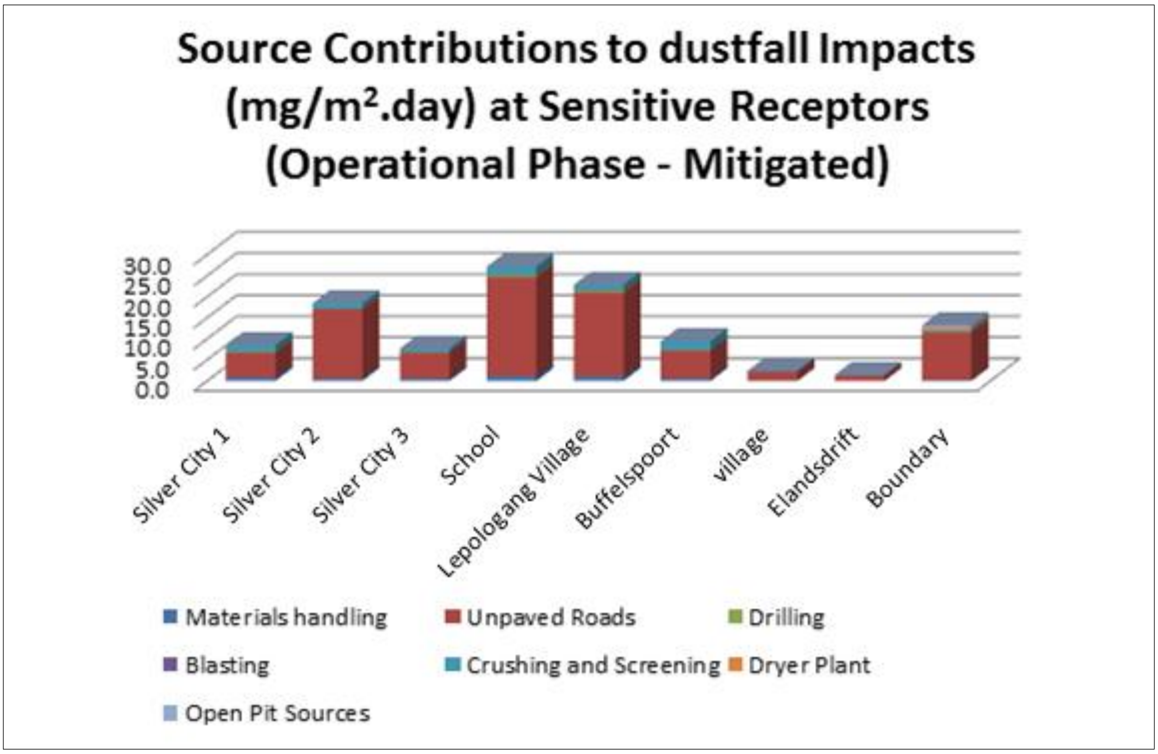

Figure 5-25: Source contributions to daily dustfall impacts at various sensitive receptors during the operational phase (mitigated scenario) of the mine.

6 CONCLUSIONS

An air quality impact assessment has been undertaken for the changes to the Tharisa Minerals open pit mine and concentrator plant in the North West Province. Nuisance dust, PM_{10} and $PM_{2.5}$ health impacts for the operation were assessed in order to identify all possible detrimental impacts on the surrounding environment and sensitive receptors.

The main findings of the study are as follows:

Emissions Inventory:

- Total PM_{10}, $PM_{2.5}$ and TSP emissions were calculated to be 1083, 657 and 5731 tpa respectively during the operational phase (partially mitigated scenario) of the mine. Vehicle entrainment from unpaved haul roads (excluding in pit roads) was estimated to be the most significant contributor to the total unmitigated PM_{10} and $PM_{2.5}$ emissions contributing approximately 49% and 80% respectively. Crushing operations contributed the most to TSP emissions (56%).

- Total PM_{10}, $PM_{2.5}$ and TSP emissions were calculated to be 234, 66 and 678 tpa respectively during the operational phase (mitigated scenario) of the mine. Open pit sources, unpaved roads and basting were the most significant sources of emissions during this phase with blasting contributing the most to PM_{10} emissions (43%), open pit sources contributing the most to $PM_{2.5}$ emissions (74%) and unpaved roads contributing the most to TSP emissions (29%).

Impact Assessment:

- **Particulate (PM_{10} and $PM_{2.5}$) Impacts**
    - Exceedances of the 2015 South African annual average and highest daily average PM_{10} standards were predicted to occur at the mining rights area boundary for both operational phase (partially mitigated) scenarios. With additional mitigation applied, these exceedances reduced to be mostly contained within the mining rights boundary – exceedances at on-site receptors Silver City, the school and Lepologang Village.
    - Exceedances of the current South African annual average and highest daily average $PM_{2.5}$ standards were predicted to occur outside the mining rights boundary for the operational (partially mitigated) phase. The mitigated scenario of the operational phase was predicted to exceed the annual $PM_{2.5}$ standard only slightly outside the mining rights boundary, with marginal exceedances only at Silver City and the school.
    - Vehicle entrainment from unpaved haul roads (excluding in-pit haul roads) is expected to be the main contributor to predicted PM_{10} and $PM_{2.5}$ exceedances at the mining rights boundary and sensitive receptors for both phases.

It should be noted that the predicted impacts only reflect the contribution from the Tharisa Mineral Mine on the surrounding environment and human health. No background concentrations were included in the predictions due to the lack of information. The monitored data reported on in Section 4.2 already indicate very high ambient background concentrations ranging between 38 µg/m³ and

53 µg/m³ for annual averages, exceeding the 2015 SA standard of 40 µg/m² on average. Thus the ambient concentrations at Tharisa Mineral Mine are likely to exceed the 2015 SA standards once operations are in place.

- **Dustfall Impacts**
  - Exceedances of the NDCR residential and non-residential limits were predicted to be exceeded within the mining rights boundary.
  - Exceedances of the NDCR residential and non-residential limits were not predicted to exceed at any of the sensitive receptors.
  - The main source group contributor to daily dustfall rates was predicted to be crushing operations.
- **Gaseous Impacts**
  - CO, NOx, SO_2 and VOC impacts due to the chrome sand dryer plant is expected to be low.
  - None of the NAAQ gaseous standards were predicted to be exceeded anywhere within or outside of the mining rights boundary or at any of the sensitive receptors.

7 PROPOSED AIR QUALITY MANAGEMENT MEASURES

The main objective of Air Quality Management measures for the changes to the Tharisa Minerals mine and concentrator plant is to ensure that all operations at the mine and concentrator plant will be within compliance with South African air quality requirements. In order to define site specific management objectives, the main sources of pollution needed to be identified. Sources can be ranked based on sources strengths (emissions) and impacts. Once the main sources have been identified, target control efficiencies for each source can be defined to ensure acceptable cumulative ground level concentrations. The main pollutants of concern identified during the impact assessment were particulates (PM_{10} and $PM_{2.5}$).

7.1 Target Control Efficiencies

Since the impact assessment and significance ranking proved to be unacceptably high, even with minimum mitigation measures in place, the following target control efficiencies for all routine sources of emissions were determined (as modelled for the mitigated operational phase scenario in this report).

- Vehicle entrainment from the unpaved haul roads – 90% control efficiency through effective water sprays combined with chemicals.
- Crushing and Screening – 98% reduction through enclosure of primary and secondary crushing and screening operations with effective dust extraction and associated bag filters.
- Drilling – 70% reduction through effective water sprays.
- Materials handling (unloading of trucks) – 70% reduction through effective water sprays.
- Materials handling (conveyor transfer/ stockpiling points) – 70% for enclosure.

Project specific management methods that can be used to obtain the control efficiencies as discussed above are discussed in Appendix A.

7.2 Monitoring Requirements

Currently there is not a weather station on-site at Tharisa Minerals. Modelled data had to be used in this study. However measured data will increase the accuracy of results and it is therefore recommended that Tharisa Minerals have an on-site meteorological station installed.

A dust fallout network has been installed at Tharisa Minerals in the past; however as particulate matter impacts were predicted to be the most pronounced during this study, it is recommended that PM_{10} monitoring be done. Available ambient monitoring data also indicate that the background concentrations in the region are already elevated. It is therefore pertinent to understand what the ambient concentrations at the Tharisa Minerals operations are.

A PM_{10} monitoring network can serve to meet various objectives, such as:

- Compliance monitoring;
- Validate dispersion model results;
- Use as input for health risk assessment;

- Assist in source apportionment;
- Temporal trend analysis;
- Spatial trend analysis;
- Source quantification; and
- Tracking progress made by control measures.

Based on the fact that particulate limits are exceeded at many sensitive receptors inside and outside the mine boundary, it is important that PM_{10} monitoring be done at these sites. It is recommended that a PM_{10} ambient monitor be place at the on-site school and at the on-site mining villages. It is essential that the PM_{10} monitoring station also record basic hourly average meteorological parameters namely wind speed, wind direction, temperature and rainfall. It is however recommended that relative humidity, pressure and solar radiation also be measured.

If measured PM_{10} results confirm the high PM_{10} and $PM_{2.5}$ concentrations predicted by the modelling during this study, then sensitive receptors within the mining rights boundary (Madithlokwa/Siler City and the school) will have to be relocated outside of the mine where exceedances of the NAAQS does not occur, as exposures to air in exceedance of the NAAQS will be detrimental to the health of all people exposed.

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9 APPENDIX A: PROJECT SPECIFIC MANAGEMENT MEASURES

Since the impact assessment and significance ranking proved to be unacceptably high, even with minimum mitigation measures in place, it is of utmost importance that mitigation steps be taken. Mitigation is necessary for those sources contributing most to ait quality impacts, such as unpaved roads, crushing, screening and materials handling operations and open pit operations.

9.1 Vehicle Entrainment on Unpaved Haul Roads

Vehicle entrained dust from unpaved road surfaces resulted in high impacts near the source and off-site predictions. It is therefore recommended that mitigation measures be considered on all unpaved haul roads.

Three types of measures may be taken to reduce emissions from unpaved roads namely:

- Measures aimed at reducing the extent of unpaved roads, e.g. paving,
- Traffic control measures aimed at reducing the entrainment of material by restricting traffic volumes and reducing vehicle speeds, and
- Measures aimed at binding the surface material or enhancing moisture retention, such as wet suppression and chemical stabilisation (EPA, 1987; Cowhert et al., 1988; APCD, 1995).

It is standard practice at most mines to utilise water trucks on the unpaved roads. It is recommended that water be used in combination with chemical surfactants to reduce the amount of water required to achieve certain control efficiencies. An empirical model, developed by the US-EPA (EPA, 1996), was used to estimate the average control efficiency of certain quantifies of water applied to a road. The model takes into account rainfall, evaporation rates and traffic. It was estimated that water and chemical sprays resulting in at least 90% control efficiency would be a requirement to result in a significant reduction in ground level concentrations from all on-site haul roads. This was based on the monthly average evaporation data for the North West Province (Shulze, 1997) and long term monthly rainfall data for Rustenburg.

The rate of watering required to ensure various control efficiencies, given site-specific evaporation, rainfall and traffic rates, calculated on the basis of this model are illustrated in Figure 9.1. As an example the watering rates required for 20 trucks per hour was included (return trips included).

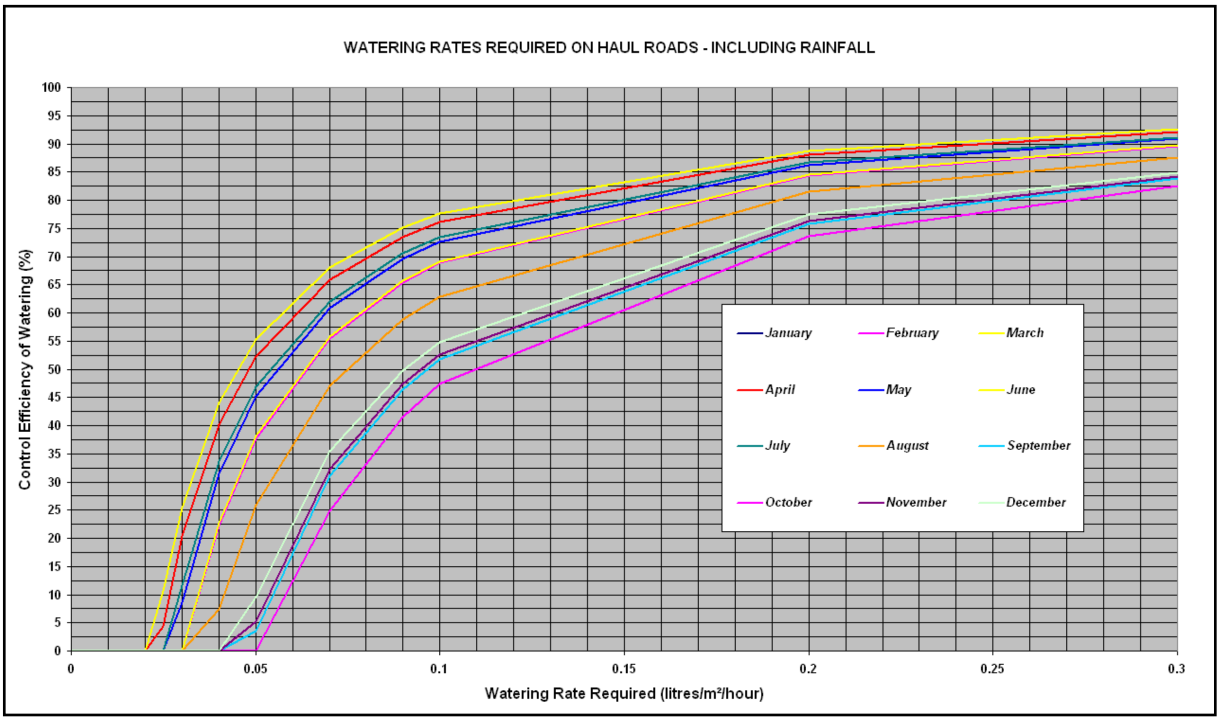

Figure 9-1: Calculated watering rates

The application of chemic dust palliatives often have economic benefits compared to watering in some environments and climates. Dust palliative classes include (Jones, 1996), (Australian Roads Research Board - ARRB., 1996), (Thompson & Visser, 2007):

- Water groundwater containing dissolved salts or watering agents.
- Hygroscopic salts
- Lignosulphonates
- Petrolium (or sulponated pertoleum) resins
- Polymer emulsions
- Tar – and butimen – emulsion products.

Of the above mentioned palliative classes each have climatic, wearing course and traffic limitations and therefore careful investigation should be done before deciding which class to use in a certain mining environment.

Table 9-1 gives a summary of the main climatic and wearing course limitations associated with each of these classes, as well as treatment maintenance and self-repair capability, tendency to leach out or accumulate and general comments (UMA Engineering Ltd., 1987), (Thompson & Visser, 2007).

Table 9-1: A summary of the main climatic, wearing course and traffic limitations associated with each of the main palliative classes.

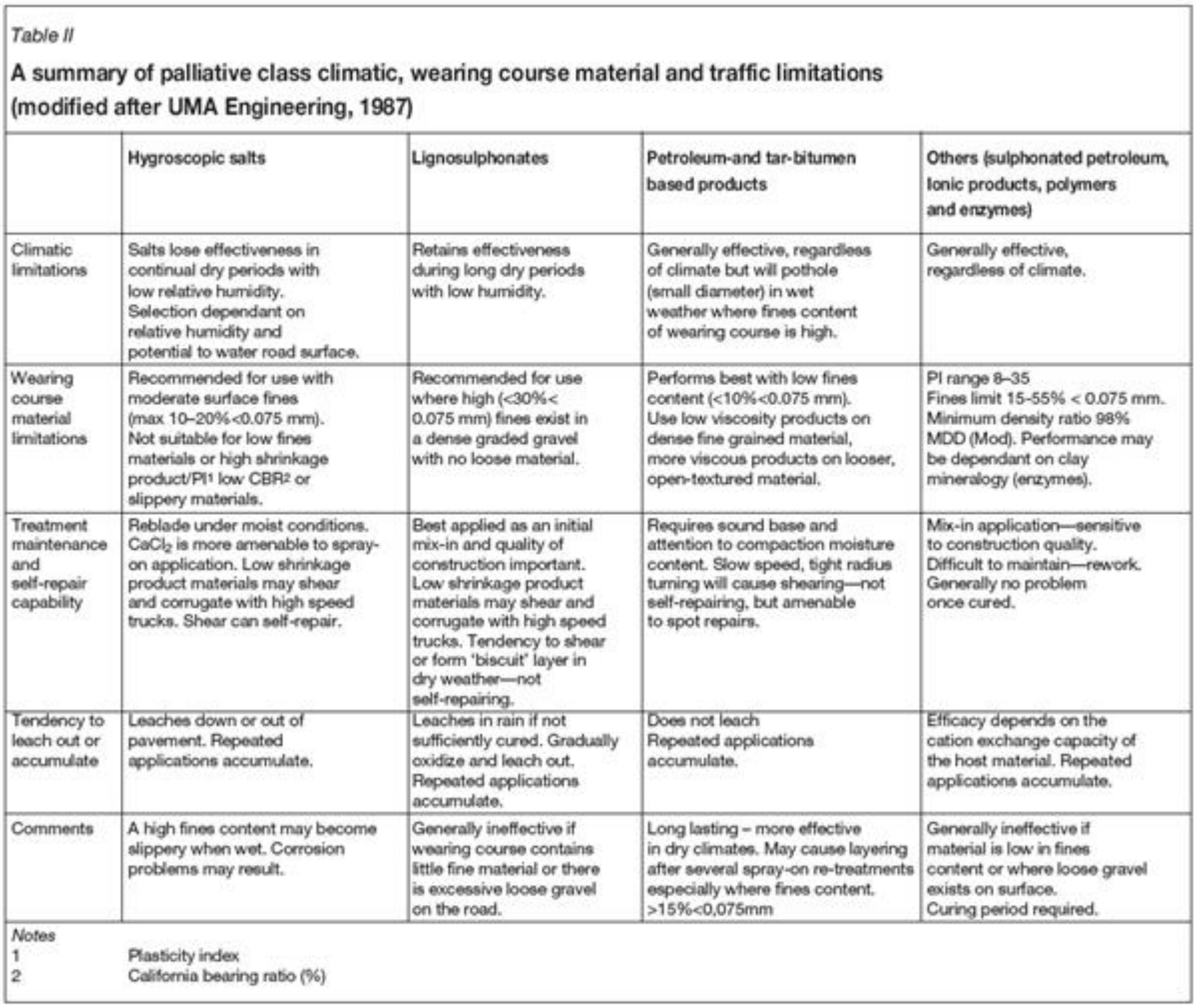

Table II

A summary of palliative class climatic, wearing course material and traffic limitations (modified after UMA Engineering, 1987)

	Hygroscopic salts	**Lignosulphonates**	**Petroleum-and tar-bitumen based products**	**Others (sulphonated petroleum, Ionic products, polymers and enzymes)**
Climatic limitations	Salts lose effectiveness in continual dry periods with low relative humidity. Selection dependant on relative humidity and potential to water road surface.	Retains effectiveness during long dry periods with low humidity.	Generally effective, regardless of climate but will pothole (small diameter) in wet weather where fines content of wearing course is high.	Generally effective, regardless of climate.
Wearing course material limitations	Recommended for use with moderate surface fines (max 10–20%<0.075 mm). Not suitable for low fines materials or high shrinkage product/PI[1] low CBR[2] or slippery materials.	Recommended for use where high (<30%< 0.075 mm) fines exist in a dense graded gravel with no loose material.	Performs best with low fines content (<10%<0.075 mm). Use low viscosity products on dense fine grained material, more viscous products on looser, open-textured material.	PI range 8–35 Fines limit 15-55% < 0.075 mm. Minimum density ratio 98% MDD (Mod). Performance may be dependant on clay mineralogy (enzymes).
Treatment maintenance and self-repair capability	Reblade under moist conditions. $CaCl_2$ is more amenable to spray-on application. Low shrinkage product materials may shear and corrugate with high speed trucks. Shear can self-repair.	Best applied as an initial mix-in and quality of construction important. Low shrinkage product materials may shear and corrugate with high speed trucks. Tendency to shear or form 'biscuit' layer in dry weather—not self-repairing.	Requires sound base and attention to compaction moisture content. Slow speed, tight radius turning will cause shearing—not self-repairing, but amenable to spot repairs.	Mix-in application—sensitive to construction quality. Difficult to maintain—rework. Generally no problem once cured.
Tendency to leach out or accumulate	Leaches down or out of pavement. Repeated applications accumulate.	Leaches in rain if not sufficiently cured. Gradually oxidize and leach out. Repeated applications accumulate.	Does not leach Repeated applications accumulate.	Efficacy depends on the cation exchange capacity of the host material. Repeated applications accumulate.
Comments	A high fines content may become slippery when wet. Corrosion problems may result.	Generally ineffective if wearing course contains little fine material or there is excessive loose gravel on the road.	Long lasting – more effective in dry climates. May cause layering after several spray-on re-treatments especially where fines content. >15%<0,075mm	Generally ineffective if material is low in fines content or where loose gravel exists on surface. Curing period required.

Notes

1 Plasticity index

2 California bearing ratio (%)

It has been found that poor wearing course material cannot be improved to deliver and adequate performance only through the addition of a dust palliative. The inherent functional deficiencies of the material will outweigh any of the financial benefit gained from dust palliatives (Thompson & Visser, 2007).

However, when a wearing course material is close to specification, the use of dust palliatives has the potential to deliver cost savings compared to water-based spraying (although not necessarily initially), but more certainly in the longer term.

9.2 Crushing, Screening and Materials Handling Operations

Materials handling operations including primary crushing and screening of ore and materials transfer to and from haul trucks were identified as potentially significant sources of emissions at the proposed mine.

Enclosure of crushing operations is very effective in reducing dust. The Australian NPI indicates that a telescopic chute with water sprays would ensure 75% control efficiency and enclosure of storage piles where tipping occur would reduce the emissions by 99%. In addition, chemical suppressants or water sprays on the primary crusher and dry dust extraction units with wet scrubbers on the secondary and tertiary crushers and screens will assist in the reduction of the cumulative dust impacts. According to the Australian NPi, water sprays can have up to 50% control efficiency and hoods with scrubbers up to 75%. If in addition, the scrubbers and screens were to be enclosed; up to 100% control efficiency can be achieved. With these control measures in place, the impacts would reduce to negligible levels. It is important that these control equipment be maintained and inspected on a regular basis to ensure that the expected control efficiencies are met.

The control efficiency of pure water suppression can be estimated based on the US-EPA emission factor which relates material moisture content to control efficiency. This relationship is illustrated in Figure 7-3. From the relationship between moisture content and dust control efficiency it is apparent that by doubling the moisture content of the material an emission reduction of 62% could be achieved. Chemicals mixed into the water will not just save on water consumption but also improve the control efficiency of the application even further.

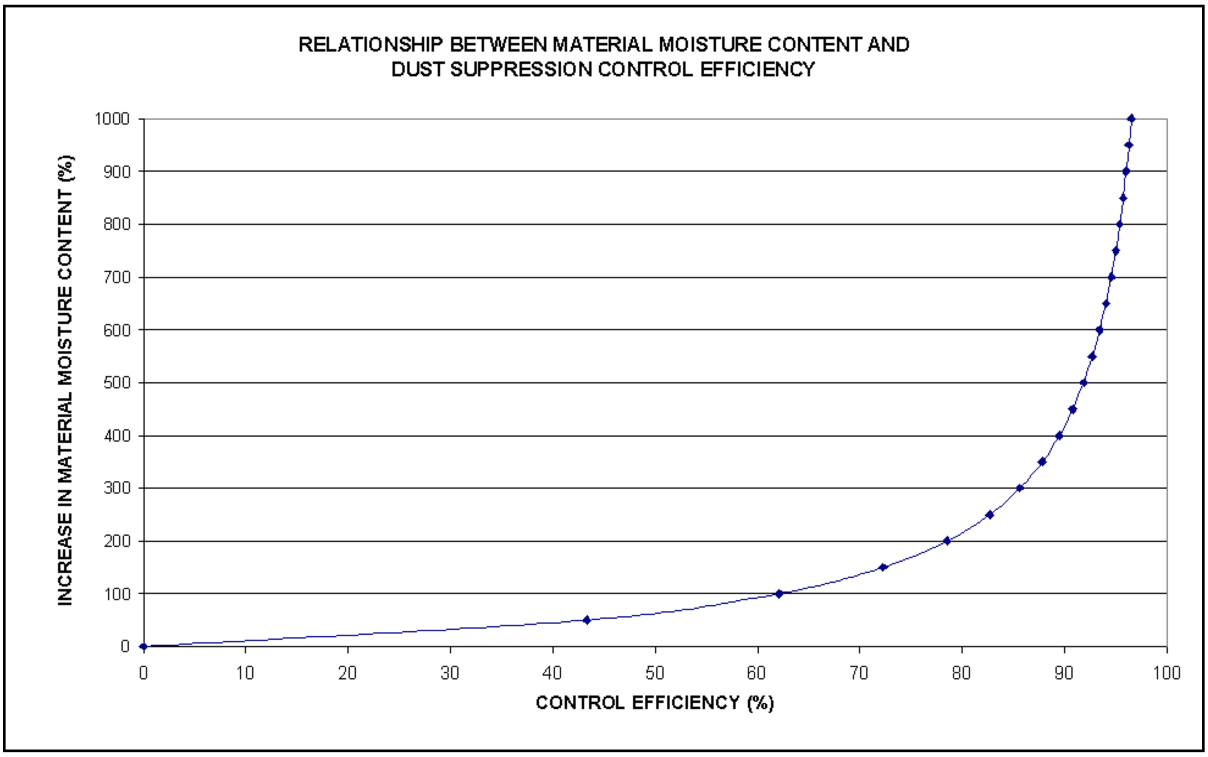

Figure 9-2: Relationship between the moisture content and dust control efficiency

Control efficiencies from the application of liquid spray systems at conveyor transfer points have *in practice* been reported to be in the range of 42% to 75%. General engineering guidelines which have been shown to be effective in improving the control efficiency of liquid spray systems are as follows:

- Of the various nozzle types, the use of hollow cone nozzles tend to afford the greatest control for bulk materials handling applications whilst minimising clogging;

- Optimal droplet size for surface impaction and fine particle agglomeration is about 500µm; finer droplets are affected by drift and surface tension and appear to be less effective; and,

- Application of water sprays to the underside of conveyor belts has been noted by various studies to improve the efficiency of water suppression systems and belt-to-belt transfer points.

9.3 Open pit operations

All materials handling operations within the open pit will reduce dust generation by 62% by merely doubling the moisture content of the material handled. An 85% reduction in dust emissions from unpaved in-pit haul roads can be achieved through effective water sprays combined with chemicals. The Australian NPI in their Emission Estimation Technique Manual for Mining states that a 70% reduction in dust emissions from drilling can be achieved through effective water sprays.

In addition, the Australian NPI stipulates a 50% reduction of TSP emissions due to pit retention, and 5% for PM10 emissions. This is based on the increase in volume (the deeper the pit becomes) and thus resulting in better dispersion potential for specifically PM_{10} emissions before reaching the surface. Similarly for TSP, the potential for deposition on the surface becomes smaller for more dust would settle within the pit.

10 APPENDIX B: PARTICULATE MATTER BACKGROUND INFORMATION

10.1 Impacts on Health

The impact of particles on human health is largely depended on (i) particle characteristics, particularly particle size and chemical composition, and (ii) the duration, frequency and magnitude of exposure. The potential of particles to be inhaled and deposited in the lung is a function of the aerodynamic characteristics of particles in flow streams. The aerodynamic properties of particles are related to their size, shape and density. Deposition of particles in different regions of the respiratory system depends on their size.

The nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne particulates. Larger particles are deposited in the nasal region by impaction on the hairs of the nose or at the bends of the nasal passages. Smaller particles (PM_{10}) pass through the nasal region and are deposited in the tracheobronchial and pulmonary regions. Particles are removed by impacting with the wall of the bronchi when they are unable to follow the gaseous streamline flow through subsequent bifurcations of the bronchial tree. As the airflow decreases near the terminal bronchi, the smallest particles are removed by Brownian motion, which pushes them to the alveolar membrane (CEPA/FPAC Working Group, 1998; Dockery and Pope, 1994).

Air quality standards for particulates are given for various particle size fractions, including total suspended particulates (TSP), inhalable particulates or PM_{10} (i.e. particulates with an aerodynamic diameter of less than 10 µm), and respirable particulates of $PM_{2.5}$ (i.e. particulates with an aerodynamic diameter of less than 2.5 µm). Although TSP is defined as all particulates with an aerodynamic diameter of less than 100 µm, and effective upper limit of 30 µm aerodynamic diameter is frequently assigned. PM_{10} and $PM_{2.5}$ are of concern due to their health impact potentials. As indicated, such fine particles are able to be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung.

Thoracic particulates or PM_{10} (i.e. particulate matter with an aerodynamic diameter of <10 µm) therefore needs to be considered for health risk purposes. PM_{10} represents particles of a size that would be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung. PM_{10} is primarily associated with mechanical processes such as mining operations, whereas $PM_{2.5}$ is associated with combustion sources.

During the 1990s the World Health Organisation (WHO) stated that no safe thresholds could be determined for particulate exposures and responded by publishing linear dose-response relationships for PM_{10} and $PM_{2.5}$ concentrations (WHO, 2005). This approach was not well accepted by air quality managers and policy makers. As a result the WHO Working Group of Air Quality Guidelines recommended that the updated WHO air quality guideline document contain guidelines that define concentrations which, if achieved, would be expected to result in significantly reduced rates of adverse health effects. These guidelines would provide air quality managers and policy makers with an explicit objective when they were tasked with setting national air quality standards. Given that air pollution levels in developing countries frequently far exceed the recommended WHO air quality guidelines (AQGs), the Working Group also proposed interim targets (IT) levels, in excess of the WHO AQGs themselves, to promote steady progress towards meeting the WHO AQGs (WHO, 2005).

10.2 Dust Effects on Vegetation

Suspended particulate matter can produce a wide variety of effects on the physiology of vegetation that in many cases depend on the chemical composition of the particle. Heavy metals and other toxic particles have been shown to cause damage and death of some species as a result of both the phytotoxicity and the abrasive action during turbulent deposition (Harmens et al, 2005). Heavy loads of particle can also result in reduced light transmission to the chloroplasts and the occlusion of stomata (Harmens et al, 2005; Naidoo and Chirkoot, 2004, Hirano et al, 1995, Ricks and Williams, 1974), decreasing the efficiency of gaseous exchange (Harmens et al, 2005; Naidoo and Chirkoot, 2004, Ernst, 1981) and hence water loss (Harmens et al, 2005). They may also disrupt other physiological processes such as budbreak, pollination and light absorption/reflectance (Harmens et al, 2005). The chemical composition of the dust particles can also affect the plant and have indirect effects on the soil pH (Spencer, 2001).

To determine the impact of dust deposition on vegetation, two factors are of importance: (i) Does dust collect on vegetation and if it does, what are the factors influencing the rate of deposition (ii) Once the dust has deposited, what is the impact of the dust on the vegetation?

Regarding the first question, there is adequate evidence that dust does collect on all types of vegetation. Any type of vegetation causes a change in the local wind fields, with an increase in turbulence which enhances the collection efficiency. The characteristics of the vegetation influences the rate; the larger the "collecting elements" (branches and leaves), the lower the impaction efficiency per element. This would seem to indicate that, for the same volume of tree/shrub canopy, finer leaves will have a better collection efficiency. However, the roughness of the leaves themselves and particularly the presence of hairs on the leaves and stems play a significant role, with veinous surfaces increasing deposition of 1-5 micron particles by up to seven times compared to smooth surfaces. Collection efficiency rises rapidly with particle size; for moderate wind speeds wind tunnel studies show a relationship of deposition velocity on the fourth power of particle size (Tiwary and Colls 2010). In wind tunnel studies, windbreaks or "shelter belts" of three rows of trees has shown a decrease in 35 to 56% in the downwind mass transport of inorganic particles.

On the effect of particulate matter once it is deposited on vegetation, this depends on the composition of the dust. South African ambient standards are set in terms of PM_{10} (particulate matter smaller than 10 µm aerodynamic diameter) but internationally it is recognised that there are major differences in the chemical composition of the fine PM (the fraction between 0 and 2.5 µm in aerodynamic diameter) and coarse PM (the fraction between 2.5 µm and 10 µm in aerodynamic diameter). The former is often the result of chemical reactions in the atmosphere and may have a high proportion of black carbon, sulphate and nitrate; whereas the latter often consist of primary particles resulting from abrasion, crushing, soil disturbances and wind erosion (Grantz et al. 2003). Sulphate is however often hygroscopic and may exist in significant fractions in coarse PM. This has been shown to be the case in South Africa, where the sulphate content of PM_{10} at the Eskom measuring station at Elandsfontein has been shown to have between 15% (winter) and 49% (spring) sulphate (Alade 2009). Grantz et al (op .cit.) do however indicate that sulphate is much less phototoxic than gaseous sulphur dioxide and that" it is unusual for injurious levels of particular sulphate to be deposited upon vegetation".

Naidoo and Chirkoot conducted a study during the period October 2001 to April 2002 to investigate the effects of coal dust on Mangroves in the Richards Bay harbour. The investigation was conducted at two sites where 10 trees of the Mangrove species: Avicennia Marina were selected and mature, fully expose, sun leaves tagged as being covered or uncovered with coal dust. From the study it was concluded that coal dust significantly reduced photosynthesis of upper and lower leaf surfaces. The reduced photosynthetic performance was expected to reduce growth and productivity. In addition, trees in close proximity to the coal stockpiles were in poorer health than those further away. Coal dust particles, which are composed predominantly of carbon, were found not to be toxic to the leaves; neither was it found that it occlude stomata as these particles were larger than fully open stomatal apertures (Naidoo and Chirkoot, 2004).

In general, according to the Canadian Environmental Protection Agency (CEPA), air pollution adversely affects plants in one of two ways. Either the quantity of output or yield is reduced or the quality of the product is lowered. The former (invisible) injury results from pollutant impacts on plant physiological or biochemical processes and can lead to significant loss of growth or yield in nutritional quality (e.g. protein content). The latter (visible) may take the form of discolouration of the leaf surface caused by internal cellular damage. Such injury can reduce the market value of agricultural crops for which visual appearance is important (e.g. lettuce and spinach). Visible injury tends to be associated with acute exposures at high pollutant concentrations whilst invisible injury is generally a consequence of chronic exposures to moderately elevated pollutant concentrations. However given the limited information available, specifically the lack of quantitative dose-effect information, it is not possible to define a Reference Level for vegetation and particulate matter (CEPA, 1998).

Exposure to a given concentration of airborne PM may therefore lead to widely differing phytotoxic responses, depending on the mix of the deposited particles. The majority of documented toxic effects indicate responses to the chemical composition of the particles. Direct effects have most often been observed around heavily industrialised point sources, but even there, effects are often associated with the chemistry of the particulate rather than with the mass of particulate.

10.3 Dust Effects on Animals

Most of the literature regarding air quality impacts and animals, specifically cattle, refers to the impacts from feedlots on the surrounding environment, hence where the feedlot is seen as the source of pollution. This mainly pertains to odours and dust generation. The US.EPA has recently started to focus on the control of air pollution from feed yards and dairies, primarily regulating coarse particulate matter (http://www.vetcite.org/publish/items/000944/index.html). The National Cattle Beef Association in the USA in response has disputed this decision based on the lack of evidence on health impacts associated with coarse dust (TSP) concentrations (http://hill.beef.org/newview.asp?DocumantID=16319).

A study was conducted by the State University of IOWA on the effects of air contaminants and emissions on animal health in swine facilities. Air pollutants included gases, particulates, bio aerosols, and toxic microbial by-products. The main findings were that ammonia is associated with lowered average number of pigs weaned, arthritis, porcine stress syndrome, muscle lesions, abscesses, and liver ascarid scars. Particulates are associated with the reduction in growth and turbine pathology, and bio aerosols could lower feed efficiency, decrease growth, and increase morbidity and mortality. Ammonia and hydrogen sulphide are regarded the two most important inorganic gases affecting the respiratory system of cattle raised in confinement facilities, affecting the mucociliary transport and alveolar macrophage functions. With regard to particulates, it was found that it is the fine inhalable fraction is mainly deriving from dried faecal dust (Holland et al., 2002).

Another study conducted by DSM Nutritional Products North America indicated that calves exposed to a dust-stress environment continued to have lower serum vitamin E concentrations

(http://www.dsm.com/en_US/html/dnpus/an_texas_study.htm).

Inhalation of confinement house dust and gases produces a complex set of respiratory responses. An individual's response depends on characteristics of the inhaled components (such as composition, particle size and antigenicity) and of the individual's susceptibility, which is tempered by extant respiratory conditions (http://www.cdc.gov/nasd/docs). Most of the studies concurred that the main implication of dusty environments are causing animal stress which is detrimental to their health. However, no threshold levels exist to indicate at what levels these are having a negative effect. In this light it was decided to use the same screening criteria applied to human health, i.e. the South African Standards and SANS limit values (Section 2).