Project done on behalf of

WSP, Environment & Energy, Africa

AIR QUALITY IMPACT ASSESSMENT FOR THE PROPOSED RIETVLEI MINE, MPUMALANGA

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Executive Summary

Airshed Planning Professionals (Pty) Ltd was appointed by WSP, Environment & Energy, Africa (WSP) to undertake an update of the air quality impact assessment for the proposed Rietvlei Mine near the town of Middelburg, Mpumalanga Province. The mine is located approximately 20km north-east of Middelburg in the Steve Tshwete local municipality which is part of the Nkangala District Municipality (NDM).

The proposed Rietvlei Mine is located near and on farms. Sensitive receptors close to the mine include various scattered settlements and farmhouses on Bankfontein, Driefontein, Shirley and Sonneblom farms.

Project Scope

The scope of the study includes a baseline characterisation and an impact assessment.

The baseline characterisation included an assessment of meteorological data to determine the dispersion potential of the site and an investigation of the ambient data available for the region. The information contained in the Highveld Priority Area (HPA) baseline study served as an assessment of existing ambient data for the region. Some additional information on background concentration of particulate matter in the Southern African region was provided by the SAFARI 2000 project.

There is no on-site weather station and meteorological data for a weather station located in the vicinity of the proposed site were obtained from the South African Weather Services. The measured meteorological data was for just under 3 years (January 2007 to August 2009). This was used as input to the dispersion model.

Particulates represent the main pollutant of concern when assessing open cast mining operations. Particulates are divided into different particle size categories with Total Suspended Particulates (TSP) associated with nuisance impacts and the finer fractions of PM_{10} (particulates with a diameter less than 10 µm) and $PM_{2.5}$ (diameter less than 2.5 µm) linked with potential health impacts. PM_{10} is primarily associated with mechanically generated dust whereas $PM_{2.5}$ is associated with combustion sources. Gaseous pollutants (such as sulphur dioxide, oxides of nitrogen, carbon monoxide, etc.) are derived from vehicle exhausts but regarded as negligible in comparison to particulate emissions and are therefore omitted from the assessment.

The impact assessment includes the qualitative assessment of construction activities, closure and post closure phases as well as the quantitative assessment of the operational phase.

Construction operations will include a series of different activities such as land clearing, topsoil removal, road grading, material loading and hauling, stockpiling, etc., each with its own duration and potential for dust generation. Due to the lack of a detailed construction activity plan, an area wide emission factor was applied to estimate the total TSP emissions that will derive for construction period.

The operational phase includes the identification and quantification of all dust generating sources at the proposed mine. A comprehensive emissions inventory was compiled based on the mine layout plan and mining rates as supplied. A total of 100 kilo tons per annum of ore and four times the amount of overhaul material will be mined per year. The operations will be for 24 hours per day, seven days per week. In the quantification of fugitive dust emissions, emission factors were used linking the quantity of a pollutant to the activity associated with the release of that pollutant. 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 and the Australian National Pollution Inventory (NPI) documents. The scenarios assessed include unmitigated; assuming no dust control measures to be in place and mitigated. The latter assumes water sprays will be applied to the unpaved roads resulting in 75% control efficiency and mitigation measured which would result in 50% control efficiency for wind erosion sources.

Dispersion modelling is used to simulate the potential for impacts on the surrounding environment and human health. Dispersion models don't contain all the features of a real system but hold the feature of interest for management issues or scientific problems to be solved. The US.EPA regulatory AERMOD model was used to simulate highest daily and annual average ground level concentrations (GLCs). AERMOD is a Gaussian plume model with an uncertainty range of between -50% to 200%. An area of 12.5 km by 12.5 km was included in the model with the mine in the centre of the modelling domain.

The averaging periods were selected to facilitate the comparison of predicted pollutant concentrations/ deposition with relevant National Ambient Air Quality Standards (NAAQS) and SANS Dust Fallout limits, respectively. According to the Air Quality Act of 2004, ambient air quality standards apply to areas where the general public has access i.e. outside the mine boundary. Nearby farm houses and homesteads were included as sensitive receptors in addition to assessing the impacts at the mine boundary.

In interpreting the study findings it is important to note the limitation and assumptions on which the assessment was based. A list of these uncertainties is provided in the report.

Conclusions

Emissions - From the emissions quantification, unpaved roads were predicted to be the most significant source of both PM_{10} and TSP in the unmitigated case scenario, with a contribution of 49.6% to PM_{10} and TSP contribution of 57.7%. Bulldozing sources were predicted to be the second significant source of PM_{10} and TSP with source contribution of 20.6% and 22.1% respectively. Blasting was predicted to be the third most significant source of PM_{10} (16.7%) and TSP (10.64%). Wind erosion was predicted to the fourth most significant source of PM_{10} and TSP, while materials handling was predicted to be the least significant contributing source of PM10 and TSP.

From the emissions quantification of operations, bulldozing was predicted to be the most significant source of both PM_{10} (30.83%) and TSP (37.36%) in the mitigated scenario with mitigation for all the sources. The unpaved sources were predicted to be the second significant source of PM_{10} and TSP with source contribution of 24.20% and 29.84% respectively. Wind erosion third, blasting fourth and drilling the fifth with materials handling predicted to be the least significant source of both PM_{10} and TSP.

PM_{10} Ground Level Concentrations for the three mining phases were as follows:

Construction operations – PM_{10} concentrations was not predicted to exceed on-site, at any of the sensitive receptors or at the mine boundary. Over an annual average no exceedances were predicted for the NAAQS of 40 µg/m³ on-site or at any of the sensitive receptors with and without mitigation in place for the modelled scenario.

<u>Operational phase</u> - PM_{10} for all the scenarios modelled, the predicted daily averaged PM_{10} ground-level concentrations only exceed the daily NAAQS limit of 75µg/m³ (2015) on-site but comply with the standard by not exceeding the limit more than four. The daily NAAQS limit of 75µg/m³ (2015) was not predicted to exceed at any of the sensitive receptors. The daily NAAQS limit of 75µg/m³ (2015) was predicted to exceed at a small portion of the mine boundary. Over an annual average exceedances were predicted for the annual 2015 NAAQS of 40 µg/m³ on-site at the stockpiles and portions of the open pit with and without mitigation in place. Over an annual average with and without mitigation in place no

exceedances were predicted for the annual 2015 NAAQS of 40 µg/m³ at any of the sensitive receptors.

Closure and Post-closure - The potential for impacts during the closure phase will be dependent on the extent of demolition and rehabilitation efforts. The proposed rehabilitation option will reduce the potential for windblown dust significantly.

Dust fallout rates for the operational phase were as follows:

Maximum daily dust fallout levels for all the operational scenarios modelled were predicted to exceed the SANS residential limit of 600 mg/m²/day on-site at the topsoil stockpile but not at the sensitive receptor sites. With 75% control efficiency for the unpaved roads and 50% control efficiency for wind erosion, the impacts were reduced, although with higher control efficiencies, further reductions could be achieved.

Recommendations

Due to the generally high existing background particulate air concentrations in the region, it is recommended to control major contributing sources. Wind erosion of exposed areas should be kept to a minimum through watering programs and avoiding unnecessary disturbance of stabilised areas.

Monitoring

A dust fallout network comprising of eight single dust fallout buckets following the American Society for Testing and Materials standard method for collection and analysis of dust fall (ASTM D1739-98) should be installed. The bucket locations are indicated on a map and located either up or down wind from the wind dependent sources (stockpiles), at the proposed open pit site and close to the unpaved road, the paved road and sensitive receptors. In addition, it is recommended that a PM_{10} sampler be installed at the nearest sensitive receptor (farmhouse) to provide daily average data especially before the mine commences and continuing afterwards.

The main objective of the dust fallout network is to ensure the following:

- dust fallout in the immediate vicinity of the road perimeter to be less than 1 200 $mg/m^2/day$ and less than 600 $mg/m^2/day$ at the mine boundary.

- dust fallout in the immediate vicinity of the open pit should be below 1 200 $mg/m^2/day$.

- dust fallout levels should not exceed 600 $mg/m^2/day$ outside the mine boundary or at any sensitive receptor.

- PM_{10} GLCs should not exceed the NAAQS at the nearest sensitive receptor (less than 40 $\mu g/m^3$ over an annual average and not exceeding the daily limit of 75 $\mu g/m^3$ more than four times per calendar year).

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LIST OF ACRONYMS AND SYMBOLS

Airshed	Airshed Planning Professionals (Pty) Ltd
APPA	The Atmospheric Pollution Prevention Act (No.45 of 1965)
C	Carbon
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CH_4	Methane
DALR	Dry Adiabatic Lapse Rate
DEAT	The Department of Environmental Affairs and Tourism.
DME	The Department of Minerals and Energy
DPM	Diesel Particulate Matter
DWEA	The Department of Water and Enviromental Affairs
EMP	Environmental Management Programme
EES	Ezendalo Enviromental Solutions
EC	European Commision

ELR	environmental lapse rate
EU	The European Union
GDP	Gross Domestic Product
ISCST3	Industrial Source Complex Short Term model (ISCST3)
IT	Interim Target (WHO)
km	Distance in Kilometers
m^3	Cubic metre
m/s	Speed in Meters per Second
NEMAQA	National Environment Management Air Quality Act No. 39 of 2004)
NO	Nitrogen Oxide
NO_x	Oxides of Nitrogen
NO_2	Nitrogen Dioxide
oktas	Parts of Eight (8)
$PM_{2.5}$	Particulates with an Aerodynamic Diameter of 2.5 µm
PM_{10}	Particulates with an Aerodynamic Diameter of 10 µm
PPM	Parts Per Million

ROM	Run Off Mine
SALR	Saturated Adiabatic Lapse Rate
SANS	South African National Standards
SO_2	Sulphur Dioxide
TCEQ	Texas Commission on Environmental Quality
tpa	Tons Per Annum
tpd	Tons Per Day
TSP	Total Suspended Particles
US-EPA	United States Environmental Protection Agency
VKT	Vehicle kilometer travelled
WB	The World Bank Group
WHO	World Health Organisation
W/m^2	Solar Radiation in Watts per Square Meter
°C	Temperature in Degrees Celsius
µ	Microns
µg	Micrograms

µm	Size in Micro Meters

AIR POLLUTION IMPACT ASSESSMENT FOR THE PROPOSED RIETVLEI MINE, MPUMALANGA

1 INTRODUCTION

Airshed Planning Professionals (Pty) Ltd was appointed by WSP, Environment & Energy, Africa (WSP) to undertake an update of the air quality impact assessment for the proposed Rietvlei Mine near the town of Middelburg, Mpumalanga Province (Figure 1-1). The mine is located approximately 20km north-east of Middelburg in the Steve Tshwete local municipality which is part of the Nkangala District Municipality (NDM).

The main objective of the study is to determine the significance of air pollution impacts from the proposed mining activities at the proposed Rietvlei Mine on the surrounding environment and on human health.

1.1 Description of Proposed Mining Activities

The proposed project will involve the mining of one coal reserve area (Figure 1-2). Mining will take place using conventional truck and shovel mining method. This method includes pre-stripping of topsoil, drilling, blasting and excavation of the overburden to expose the coal. The coal will be removed and the overburden and topsoil will be backfilled to the mined-out pits during a continuous rehabilitation process. The disturbed areas will be left for normal growth of vegetation to occur over time.

Mined coal will be stockpiled and transported off site to Mafube Collery on a diverted road.

Figure 1-1: Location of the town of Middelburg, Mpumalanga

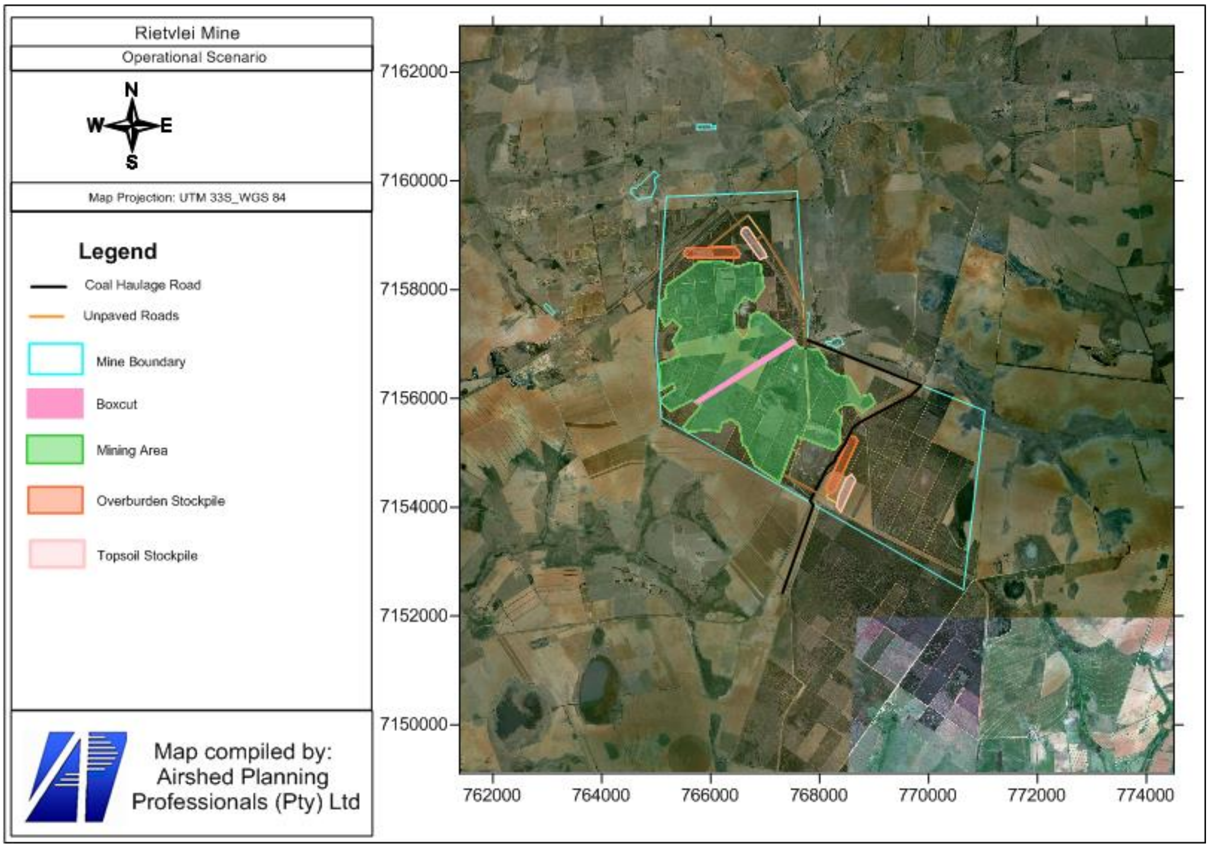

Figure 1-2: Layout of proposed Rietvlei Mine

1.2 Site Description and Sensitive Receptors

The proposed Rietvlei Mine is located near and on farms. Sensitive receptors close to the mine include various scattered settlements and farmhouses on Bankfontein, Driefontein, Shirley and Sonneblom farms (Figure 1.4).

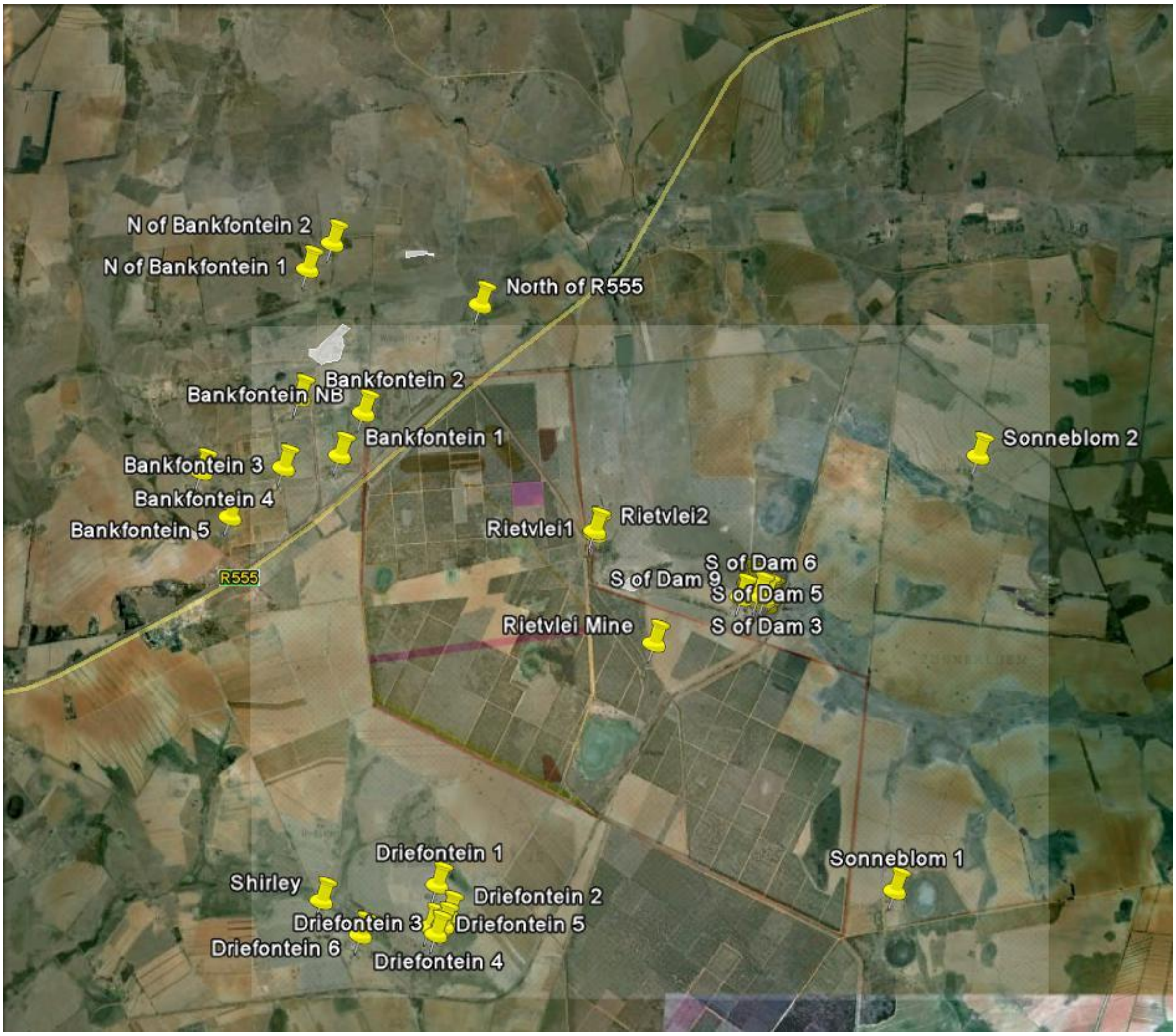

Figure 1-3: Location of the Sensitive Receptors around the proposed mine site

The current land uses in the area include primarily mining and agricultural activities. Regionally, there are several mining (mostly coal mining) and mining related activities.

1.3 Terms of Reference

The terms of reference for the study comprise of two main components, viz, (i) a baseline assessment, and (ii) and air quality impact assessment.

The establishment of the baseline:

- Establishment of current air quality
- Establishment of meteorological conditions

The air quality impact assessment comprises the following:

- Quantification of fugitive dust emissions
    - Construction phase: This mainly pertains to the construction activities including drilling and blasting of the initial box cut areas and land clearing and construction activities associated with the infrastructure setup.
    - Operational Phase: This mainly focuses on emissions from the both the proposed open pit, ore transfer points, crushing and screening operations, vehicle entrained dust from all unpaved roads, and wind-blown dust from the stockpiles.
    - Closure and Post- Closure Phase: The closure and post closure phase comprise of a qualitative assessment since most of the air quality related sources would have ceased.
- Simulation of ambient air pollutant concentrations (PM_{10}) and dust fallout rates (TSP) due to operational activities.
- Evaluation of predicted air pollutant concentrations on the basis of local ambient air quality standards and limits (specifically NAAQS limits) and international ‘good practice’ criteria (e.g. EC, WHO and WB).
- Recommendation on mitigation and management measures as part of an air quality management plan including:
    - Estimation of emission control efficiencies required for mining sources;
    - Identification of suitable pollution abatement measures, and possible contingency measures;
    - Specification of source-based performance indicators, targets and monitoring methods applicable for each source;
    - Recommendation of receptor-based performance indicators and targets; Recommendations pertaining to record keeping, environmental reporting and community liaison.

1.4 Assumptions and Limitations

- The impact assessment focuses primarily on particulate emissions, these having been identified as the primary pollutants associated with the proposed mining activities. Although gases will be emitted by exhausts from blasting, haul trucks and mine vehicles, such activities and hence the associated emissions would be limited and the potential for ambient air pollutant concentrations considered negligible.

- No baseline air pollution monitoring data could be sourced for the study. The predicted concentrations are limited to incremental impacts only (only the proposed Rietvlei mining activities' emissions). Given the fact that the mine is relatively close to other open cast mines in the area and since such mining activities generate air pollution, cumulative impacts are expected to be of some environmental significance.

- The scope of the study does not include other surrounding mines and since there is generally a lack of information on a lot of industries, a holistic approach is therefore required for baseline conditions.

- Particle size distributions for stockpiles (topsoil, overburden, ROM) and road surfaces were not available and therefore particle sizes from similar operations were utilised for the purposes of the study.

- For the construction phase it was assumed that there would be no modification to the existing roads which are proposed to be used during mining operations.

- The construction was taken to be for 9 hours per a day, 260.7 days per a year and assumed to take place in 25% of each of the construction areas simultaneously.

Based on the detail of the process description, the following dust generating sources are included:

- Drilling;
- Blasting;
- Materials transfer in the pit;
- Material transfer of topsoil and mined material (ROM and overburden) at stockpiles;
- Bulldozing in the pit (removal of topsoil and overburden at the proposed pit site);
- Bulldozing at stockpiles (topsoil and overhaul stockpile management);

- Vehicle dust entrainment from unpaved and in-pit roads; and
- Wind erosion of exposed areas (proposed stockpiles).

The impact assessment is limited to airborne particulates only. No chemical speciation was available to quantify specific airborne metal concentrations and fallout rates.

The following qualifications apply to the study:

- The dispersion model cannot compute real time mining processes, therefore *average* mining process throughputs were utilised.
- Routine emissions for the proposed mining operations were simulated. Atmospheric releases occurring as a result of upset conditions were accounted for in the form of blasting operations.
- Since no on-site meteorological data exist for the proposed mine, measured data for a station nearby were used as input into a meteorological model.

1.5 Report Structure

The report is outlined as follows:

- Section 2: Policy and Regulatory Requirements
- Section 3: Regional Climate and Atmospheric Dispersion Potential
- Section 4: Baseline Characteristics
- Section 5: Methodology
- Section 6: Construction Phase
- Section 7: Operational Phase
- Section 8: Closure and Post-Closure Phase
- Section 9: Conclusion and Recommendations
- Section 10: Air Quality Management Plan for Rietvlei Mine

2 POLICY AND REGULATORY REQUIREMENTS

The National Environmental Management Air Quality Act (NEMAQA) has shifted the approach of air quality management from source-based control to the control of the receiving environment. The act has also placed the responsibility of air quality management on the shoulders of local authorities that will be tasked with baseline characterisation, management and operation of ambient monitoring networks, licensing of listed activities, and emissions reduction strategies. The main objective of the act is to ensure the protection of the environment and human health through reasonable measures of air pollution control within the sustainable (economic, social and ecological) development framework.

NEMAQA commenced on the 11th of September 2005[1] with the exclusion of the sections pertaining to the listing of activities and the issuing of atmospheric emissions licences. Listed Activities and associated Minimum Emission Standards were published in the Government Gazette on the 31st of March 2010 (No. 33064) as Section 21 of the AQA. The Atmospheric Pollution Prevention Act (APPA) of 1965 was repealed on the 1st of April 2010 bringing NEMAQA into full force.

According to the Air Quality Act, air quality management control and enforcement is in the hands of local government with District and Metropolitan Municipalities as the licensing authorities. Provincial government is primarily responsible for ambient monitoring and ensuring municipalities fulfil their legal obligations, with national government primarily as policy maker and co-ordinator. Each sphere of government must appoint an Air Quality Officer responsible for co-ordinating matters pertaining to air quality management. Given that air quality management under the old Act was the sole responsibility of national government, local authorities have in the past only been responsible for smoke and vehicle tailpipe emission control.

Emission limits are generally provided for point sources and specify the amount of the pollutant acceptable in an emission stream and are often based on proven efficiencies of air

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[1] The National Environmental Management: Air Quality Act (Act no.39 of 2004) commenced with on the 11th of September 2005 as published in the Government Gazette on the 9th of September 2005. Sections omitted from the implementation are Sections 21, 22, 36 to 49, 51(1)(e),51(1)(f), 51(3),60 and 61.

pollution control equipment. Minimum Emission Standards associated with Listed Activities do not apply to the proposed Rietvlei Mine project.

2.1 Ambient Air Quality Standards and Dust fallout Limits

2.1.1 Ambient Air Quality Standards

Ambient air quality standards are defined in the Integrated Pollution and Waste Management Policy (IP&WM, 2000) as those that define "targets for air quality management and establish the permissible amount or concentration of a particular substance in or property of discharges to air, based on what a particular receiving environment can tolerate without significant deterioration."

The National Framework provided a stepped approach in setting ambient air quality standards. Based on this the standard for a specific pollutant must include limit values for specific exposures, the number of allowable exceedances and a timetable for compliance. The limit values (concentrations) are based on scientific evidence. The South African Standards were published on 24 December 2009.

Standards were determined based on international best practice for particulate matter less than 10 µm in aerodynamic diameter (PM_{10}), sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide, lead and benzene[2]. With the focus of the current study being on particulates, only the standards for PM_{10} are listed in Table 3-1.

Table 2-1: National ambient air quality standards for PM10

Pollutant	Averaging Period	Limit Value (µg/m³)	Frequency of Exceedance	Compliance Date
PM_{10}	24 hour	120	4	Immediate – 31 Dec 2014

[2] *SANS 69 - South African National Standard* - Framework for setting & implementing national ambient air quality standards, and *SANS 1929 - South African National Standard* - Ambient Air Quality - Limits for common pollutants.

Pollutant	Averaging Period	Limit Value (µg/m³)	Frequency of Exceedance	Compliance Date
	24 hour	75	4	1 Jan 2015
	1 year	50	0	Immediate – 31 Dec 2014
	1 year	40	0	1 Jan 2015

2.1.2 National Regulations for Dust Deposition

South Africa's Draft National Dust Control Regulations (NDCR) was published on the 27 May 2011 with the dustfall standards passed and subsequently published on the 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 standard for the acceptable dustfall rate is set out in Table 2-2 for residential and non-residential areas. In addition to the dustfall limits, the NDCR prescribes monitoring procedures and reporting requirements.

Table 2-2: Bands of dust-fall rates proposed for adoption

Restriction Area	Dustfall rate (D) (mg/m²/day, 30-day average)	Permitted frequency of exceeding dustfall rate
Residential	D < 600	Two within a year, not sequential months.
Industrial	600 < D < 1 200	Two within a year, not sequential months

Notes: The method to be used for measuring dustfall rate and the guideline for locating sampling points shall be ASTM D1739: 1970, or equivalent method approved by any internationally recognized body

2.1.3 Screening criteria for animals and vegetation

The impact of dust on vegetation and grazing quality was raised as a concern during the public meetings. While there is little direct evidence of what the impact of dust fall on vegetation is under a South African context, a review of European studies has shown the potential for reduced growth and photosynthetic activity in Sunflower and Cotton plants exposed to dust fall rates greater than 400 mg/m²/day (Farmer 1991).

A summary of available literature information on the impacts from dust on plants and animals are provided in Appendix A.

2.2 Air Quality Management Plans

With the shift of the new Air Quality Act from source control to the impacts on the receiving environment, the responsibility to achieve and manage sustainable development has reached a new dimension. The Air Quality Act has placed the responsibility of air quality management on the shoulders of provincial and local authorities that will be tasked with baseline characterisation, management and operation of ambient monitoring networks, licensing of listed activities, and emissions reduction strategies. The main objective of the act is to ensure the protection of the environment and human health through reasonable measures of air pollution control within the sustainable (economic, social and ecological) development framework.

The proposed Rietvlei Mine falls within the Highveld Priority Area for which an Air Quality Management Plan is being developed. The baseline study was completed in September 2010 with the draft management plan published in April 2011. The plan will identify specific conditions and mitigation requirements for mining operations within the priority area.

3 REGIONAL CLIMATE AND ATMOSPHERIC DISPERSION POTENTIAL

The macro-scale atmospheric dispersion potential is discussed in appendix B.

3.1 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 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 (Oke, 1990; Godish, 1990).

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. A qualitative description of the synoptic systems determining the macro-ventilation potential of the region may be provided based on the review of pertinent literature. Meso-scale systems may be investigated through the analysis of meteorological data observed for the region.

Parameters that need to be taken into account in the characterisation of meso-scale ventilation potentials include wind speed, wind direction, extent of atmospheric stability and ambient air temperature. In the description of the atmospheric dispersion potential of the study area, reference was made to hourly measured meteorological data for the years 2007 to 2009.

3.2 Meso-scale ventilation and site-specific dispersion potential

The meteorological characteristic 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.

3.2.1 Local Wind Field

The vertical dispersion of pollution is largely a function of the wind field. The wind speed determines both the distance of downward transport and the rate of dilution of pollutants. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness. In order to understand the potential for dispersion at a given site, it is preferred to have an on-site meteorological station. No meteorological station is in place at the proposed Rietvlei Mine and to overcome this problem it was decided to make use of measured meteorological data obtained from the South African Weather service for their Rietvallei station. The weather station is approximately 23 km east of the proposed Rietvlei Mine. Figure 3-1 shows the local wind field for Rietvallei based on the measured meteorological data.

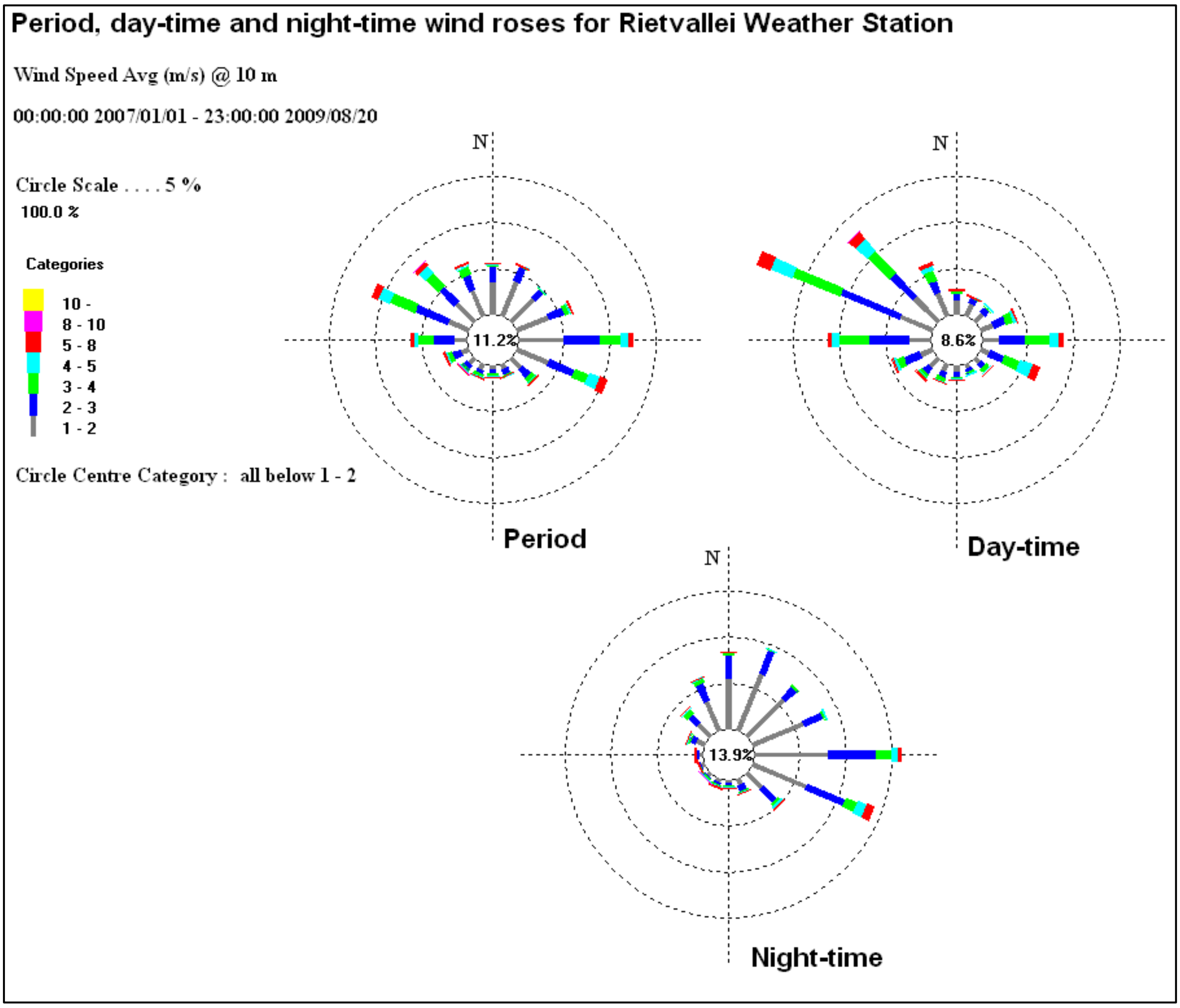

Figure 3-1: Wind roses for Rietvallei for January 2007 to August 2009

Over the January 2007 to August 2009 period, predominant winds are from the north-west and east with strong wind speeds of up to 10m/s. Calm conditions (wind speeds below 1 m/s) occur 11.2% of the time. Day-time conditions show a similar pattern with winds predominantly from the north-westerly and easterly sectors, with an increase in frequency of winds from the north-westerly sector. Night-time conditions are characterised by winds from the north-easterly, easterly and south–easterly sectors.

The seasonal variability in the wind field for Rietvallei is shown in Figure 3-2. During the summer months, winds from the easterly, south easterly sectors dominate, with strong winds of up to 15 m/s occurring. During autumn, the strong winds of up to 8 m/s blow more frequently from the north-westerly, south easterly and easterly sectors. The winter months reflect dominancy of winds from the north-westerly sectors although there is a noticeably decrease in the frequency of winds from the south-easterly sector compared to the summer months. In spring, wind flow is predominant from the north-westerly and north-easterly sectors, with an increase in frequencies of occurrence being evident.

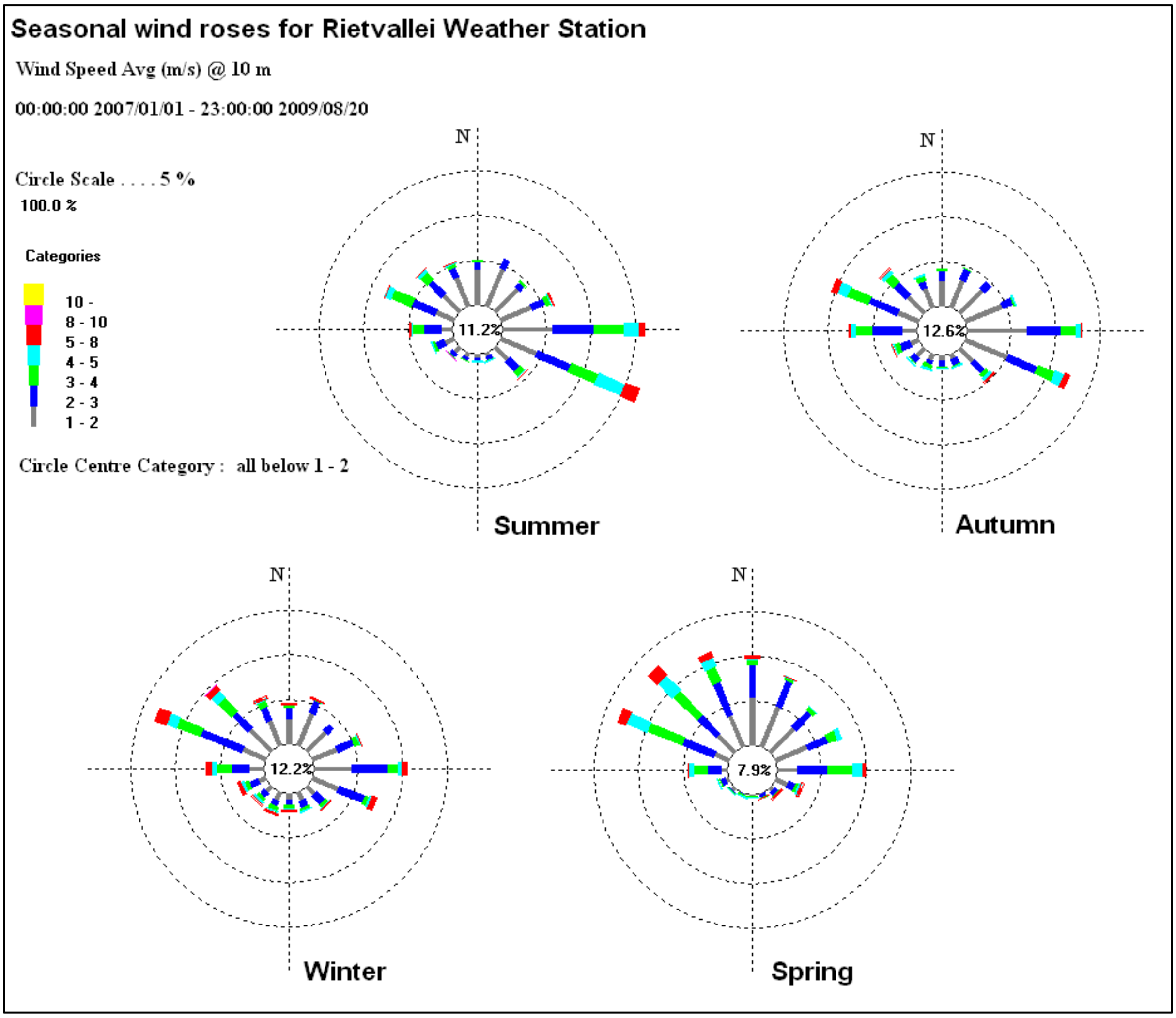

Figure 3-2: Seasonal wind roses for Rietvallei for January 2007 to August 2009

3.2.2 Air Temperature

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. The temperature trends for Rietvallei Mine for the year 2008 are presented in Figure 3-3.

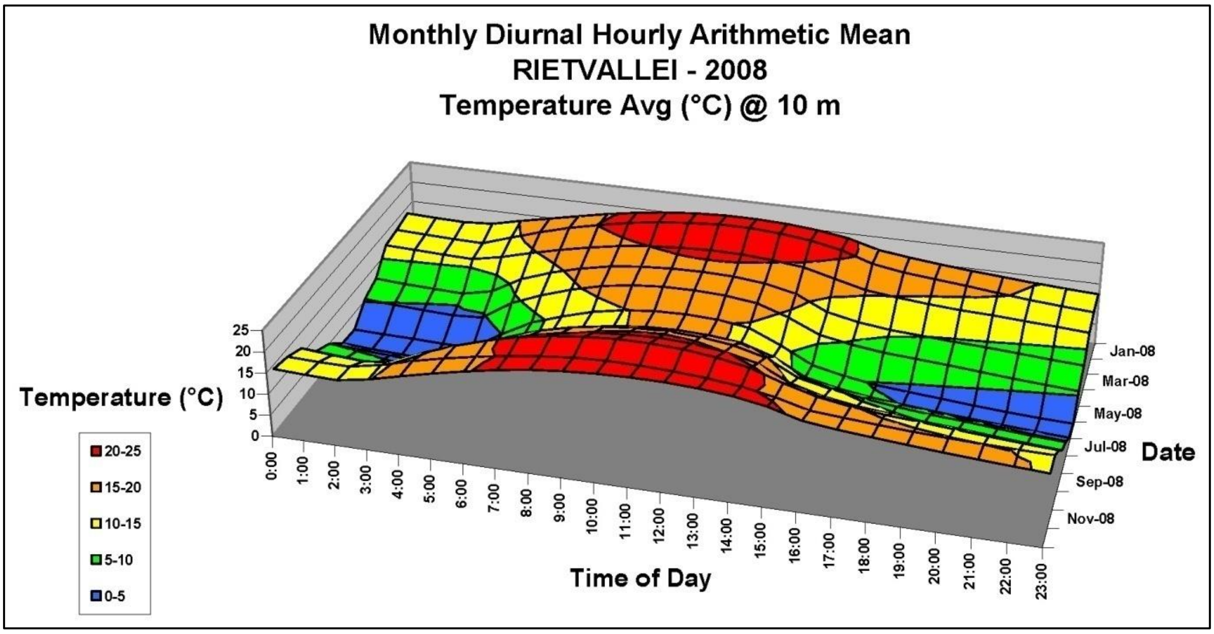

Figure 3-3: Air temperature trends for Rietvallei for 2008.

Since no long term data are available for the proposed Rietvlei Mine area, reference was made to long term climate data for Middelburg. The long term temperature trends recorded for Middelburg from 1925-1950 are presented in Table 3-1. Minimum long-term temperatures recorded range from -1.8°C to 13.7°C with maximum temperatures ranging between 18.4°C and 27.1°C, as presented in Table 3-1. Mean temperatures, recorded over the long-term, range between 8.3°C and 20.5°C.

Table 3-1: Long-term minimum, maximum and mean temperature for Middelburg - 1925-1950 (Schulze, 1986)

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Middelburg	Maximum	27.2	26.8	26.0	23.9	21.3	18.5	18.4	21.4	24	26	26.2	27.1
	Mean	20.5	20.1	18.7	15.7	11.7	8.3	8.3	11.1	14.7	18.0	19.0	20.1
	Minimum	13.7	13.4	11.4	7.4	2.2	-1.8	-1.7	0.8	5.3	10.1	11.8	13.2

3.2.3 Precipitation

Precipitation is important to air pollution studies since it represents an effective removal mechanism for atmospheric pollutants and inhibits dust generation potentials. The average monthly measured precipitation data for Rietvallei station is shown in Figure 3-4. Long-term monthly average rainfall data for Middelburg are shown in Table 3-2. No data for hail, snow and fog days observed to occur at Middelburg during the period 1904-1950 are available. The average total annual rainfall is ~735 mm. Rain falls mainly in summer from October to April, with the peak being in January for the region (Weather Bureau, 1986).

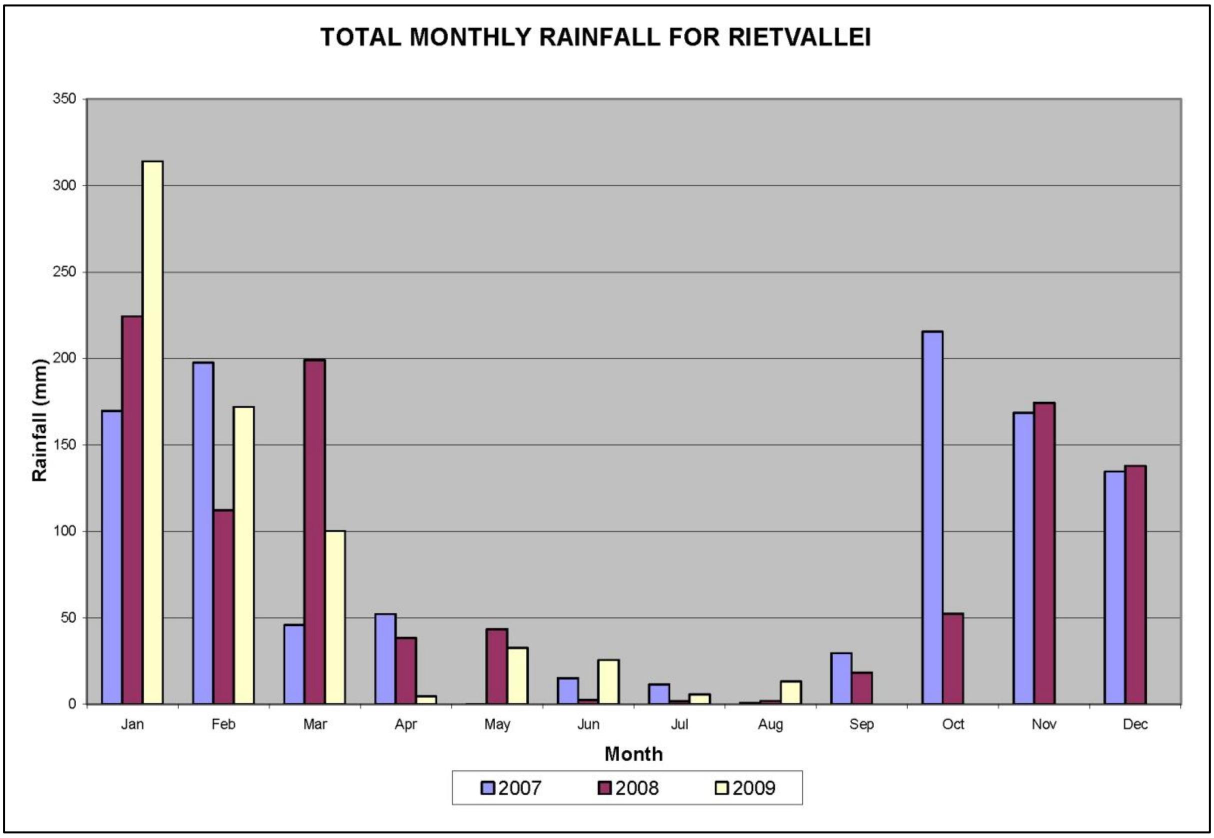

Figure 3-4: The average monthly rainfall for Rietvallei.

Table 3-2: Long-term average monthly rainfall figures (mm) for Middelburg (Schulze, 1986)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Lydenburg (1904 – 1950)	132	103	88	42	19	7	9	8	22	63	124	118	735

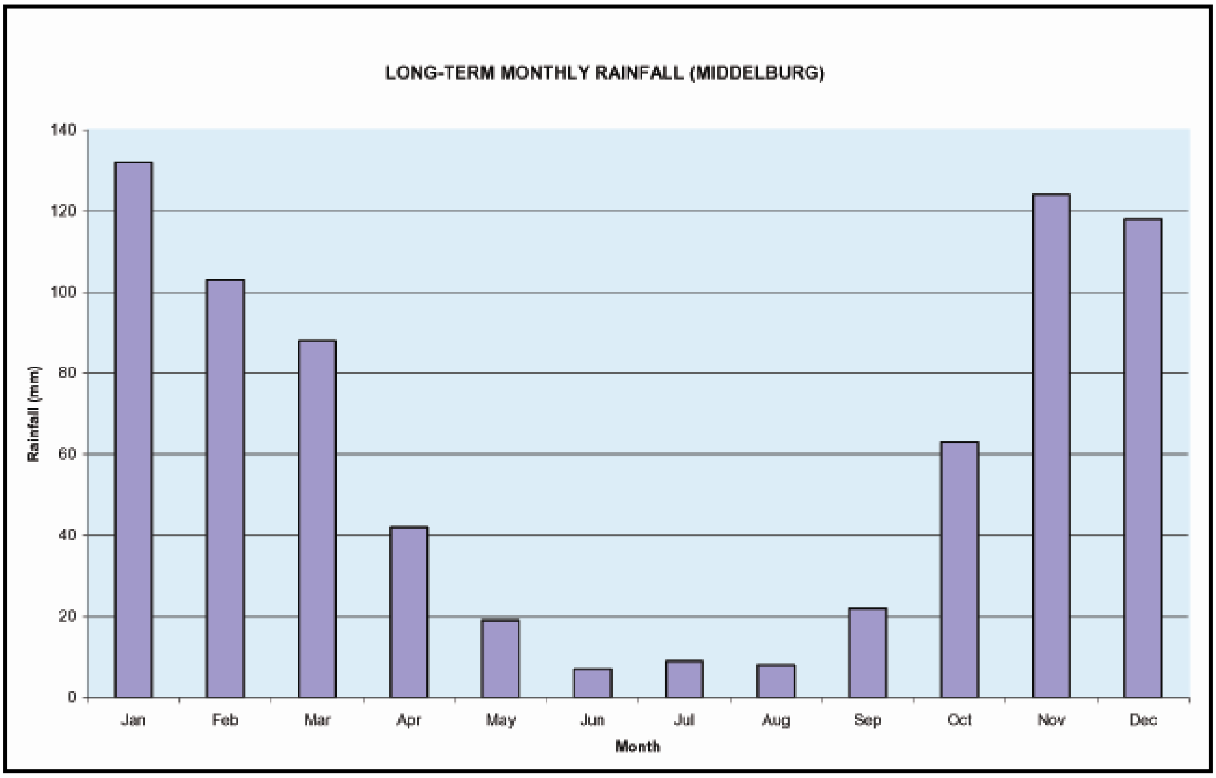

Figure 3-5: Long term average monthly rainfall for Middelburg.

3.2.4 Atmospheric Stability and Mixing Depth

The atmospheric boundary layer constitutes the first few hundred metres of the atmosphere. This layer is directly affected by the earth's surface, either through the retardation of flow due to the frictional drag of the earth's surface, or as result of the heat and moisture exchanges that take place at the surface. 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. Night times are characterised by weak vertical mixing and the predominance of a stable layer. These conditions are normally associated with low wind speeds, hence less dilution potential.

The mixed layer (i.e. layer within which air pollutants are able to mix) therefore ranges in depth from a few metres during the evening and early morning to the base of the lowest-level elevated inversion during unstable, daytime conditions. Elevated inversions may occur for a variety of reasons, and on some occasions as many as five may occur in the first 1000 m above the surface. The lowest-level elevated inversion is located at a mean height above ground of 1 550 m during winter months with a 78 % frequency of occurrence. By contrast, the mean summer subsidence inversion occurs at 2 600 m with a 40% frequency.

For low level releases, such as due to vehicle entrainment from unpaved roads, the highest ground level concentrations will occur during weak wind speeds and stable (night-time) atmospheric conditions. Wind erosion, on the other hand, requires strong winds together with fairly stable conditions to result in high ground level concentrations i.e. neutral conditions. The highest ground level concentrations from stack releases will occur during unstable, daytime conditions.

Atmospheric pressure decreases exponentially with height. An air parcel moving up (or down) in the atmosphere must therefore expand (or compress) and cool (or warm up). In an atmosphere containing water vapour, a dry atmosphere with no liquid water drops, the rate at which temperature decreases with height is called the dry adiabatic lapse rate (DALR). When the total energy in an air parcel is conserved and not exchanged with the surrounding air as it is vertically displaced, it is referred to as adiabatic. The DALR of 9.8 °C/km is determined from physical constants (the acceleration due to gravity and the specific heat of air at constant pressure) and applies to the lower 20 km of the atmosphere (Colls, 2002).

The environmental lapse rate (ELR), the actual vertical variation of temperature with height, may be equal to the adiabatic lapse rate (DALR or SALR) over at least part of the height range of interest but may also differ significantly. The balance between the environmental lapse rate and the adiabatic lapse rate is used to provide an understanding of the concept known as atmospheric stability.

A parcel of air moving upwards will cool at the DALR. If the ambient air temperature increases with height the parcel of air will be at a lower temperature and denser than the surrounding air at the same height and the parcel of air will tend to sink back towards its starting height. If the parcel's initial displacement is downward, it will become warmer and less dense that the surrounding air and tend to rise back up. This is referred to as a stable ELR where vertical motions are damped (Colls, 2002).

When the ELR is equal to the DALR, a parcel of air rising and cooling at the DALR will be in surrounding air at the same temperature and density after the vertical displacement. The ELR is called neutral since vertical motions are neither accelerated nor damped.

When surrounding air cools faster than the DALR a parcel of air rising (descending) and cooling (heating up) at the DALR will always be warmer (cooler) and less dense (more dense) than the surrounding air and will continue to rise (descend). This is referred to as an unstable ERL as vertical displacements are accelerated.

In reality, temperature profiles in the atmosphere often consist of a combination of different ELRs. Vertical dispersion will therefore vary at different heights above the earth's surface. Vertical dispersion during unstable conditions tends to be better than under stable conditions. Under certain meteorological conditions, i.e. anticyclonic high pressure systems, high level air may sink raising temperatures and creating elevated inversions (temperature increases with height) (Colls, 2002). Inversions may act as a "lid" to vertical plume dispersion and increase pollutant concentrations at ground level.

The influence of solar radiation and wind speed on stability was described by Pasquill in 1961 as stability classes from A (very unstable) to D (neutral) to G (very stable) (Table 3-3) (Colls, 2002) for use in older dispersion models. Calm (low wind speed) daytime conditions with clear skies are characterised by unstable conditions (A to C stability). As the wind speed increases and incoming solar radiation decreases, conditions change to neutral (D stability).

At night, cloud cover determines the rate at which heat is radiated from the earth's surface. On cloudless, calm nights, very stable atmospheric conditions exist (G stability). An increase in cloud cover and wind will result in a change from stable to neutral atmospheric conditions.

In the dispersion model used here, atmospheric stability is not defined in terms of the above discrete classes, but as a continuous variable in terms of the Monin-Obukhov length and the mixing depth.

Table 3-3: Dependence of Pasquill stability on meteorological parameters

Surface Wind Speed [m/s]	Day-time Solar Radiation [W/m²]			Night-time Cloud Cover [in oktas]		
	Strong [>560 W/m²]	Moderate [300 - 560 W/m²]	Weak [<290 W/m²]	8	4 - 7	0 - 3
< 2	A	A – B	B	D	G	G
2 – 3	A – B	B	C	D	E	F
3 – 5	B	B – C	C	D	D	E
5 – 6	C	C – D	D	D	D	D
> 6	C	D	D	D	D	D

4 BASELINE CHARACTERISATION

Various components of the bio-physical and socio-economic environment may be impacted by atmospheric emissions associated with the various phases of the project. These components include the possible impact on:

- ambient air quality;
- the aesthetic environment;
- local residents and neighbouring communities; and
- employees.

It is important to identify significant sources of air pollutants in a region, as these are important to consider in terms of assessing the cumulative impact potential on air quality. Sources identified as possibly impacting the air quality in the region include, but are not limited to:

- Industrial sources;
- Fugitive dust sources;
- Mining emission sources;
- Domestic fuel combustion;
- Biomass burning; and
- Vehicle tailpipe emissions.

4.1 Ambient Monitoring at the Proposed Site

Ambient monitored data for at least one year is required for a comprehensive baseline. Eight single dust fallout buckets were installed in April 2014 (Figure 4-1). A PM_{10} minivol sampler was not installed due to a lack of security on-site. The monitoring network will serve to measure background dust deposition. Available data are included in this study to provide an indication of the background dust fallout rates and PM_{10} concentrations prior to the commencement of mining operations.

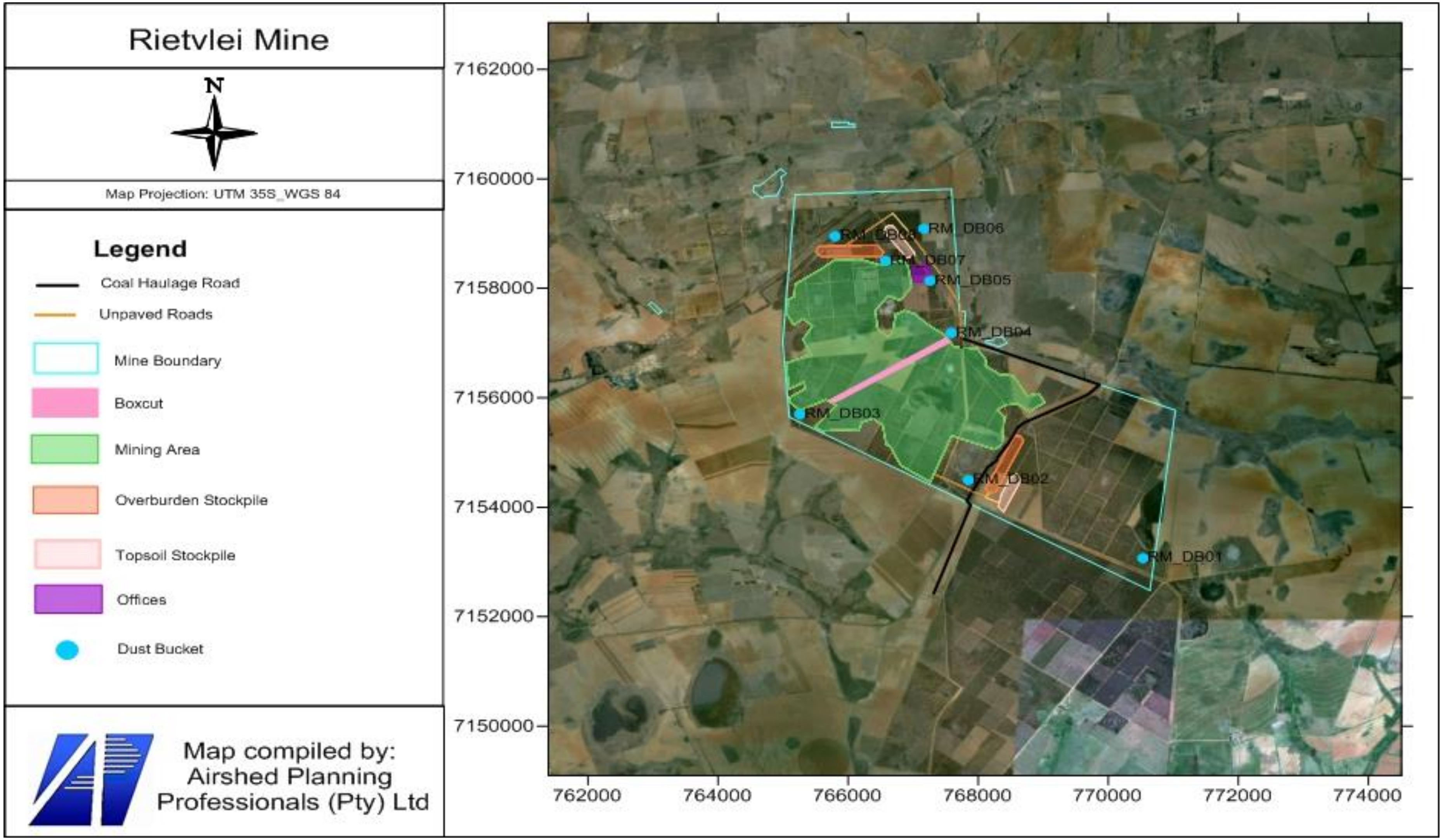

Figure 4-1: The current monitoring network in relation to the proposed operations

4.1.1 Dustfall

The locations of the single dust buckets in relation to the project site are shown in Figure 4-1. A total of eight dust buckets are located close to potential sources of particulates such as the proposed unpaved roads, paved road, overburden stockpiles, topsoil stockpiles and pit area. Two of the single dust units are located in close proximity to farmsteads near the mine boundary. Three months dustfall data was available for incorporation into this report. The data is for the period 08 April 2014 to 09 May 2014 (31 days), 09 May 2014 to 10 June 2014 (32 days) and 10 June 2014 to 11 July 2014 (31 days). The monitored dust fallout results for the period April 2014 to June 2014 are shown in Table 4-1 and Figure 4-2.

Table 4-1 : Dustfall results for April 2014 to June 2014

Site	Dustfall (mg/m^2-day)				
	Apr-14	May-14	Jun-14	Maximum	Average
RM_DB01	242	142	70	242	151
RM_DB02	61	120	103	120	95
RM_DB03	117	116	62	117	98
RM_DB04	101	181	82	181	121
RM_DB05	313	166	82	313	187
RM_DB06	253	85	62	253	133
RM_DB07	176	83	73	176	111
RM_DB08	152	105	99	152	119

All results showed dustfall rates below the residential dustfall limit of 600 mg/m^2/day (Table 4-1 and Figure 4-2). The highest dustfall rates over the entire period were collected at DB05 (313 mg/m^2/day in April 2014) and DB06 (253 mg/m^2/day in April 2014). The DB01 indicated the third highest dustfall of 242 mg/m^2/day over the period (in April 2014). These dust buckets recording the highest dustfall rates (i.e. DB01, DB04 and DB05) are located near current unpaved roads, assumed to be utilized by the surrounding residents. The month of June had on average, lower dust fallout rate than the previous two months.

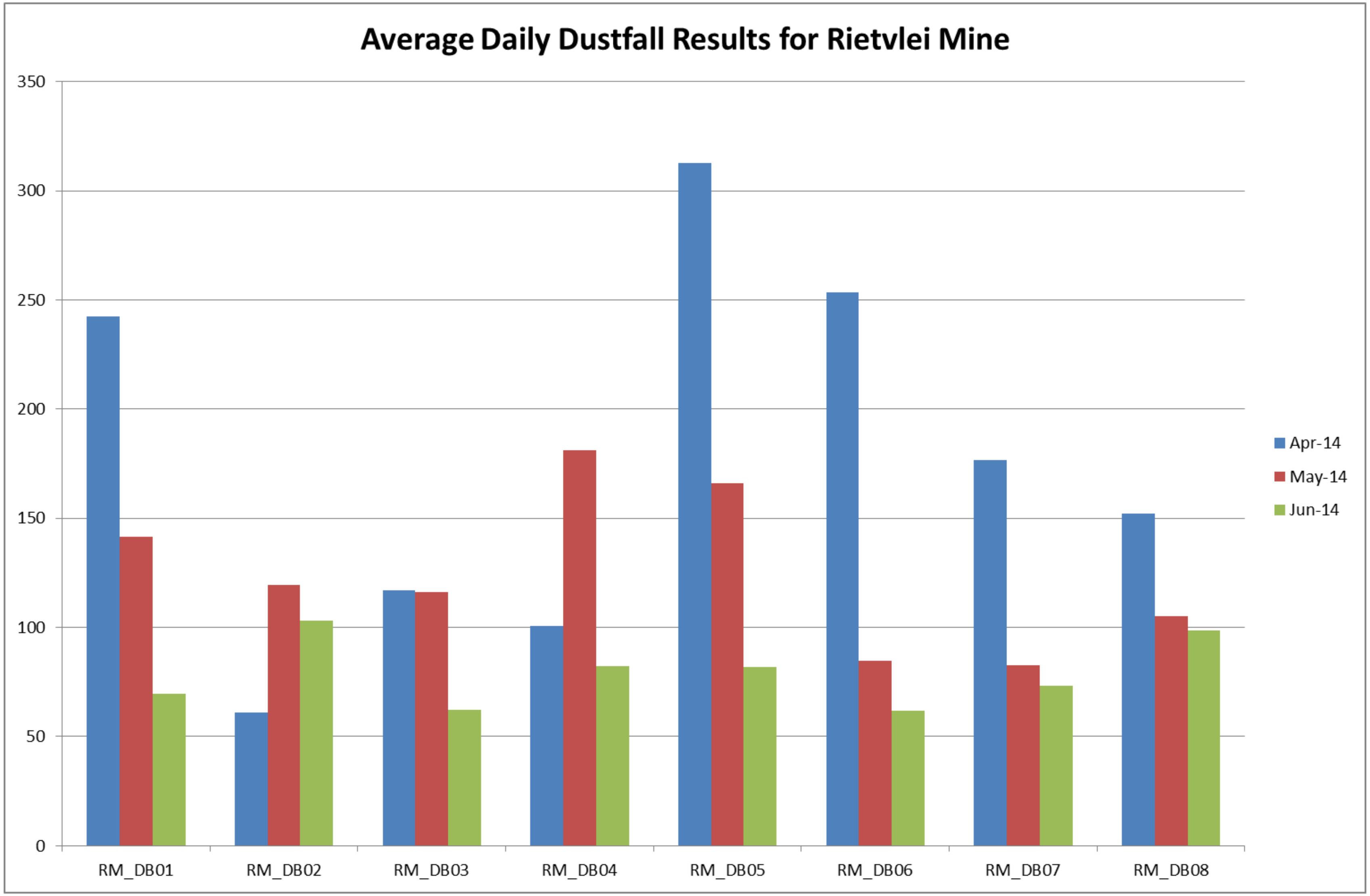

Figure 4-2 : Dustfall results for April 2014 to June 2014

4.1.2 PM_{10}

PM_{10} monitoring has not commenced. A secure location for the PM_{10} monitor could not be established.

4.2 Ambient Air Quality within the Mpumalanga Highveld Region

The identification of existing sources of emission in the region, and the characterisation of ambient pollutant concentrations is fundamental to the assessment of the potential for cumulative impacts and synergistic effects given the proposed operation and its associated emissions.

A comprehensive emissions inventory has recently been completed for the region as part of the Highveld Priority Area (HPA) baseline study. The results of the inventory were then used to carry out a comprehensive dispersion modelling study over the area using the CALPUFF model (DEA 2011). Results of this dispersion study are illustrated in Figures 5-1. The figure give the areas in which ambient air quality standards are predicted to be exceeded for more than the allowed 1% of the time. It will be noted that the portion of Steve Tshwete area in which the proposed Rietvlei mine will be located is indicated to have little or no exceedences with respect to PM_{10}.

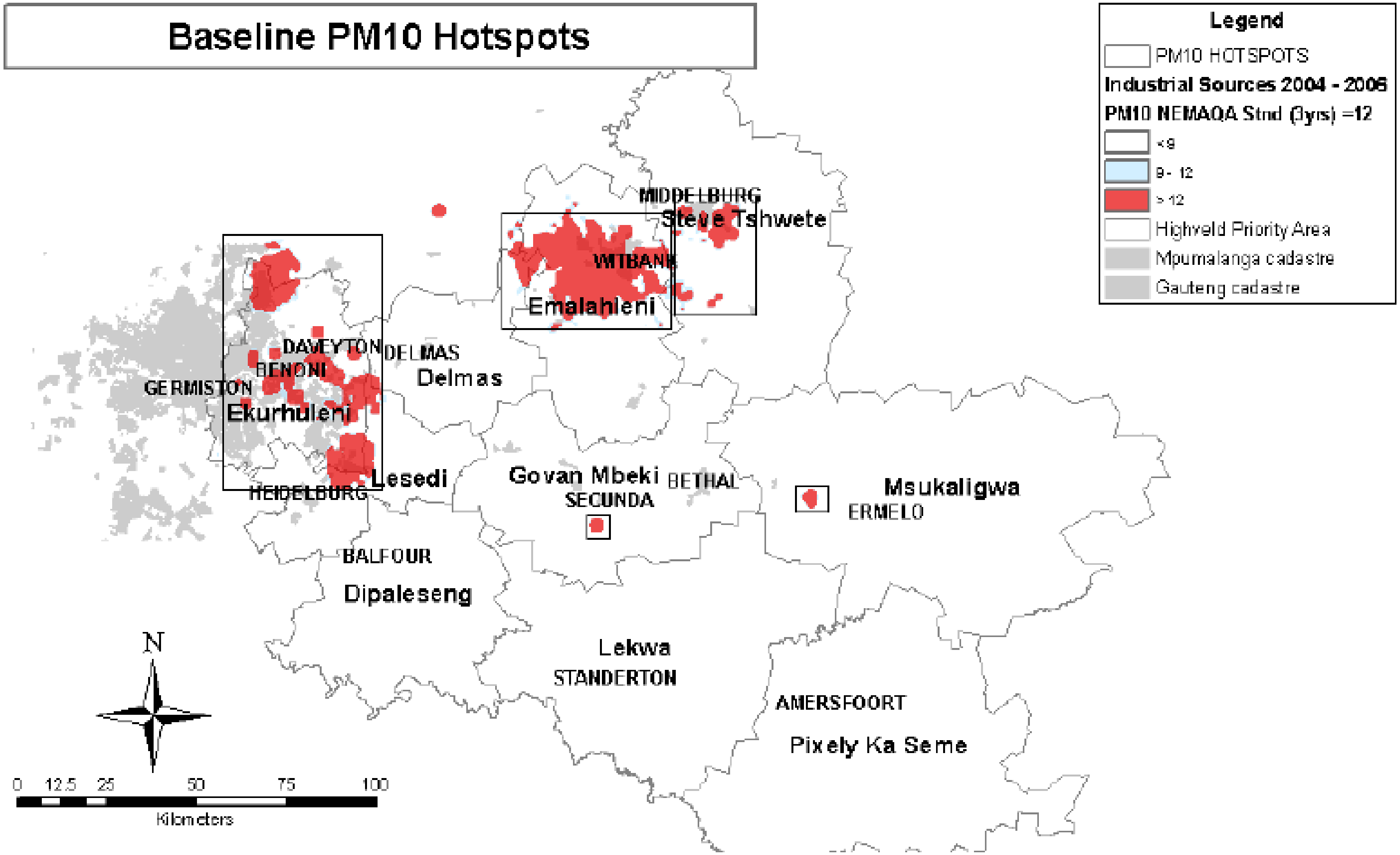

Figure 4-3: Predicted frequencies of exceedence of SA ambient PM_{10} standards (DEA 2011)

Some additional information on background concentration of particulate matter in the Southern African region was provided by the SAFARI 2000 project, during which several overflights at 5 km altitude were made over the countries of the region (Eatough *et al.* 2003). The average concentration of particulate matter observed from five samples collected over South Africa early in August was 18.7 ±3 μg/m³ and from two samples collected after 22 August (and thus presumably more impacted by biomass burning) was 42.1±3.1 μg/m³. At that altitude, it can be accepted that good mixing has taken place and that this measurement is equivalent to PM_{10}. Individual source contributions to this figure are difficult to determine; from the composition of the samples a large contribution from biomass burning is evident.

4.3 General Pollution Generators in the Region

Neighbouring land-use in the region comprises of power generation, mining activities, farming and residential, contributing vehicle tailpipe emissions, household fuel combustion, biomass burning and various fugitive dust sources.

4.3.1 Power Generation

Multiple operational power stations fall within the Mpumalanga Highveld region. The main emissions from such electricity generation are carbon dioxide, sulphur dioxide, nitrogen dioxides and ash (particulates). Fly-ash particles emitted comprise various trace elements such as arsenic, chromium, cadmium, lead, manganese, nickel, vanadium and zinc. Small quantities of volatile organic compounds are also released from such operations.

The power stations are large sources of sulphur dioxide. Sulphur dioxide oxidises in the atmosphere to particulate sulphate at a rate of between 1 and 4% per hour. Fine particulate sulphate has been used to trace the transportation of power station plumes across the Southern African sub-continent. The power stations in close proximity to the proposed Rietvlei mine area include Arnot Power Station located ~31 km south east, Hendrina Power Station (~40 km south), Komati (~49 km south west), Duvha Power Station (~45 km south west), Kriel Power Station (~80 km south west), Kendal (~83 km south west) and Matla Power Station located approximately ~85 km south west of Mafube Colliery. Due to the elevated height at which these power stations emit, the potential exists for their emissions to impact on the air quality of the Witbank and Middelburg areas.

4.3.2 Mining Operations

There are numerous coal mines located to the south and southeast of Middelburg. Some of the mines located close to the proposed Rietvlei Mine include Arnot North Mine, Kopermyne Colliery, Klippan, Steelcoal Colliery, Arnot Colliery, Glisa Colliery, Optimum Colliery, Blackwattle Colliery, Middelburg Mine and Bank Colliery. Fugitive emissions from open cast and underground mining operations mainly comprise of land clearing operations (i.e. scraping, dozing and excavating), materials handling operations (i.e. tipping, off-loading and loading, conveyor transfer points), vehicle entrainment from haul roads, wind erosion from open areas and drilling and blasting. These activities mainly result in fugitive dust releases with small amounts of NO_x, CO, SO_2, methane and CO_2 being released during blasting operations.

4.3.3 Fugitive Dust Sources

These sources are termed fugitive because they are not discharged to the atmosphere in a confined flow stream. Sources of fugitive dust identified to potentially occur in the study area include paved and unpaved roads; agricultural tilling operations; and wind erosion of sparsely vegetated surfaces.

4.3.3.1 Unpaved and paved roads

Emissions from unpaved roads constitute a major source of emissions to the atmosphere in the South African context. When a vehicle travels on an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong turbulent air shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed. Dust emissions from unpaved roads vary in relation to the vehicle traffic (including average vehicle speed, mean vehicle weight, average number of wheels per vehicle) and the silt loading on the roads.

Emissions from paved roads are significantly less than those originating from unpaved roads; however, they do contribute to the particulate load of the atmosphere. Particulate emissions occur whenever vehicles travel over a paved surface. The fugitive dust emissions are due to the resuspension of loose material on the road surface.

4.3.3.2 *Wind erosion of open areas*

Emissions generated by wind erosion are dependent on the frequency of disturbance of the erodible surface. Every time a surface is disturbed, its erosion potential is restored (EPA). Further erodible surfaces may occur as a result of agriculture and/or grazing activities.

4.3.4 Domestic Fuel Combustion

Domestic households are known to have the potential to be one the most important sources contributing to poor air quality within residential areas. Individual households are low volume emitters, but their cumulative impact is significant. It is likely that households within the local communities/settlements utilise coal, paraffin and /or wood for cooking and/or space heating (mainly during winter) purposes. Pollutants arising from the combustion of wood include respirable particulates, carbon monoxide (CO) and sulphur dioxide (SO_2) with trace amounts of polycyclic aromatic hydrocarbons (PAHs), in particular benzo(a)pyrene and formaldehyde. Particulate emissions from wood burning have been found to contain about 50% elemental carbon and about 50% condensed hydrocarbons.

Coal is relatively inexpensive in the Mpumalanga region and is easily accessible due to the proximity of the region to coal mines and the well-developed coal merchant industry. 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) such as benzo(a)pyrene, NO_2 and various toxins. Polyaromatic hydrocarbons are recognised as carcinogens. The main pollutants emitted from the combustion of paraffin are NO_2, particulates carbon monoxide and polycyclic aromatic hydrocarbons.

4.3.5 Biomass Burning

Biomass burning includes the burning of evergreen and deciduous forests, woodlands, grasslands, and agricultural lands. Within the project vicinity, crop-residue burning and wild fires (locally known as veldt fires) may represent significant sources of combustion-related emissions.

Biomass burning is an incomplete combustion process (Cachier, 1992), with carbon monoxide, methane and nitrogen dioxide gases being emitted. Approximately 40% of the nitrogen in biomass is emitted as nitrogen, 10% is left in the ashes, and it may be assumed that 20% of the nitrogen is emitted as higher molecular weight nitrogen compounds (Held *et al*, 1996). The visibility of the smoke plumes is attributed to the aerosol (particulate matter) content. In addition to the impact of biomass burning within the vicinity of the proposed mining activity, long-range transported emissions from this source can be expected to impact on the air quality between the months August to October. It is impossible to control this source of atmospheric pollution loading; however, it should be noted as part of the background or baseline condition before considering the impacts of other local sources.

4.3.6 Vehicle Tailpipe Emissions

Emissions resulting from motor vehicles can be grouped into primary and secondary pollutants. While primary pollutants are emitted directly into the atmosphere, secondary pollutants form in the atmosphere as a result of chemical reactions. Significant primary pollutants emitted by internal combustion engines include carbon dioxide (CO_2), carbon monoxide (CO), carbon (C), sulphur dioxide (SO_2), oxides of nitrogen (mainly NO), particulates and lead. Secondary pollutants include NO_2, photochemical oxidants such as ozone, sulphur acid, sulphates, nitric acid, and nitrate aerosols (particulate matter). Vehicle (i.e. model-year, fuel delivery system), fuel (i.e. type, oxygen content), operating (i.e. vehicle speed, load), and environmental parameters (i.e. altitude, humidity) influence vehicle emission rates (Onursal, 1997).

4.3.7 Informal refuse burning

Additional sources of emissions come from the waste sector and typically includes informal refuse and tyre burning. The informal burning of refuse tips within former township areas and burning of waste at local municipal landfill sites represents a source of concern in all provinces. For example, refuse tip combustion has been found to contribute significantly to the total airborne particulate concentrations within Soweto in the Gauteng Province. This source was estimated during a source apportionment study conducted in Soweto during 1996-1997 to be responsible for between 10% and 25% of the $PM_{2.5}$ concentrations recorded (Annegarn and Grant, 1999).

5 METHODOLOGY

In assessing atmospheric impacts from the proposed mining activities an emissions inventory was undertaken, atmospheric dispersion modelling conducted and predicted air pollutant concentrations evaluated.

The phases undertaken in the impact assessment are described in the following subsections.

5.1 Emissions Inventory

The main pollutant of concern associated with the proposed mining operations is particulates. Particulates are divided into different particle size categories with Total Suspended Particulates (TSP) associated with nuisance impacts and the finer fractions of PM_{10} (particulates with a diameter less than 10 µm) and $PM_{2.5}$ (diameter less than 2.5 µm) linked with potential health impacts. Gaseous pollutants (such as sulphur dioxide, oxides of nitrogen, carbon monoxide etc.) will derive from vehicle exhausts but are regarded as negligible in comparison to particulate emissions.

The establishment of an emissions inventory for the proposed operations is necessary to provide the source and emissions data required as input to the dispersion simulations. The release of particulates represents the most significant pollutant and is the focus of the current study.

In the quantification of emissions (Chapter 6) use was made of predictive emissions factor equations published by the US-EPA (EPA, 1996) and by the Australian National Pollutant Inventory (NPI, 2001). An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Detailed information pertaining to these quantifications is provided in Appendix C.

5.2 Dispersion Model Selection

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 (GLCs) arising from emissions of various sources. Increasing reliance is 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.

Gaussian plume models are best used for near-field applications where the steady-state meteorology assumption is most likely to apply. The topography of the study area is fairly flat comprising of undulating hills, making it suitable for using a Gaussian plume model. The most widely used Gaussian plume model, the US.EPA Regulatory AERMOD model, was used in this study.

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

As with most Gaussian Plume models, a disadvantage is that spatial varying wind fields, due to topography or other factors cannot be included. Also, the range of uncertainty of the model predictions could to be -50% to 200%. The accuracy improves with fairly strong wind speeds and during neutral atmospheric conditions.

There will always be some error in any geophysical model, but it is desirable to structure the model in such a way to minimise the total error. A model represents the most likely outcome of an ensemble of experimental results. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere.

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. Nevertheless, dispersion modelling is generally accepted as a valuable tool in Air Quality Management, especially for predictive purposes.

Input data types required for the AERMOD model include: meteorological data, source data, and information on the nature of the receptor grid. Each of these data types will be described below.

5.3 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). Since the model was designed for the USA environment, various difficulties are found compiling the required dataset for the South African environment. The main data shortfalls include the following:

- No national meteorological database exists.
- Upper air measurements are taken at a few locations in South Africa. The South African Weather Services has modeled upper air data for the entire country on a half degree interval.

- Surface meteorological stations seldom measure all the required parameters (such as solar radiation, cloud cover, humidity).

5.4 Preparation of source data

The AERMOD model is able to model point, open pit area, area, line, and volume sources. Sources in the current study were modelled as follows:

- Construction – modelled as area sources;
- Open cast mine – modelled as area source;
- Wind erosion – modelled as volume sources;
- Materials handling– modelled as volume sources;
- Bulldozing – modelled as area sources;
- Unpaved roads – modelled as area sources; and
- Wind erosion – modelled as area sources.

Hourly files incorporating meteorological data were prepared for the various stockpiles.

5.5 Preparation of receptor grid

Due to the location of the proposed mining area the dispersion of pollutants was modelled for an area covering 12.5km (north-south) by 12.5km (east-west). The area was divided into a grid matrix with a resolution of 250 m by 2500 m (400 m by 400 m for TSP), with operations located approximately in the centre of the receptor area. AERMOD simulates ground-level concentrations for each of the receptor grid points. The nearby settlements were included as boundary and discrete receptors.

5.6 Model input and execution

Input into the dispersion model includes prepared upper air and surface meteorological data, source data, information on the nature of the receptor grid and emissions input data. The model inputs were verified before the model was executed.

5.7 Plotting of model outputs

Simulated outputs for PM_{10} (daily, frequency of exceedence and annual) and TSP (average) were plotted.

5.8 Compliance analysis and impact assessment

The predicted air pollution concentrations and dust fall rates were compared to current air quality limits and health and welfare thresholds to facilitate compliance and impact assessments. These concentrations were summarised and form the basis of the compliance assessment and evaluation.

6 CONSTRUCTION PHASE

It was assumed that construction activities will be limited to 9 hours a day and 5 days of the week. The mining operations are expected to be 24 hours per day, 7 days a week.

Partially mitigated particulate (PM_{10} and TSP) emissions were quantified for the construction and operational phases. The efficiency of fugitive dust emission mitigation measures, as specified, are obtained from the Australian NPI emission estimation document for mining (NPI, 2001).

A summary of the sources of emission associated with the construction phase of the mine considered in the study are provided in Table 6-1**.**

Table 6-1 : Summary of construction scenario sources of emission, mitigation measures and assumed mitigation efficiencies

Emissions & Activity		Rietvlei Mine Construction Phase	Mitigation Measures and Efficiencies
Fugitive Dust Emissions	**Construction**	• Boxcut • ROM Stockpile • Topsoil Stockpile • Overhaul Stockpile • In-Pit Roads • Topsoil Road • Overhaul Road • Temporary Offices	• 50%

6.1 Emission Estimation

Construction normally comprises a series of different operations including land clearing, topsoil removal, road grading, material loading and hauling, stockpiling, grading, bulldozing, compaction, (etc.). Each of these operations has their own duration and potential for dust generation. It is anticipated that the extent of dust emissions would vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing meteorological conditions. This is in contrast to most other fugitive dust sources where emissions are either relatively steady or follow a discernible annual cycle.

A list of all the potential dust generation activities expected during the construction phase is provided in Table 6-2. If more detailed information regarding the construction phase of the proposed project had been available, the construction process would have been broken down into component operations as shown in Table 6-3, for emissions quantification and dispersion simulations. Due to the lack of detailed information, emissions from the construction were instead estimated on an area wide basis for the following project areas:

- Proposed boxcut (18.59 ha)
- Non existing unpaved roads (12.73 ha)
- Proposed temporary office area (11.24 ha)
- Proposed topsoil stockpiles (20.59 ha)
- Proposed overburden stockpiles (37.00 ha)
- Proposed ROM stockpile (0.01 ha)

The quantity of dust emissions was assumed to be proportional to the area of land being worked and the level of construction activity. The US-EPA (EPA, 1996) emission factor for construction activity operations is given as:

$$\mathbf{E_{TSP} = 2.69 Mg/hectare/month\ of\ activity}$$

Table 6-2: Typical sources of fugitive particulate emission associated with construction

Impact	Source	Activity
TSP and PM_{10}	Mine site	Clearing of groundcover
		Leveling of area
		Infrastructure edifice (on site unpaved roads, storage areas, administration buildings)
		Drilling and blasting
		Wind erosion from topsoil storage piles
		Tipping of topsoil to storage pile
	Unpaved roads	Clearing of vegetation and topsoil
		Loading and unloading of topsoil
		Wind erosion from topsoil storage pile
		Tipping onto topsoil storage pile
		Vehicle entrainment on unpaved road surfaces
	Transport infrastructure	Clearing of vegetation and topsoil
		Leveling of proposed transportation route areas

The PM_{10} fraction was assumed at 35% of the US-EPA total suspended particulate factor. It is applicable to construction operations with active large –scale earth moving operations. These emission factors are most applicable to construction operations with (i) medium activity levels, (ii) moderate silt contents, and (iii) semi-arid climates. It was also assumed that only 25% of the areas identified would be under construction at any given point in time.

Mitigation in the form of water sprays, with a control efficiency of 50% (NPI, 2001), were assumed for mitigation construction emissions.

6.1 Summary of Estimated Emissions

Emissions from construction of infrastructure associate with the proposed mine amount to 141.18 and 403.36 tpa PM_{10} and TSP respectively.

6.2 Impact assessment: Construction Phase

The construction phase will comprise land clearing and site development operations at the proposed Rietvlei mine site and the associated infrastructure.

Aspects associated with the construction phase in terms of air quality are outlined in Table 6-3.

Topsoil and overburden storage piles prone to wind erosion will result from land clearing activities. Vehicle-entrainment of dust from construction sites represents a relatively large source of fugitive dust emissions during construction. Gaseous and particulate emissions from vehicle tailpipes are far lower and therefore of less significance in terms of their impacts. Surface blasting activities is another main source of concern resulting mainly in particulate emissions and to a lesser extent gaseous emissions which are directly related to the type of explosives used.

Table 6-3: Environmental impacts and associated activities during the construction phase

Impact	Source	Activity
Particulates	Unpaved roads	Vehicle entrainment on unpaved roads surface
		Clearing and levelling of roads
	Mine site	Clearing of groundcover
		Drilling and blasting
		Materials handling (loading and hauling)
		Wind erosion from stockpiles
		Vehicle entrainment on unpaved road surfaces
		Establishment of infrastructure
Gases and particulates	Vehicles	Tailpipe emissions from construction vehicles at the site.
	Explosives	Gaseous emissions from blasting

6.3 Qualitative assessment of potential impacts from construction activities

A detailed construction plan is required to quantitatively assess air pollution. Due to the lack of information and the relatively short duration of most of the activities associated with the construction phase, no dispersion simulations were undertaken and a qualitative assessment was done.

From the proposed operations, the main construction activities likely to result in noticeable impacts of PM_{10} and TSP include vehicle entrainment from unpaved roads, drilling and blasting and wind erosion from the topsoil stockpiles. According to the Australian Environment Protection Agency's guidelines for separation distances (AEPA, 2001), a generic buffer zone of 500m is set for quarrying or processing activities where blasting takes place. In addition, dustfall impacts are generally confined to the near-field (<1 km to 3 km) of sources. This is due to the fact that larger particles, which contribute most to dustfall rates given their mass, are likely to settle out in close proximity to the source (assuming a ground-based source). The area influenced by the operations of course depends on the dispersion potential of the site and the extent of the construction operations.

Blasting is considered an upset emission source due to the intermittent nature of the activity (usually once or twice per day). Furthermore, drilling and blasting will only be conducted for a limited period of time.

Vehicle entrainment from unpaved roads is likely to be one of the main sources resulting in impacts of sensitive receptors (Liebenberg-Enslin & Petzer, 2006). The magnitude of the impacts will depend on the distances travelled between the various construction operations, the number of vehicles and the average travelling speed. Since the roads within the proposed construction site are unlikely to be paved during the construction phase, the force of the wheels travelling on unpaved roadways causes 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 affect the road surface once the vehicle has passed. The quantity of dust emissions from unpaved roads varies linearly with the volume of traffic. In addition to traffic volumes, emissions also depend on a number of parameters which characterise the condition of a particular road and the associated vehicle traffic, including average vehicle speed, mean vehicle weight, average number of wheels per vehicle, road surface texture, and road surface moisture (EPA, 2003). Wind-blown dust from open and exposed surfaces could result in considerable emissions under high wind speeds. Significant 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. As with blasting, these incidences usually occur for limited time periods, but when it occurs the impacts could be significant.

6.4 Proposed mitigation measures

Although *incremental* concentrations and deposition rates due to the construction phase of the proposed Rietvlei Mine project are estimated to be of low environmental significance, it is recommended that effective dust control measures be implemented based on good practice. The implementation of effective controls during this phase would also serve to set the precedent for mitigation during the operational phase.

Control techniques for fugitive dust sources generally involve watering, chemical stabilization, and the reduction of surface wind speed though the use of windbreaks and source enclosures. Proposed dust control measures which may be implemented during the construction phase are as follows:

- Debris handling - wind speed reduction through sheltering and wet suppression.
- Truck transport - wet suppression or chemical stabilization of unpaved roads;
- Dust entrainment – reduction of unnecessary traffic and strict speed control, require haul trucks to be covered, and ensure material being hauled is wet.

- Materials storage, handling and transfer operations - wet suppression.
- Earthmoving and dozing operations - wet suppression.
- General construction - wind speed reduction, wet suppression and early paving of permanent roads. Phasing of earthmoving activities to reduce source size.
- Open areas (wind-blown emissions) - early vegetation, compaction and stabilization of disturbed soil and reduction of the frequency of disturbance.

7 OPERATIONAL PHASE

Emissions are estimated for pollutants generally associated with opencast mining. The category of emissions that will occur at the proposed mine is fugitive dust emissions. Fugitive emissions refer to emissions that are spatially distributed over a wide area and not confined to a specific discharge point (IFC, 2007).

Sources of atmospheric emission associated with the proposed Rietvlei Mine were identified from layout maps provided by the client and other information provided through consultation.

A summary of the sources of emission associated with the operational phase of the mine considered in the study are provided in Table 7-1

Table 7-1: Summary of operational scenario sources of emission, mitigation measures and assumed mitigation efficiencies

Emissions & Activity		Operational Scenarios	Mitigation Measures and Efficiencies
Fugitive Dust Emissions	**Drilling and Blasting**	• In-pit drilling and blasting	• N/M
	Materials Handling and Transfer	• In-pit ore and waste handling • Topsoil and overhaul tipping on stockpile and reclaim • Ore handling on ROM stockpile and reclaim	• In-pit materials handling – N/M • Topsoil and Overhaul materials handling – N/M • ROM materials handling – Water Sprays (50%)
	Bulldozing	• In-pit topsoil and overhaul bulldozing • Topsoil and overhaul management on stockpiles	• In-pit materials handling – N/M • Other materials handling – N/M
	Unpaved Haul Roads	• Hauling	• Water Sprays – 75%
	Wind Blown Dust	• Topsoil Stockpile • Overhaul Stockpile • ROM Stockpile	• 50%

<u>Note:</u> N/M represents No Mitigation.

7.1 Emissions Inventory

Mining rates as applied in the calculation of emissions from the operational phase are provided in Table 7-2.

Table 7-2: Mining and ore processing rates as applied in the emissions inventory

Source	Material	Mining Rates
Rietvlei Mine	Topsoil removed	67 Kt
	Overburden removed	400 Kt
	Ore mined	100 Kt

Techniques, emission factors and emission equations applied in the estimation of fugitive dust emissions are discussed in detail in Appendix A. A short discussion on information used in the estimation of fugitive dust emissions are provided below.

7.1.1 Materials Handling

A summary of the information used in the estimation of emissions from materials handling and transfer points are provided in Table 7-3.

Emissions were calculated based on annual average mining and ore processing rates and an average wind speed of 1.39 m/s.

Table 7-3: Parameters used in estimation of materials handling emissions

Parameter	Operational Scenario			
Location	**Pit**	**Topsoil Stockpile**	**Overburden Stockpile**	**ROM Stockpile**
Ore handling (tph)	11.42			11.42
Topsoil handling (tph)	7.64	7.64		
Overhaul handling (tph)	44.66		44.66	
Ore moisture content	8.4%			8.3%
Topsoil moisture content	6%	6%		

Parameter	Operational Scenario			
Overburden moisture content	6%		6%	
Mitigation Applied	None	None	None	50%

7.1.2 Bulldozing

A summary of information used in the estimation of emissions from dozing are provided in Table 7-4**.** Emissions were calculated based on the operational hours per annum.

Table 7-4: Parameters used in estimation of dozing emissions

Parameter	Operational Scenario		
Location	**Pit**	**Topsoil Stockpile**	**Overhaul Stockpile**
Silt Content	8.4%	8.4%	8.4%
Topsoil moisture content	6%	6%	
Overhaul moisture content	6%		6%
Mitigation Applied	None	None	None

7.1.3 Unpaved Roads

A summary of information used in the estimation of emissions from unpaved roads are provided in Table 7-5.

Vehicle-entrained dust emissions have been found to account for a great portion of fugitive dust emissions from mining operations. Road lengths were estimated from site layout maps provided. No road between the main unpaved road and the topsoil and overburden stockpiles were shown and potential location and lengths for these roads were assumed. The road widths were assumed to be 10m. The silt content on the unpaved roads was not available and reference is therefore made to the default silt content published by the US EPA. Traffic on all unpaved roads was estimated using the number of operational vehicles per month.

For the mitigated scenario it was assumed that water sprays will be used to suppress dust on all haul roads.

Table 7-5: Parameters used in estimation of unpaved road emissions

Parameters Used in the Estimation of Unpaved Road Emissions

Parameter	Operational Scenario
Roads Included	In-Pit Roads Coal haul road Unpaved road 1 (from pit to topsoil and overhaul stockpiles) Unpaved road Topsoil (from unpaved road 1 to topsoil stockpile) Unpaved road 2 (continuation of unpaved road 1) Unpaved road Overhaul (from unpaved road 2 to overhaul stockpile) Unpaved road 1SE (from pit to south east (SE) topsoil and overhaul stockpiles) Unpaved road Topsoil SE (from unpaved road 1SE to SE topsoil stockpile) Unpaved road Overhaul SE (from unpaved road 1SE to SE overburden stockpile)
Total unpaved road length	18.05 km
Unpaved haul road width	10 m
Haul road silt content	8.4 %
Haul truck capacity	48.5 t
Haul truck average Weight	59.25 t
Total VKT on unpaved haul roads	4.94 km per hour
Mitigation Applied	Water Sprays – 75%

7.1.4 Wind-blown Dust

Wind-blown dust emissions were not estimated for the open pit. Calculations were done for wind erosion on the topsoil, overburden and ROM stockpiles.

Particle size distribution (Table 7-7), moisture content and bulk density of areas considered sources of wind-blown dust were acquired from an air quality impact study for a nearby mine with similar operations.

The stockpile parameters used for the calculation of emissions from proposed operations are shown in Table 7-6.

Table 7-6: Information Input into the AERMOD and ADDAS Models for Operations Stockpiles

Source	Height (m)	Area (m²)	Particle density (g/cm3)	Bulk density (kg/m3)	Moisture (%)
ROM stockpile	5	100	1.6	1000	8.4
Topsoil stockpiles	5	130,107.25	2.4	1200	6
Overburden stockpiles	5	203,174.56	2.5	1900	6

Table 7-7: Particle Size Distribution Used for the Proposed Mining Activities

SOURCE	PARTICLE SIZE FRACTION (%)							
	75µm	45µm	30µm	15µm	10µm	5µm	2.5 µm	1µm
Topsoil stockpiles	0.12	0.14	0.21	0.09	0.14	0.1	0.13	0.07
Overburden stockpiles	0.3	0.19	0.2	0.07	0.098	0.05	0.05	0.05
Run of Mine	0.28	0.16	0.2	0.07	0.1	0.05	0.07	0.07

7.2 Summary of Estimated Emissions

7.2.1 Operational Scenario

A summary emission inventory for Operational Scenario is given in Table 7-8.

Table 7-8: Summary of emissions for Operational Scenario

Source Group	Operational Scenario - Unmitigated Emissions [tpa]	
	PM10	TSP
Unpaved Roads	69.39	243.42
Bulldozing	44.21	152.37
Wind Erosion	32.72	72.65
Blasting	31.30	60.18
Drilling	0.57	1.08

Materials handling	0.12	0.26
Total	**178.30**	**529.95**

Source Group	Operational Scenario - Mitigated Emissions [tpa]	
	PM10	TSP
Bulldozing	22.10	76.18
Unpaved Roads	17.35	60.86
Wind Erosion	16.36	36.33
Blasting	15.65	30.09
Drilling	0.17	0.32
Materials handling	0.06	0.13
Total	**71.69**	**203.91**

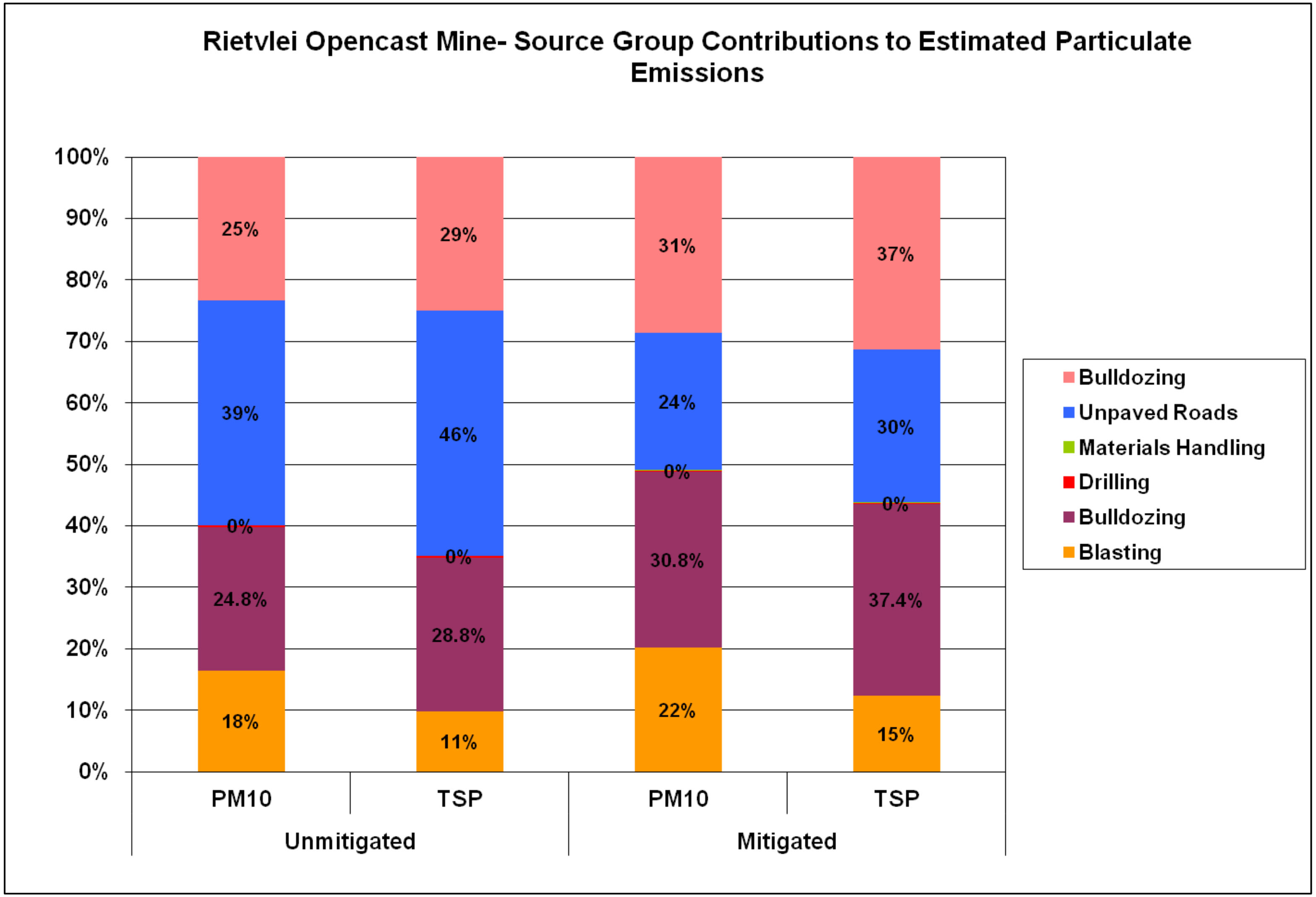

Figure 7-1: Source group contributions to emissions for Operational Scenario

7.3 Impact Assessment: Operational Phase

Dispersion modelling was undertaken to determine highest daily and annual average ground level concentrations for PM_{10} and total daily dust fallout rates. These averaging periods were selected to facilitate the comparison of predicted pollutant concentrations/ deposition with relevant air quality standards and SANS limits, respectively. Predicted GLCs are screened against the NAAQS and the dust fallout limits. In addition, dust fallout was also screened against the European threshold for vegetation impact.

Ground level concentration (GLC) isopleths plots presented in this section depict interpolated values from the concentrations predicted by AERMOD for each of the receptor grid points specified. Plots reflecting daily averaging periods contain only the 99.73^{th} percentile of 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 at certain locations, this may only be true for one day during the period.

Typically, ambient air quality applies to areas where the Occupational Health and Safety regulations do not apply, thus outside the mine property or lease area. Ambient air quality standards are therefore not occupational heath indicators but applicable to areas where the general public has access i.e. off-site. Farm houses and homesteads were included as discrete receptors.

7.3.1 PM_{10} concentrations due to operational phase activities

The PM_{10} concentrations were simulated for two scenarios and the description is outlined in Table 8-1.

Table 7-9: Scenarios simulated for the PM_{10} concentrations

Operational Scenario	○ All sources were simulated to determine the unmitigated impacts of the proposed operations. ○ All sources were simulated to determine the mitigated impacts of the proposed operations. ○ Mitigation measures applied result in the following mitigation efficiencies: 75% control efficiency for the unpaved roads, 50% for wind erosion sources.

- The predicted unmitigated and mitigated daily average ground level concentrations for the proposed mining operations don't exceed the daily NAAQS limit for 2015 of 75µg/m³ at any of the sensitive receptor sites.

- The predicted unmitigated and mitigated highest daily PM_{10} concentrations at the mine boundary exceeds the daily 2015 NAAQS limit of 75 µg/m³ over a small portion in the lower left region.

- The predicted unmitigated and mitigated highest daily PM10 concentrations on-site reach the daily 2015 NAAQS limit of 75 µg/m³, at and surrounding the stockpiles and over a portion of the pit. However, the frequency of exceedence is below four and thus within the standard.

- The predicted unmitigated annual average PM_{10} concentrations for the mining operations exceed the annual 2015 NAAQS of 40 µg/m³ at a small portion of the mine boundary.

- The predicted unmitigated and mitigated annual average PM_{10} concentrations for the mining operations exceeds the annual 2015 NAAQS of 40 µg/m³, at and surrounding the stockpiles and over a portion of the pit.

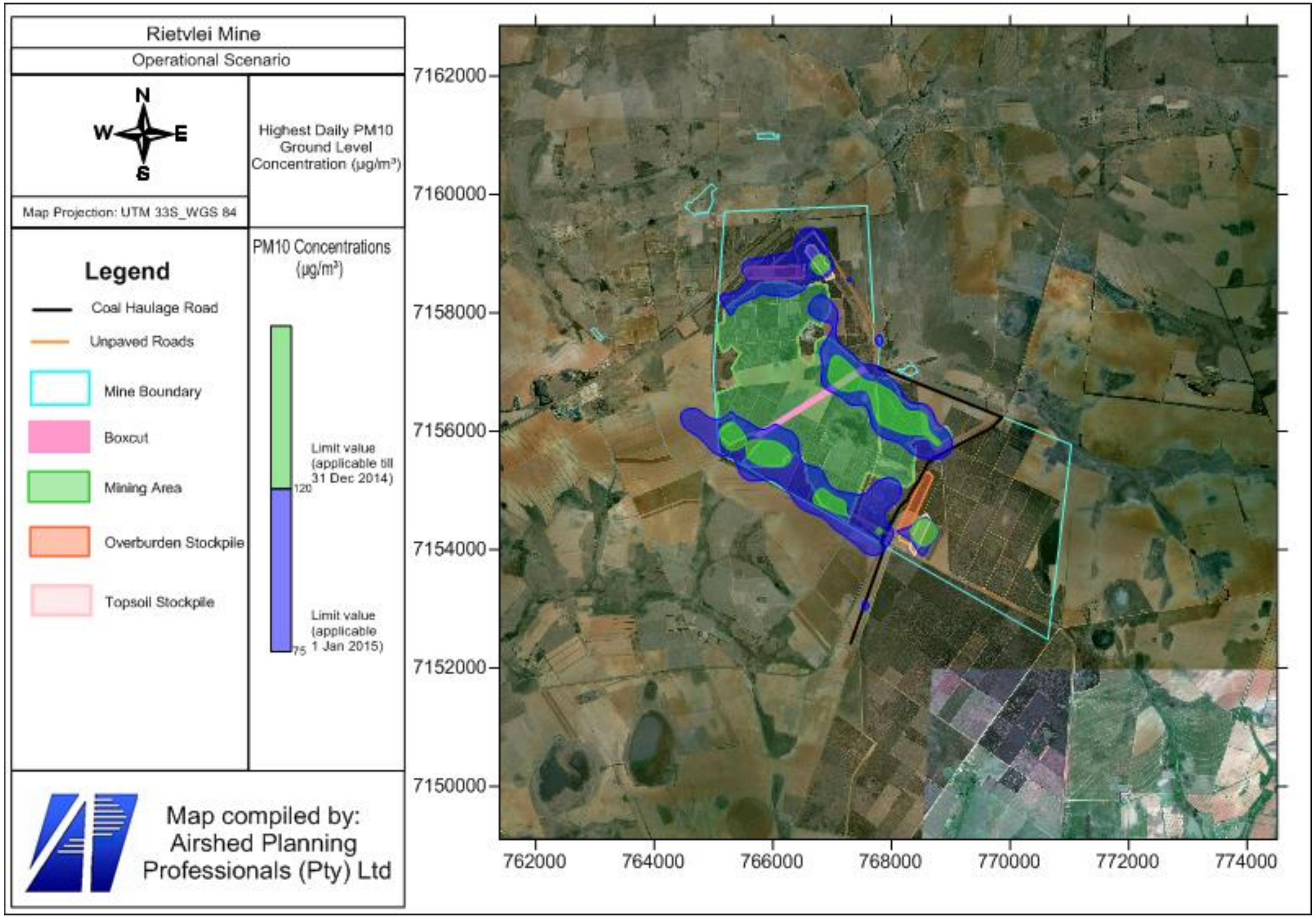

Figure 7-2: Highest daily average predicted PM_{10} ground level concentrations (µg/m³) for all sources due to uncontrolled emissions for the proposed operations

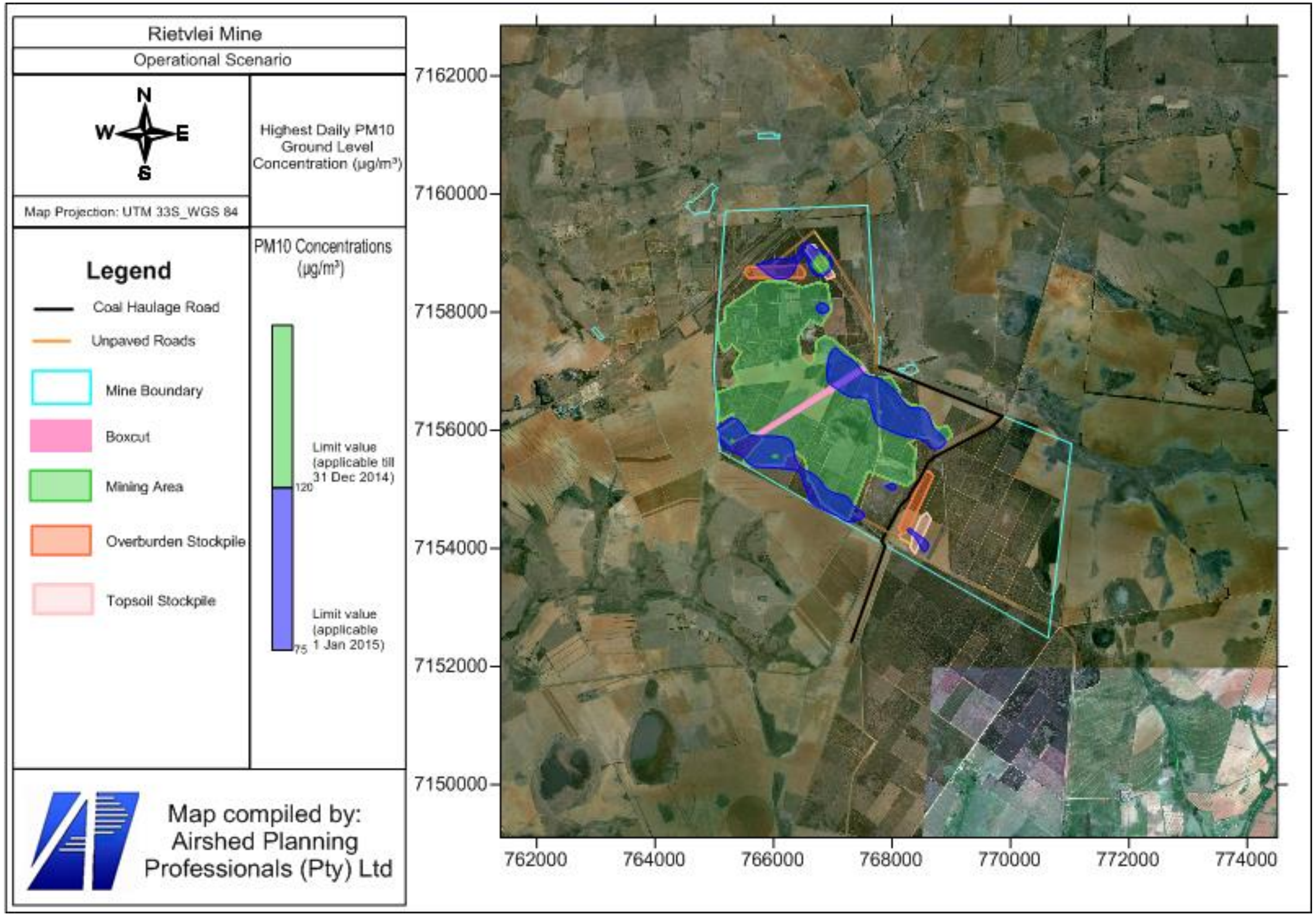

Figure 7-3: Highest daily average predicted PM_{10} ground level concentrations (µg/m³) for all sources due to controlled emissions for the proposed operations

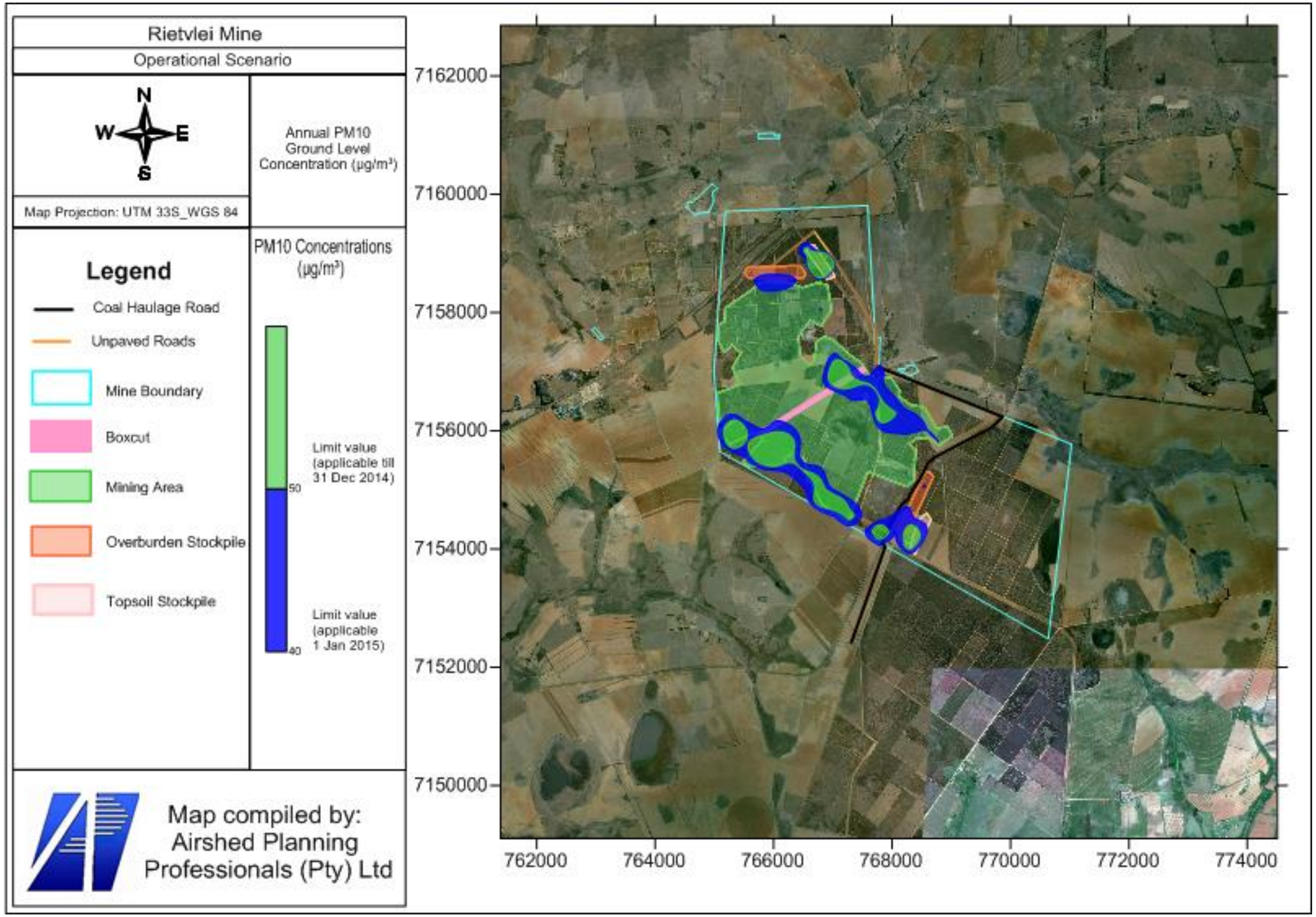

Figure 7-4: Annual average predicted PM_{10} concentrations (µg/m³) for all sources due to uncontrolled emissions for the proposed operations

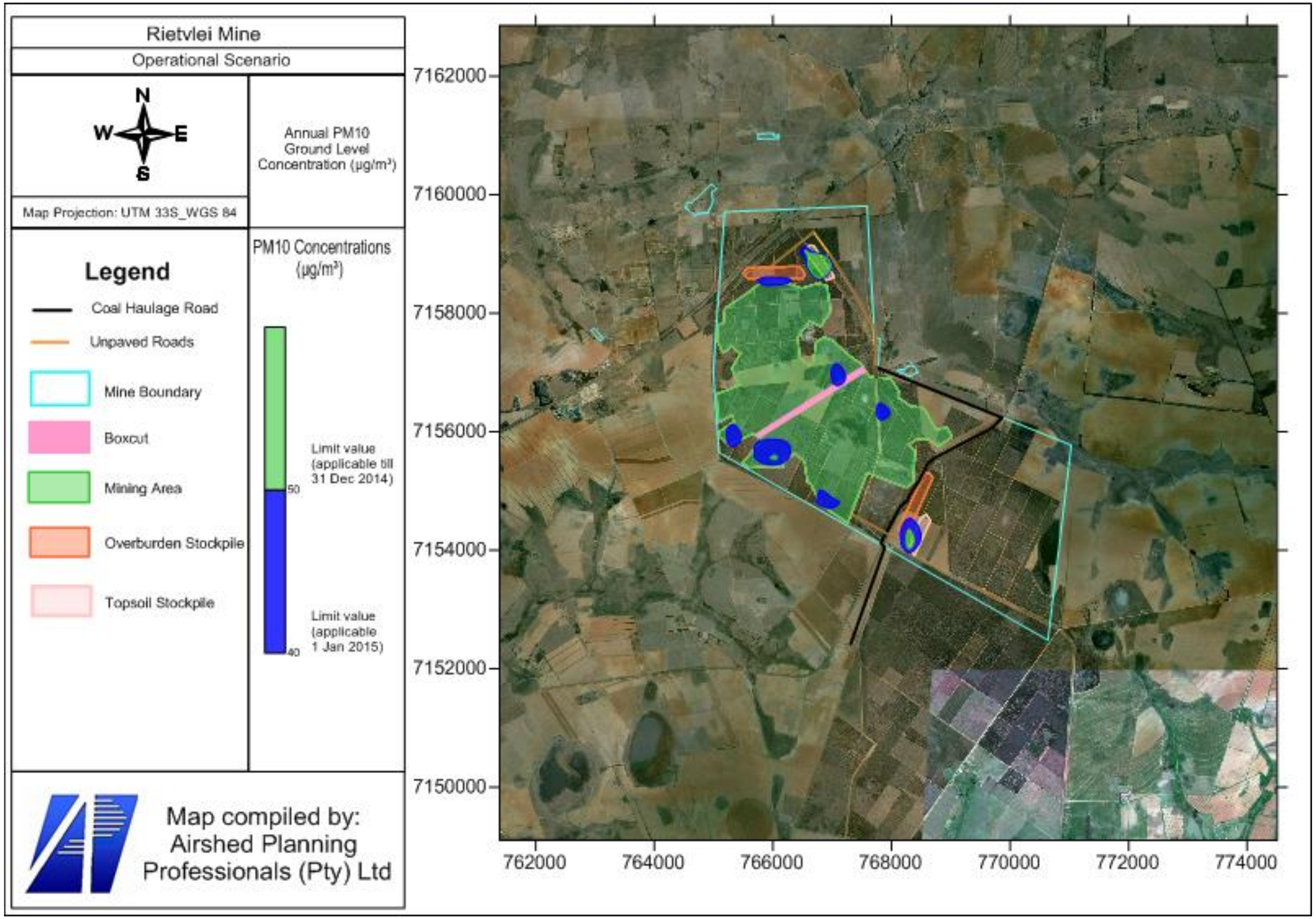

Figure 7-5: Annual average predicted PM_{10} concentrations (µg/m³) for all sources due to controlled emissions for the proposed operations

7.3.2 Dust deposition due to operational phase activities

Dust impacts are generally confined to the near-field (<1km to 3km) of sources. This is due to the fact that the larger particles, which contribute most to dust fall rates given their mass, are likely to settle out in close proximity to the source (assuming a ground-base source). The US-EPA (1992) estimates that for a typical mean wind speed (16km/hr (~4.4m/s), particles larger than about 100µm are likely to settle out within 6 to 9 metres from the edge of the source. Particles that are between 30µm and 100µm are subject to impeded settling, and are likely to settle out within 100 metres from the source.

Similar scenarios to those of PM_{10} were simulated for TSP (Table 7-9).

- The predicted unmitigated and mitigated maximum daily dust deposition rates for the proposed Rietvlei Mine operations do not exceed the SANS residential dust fallout limit of 600 mg/m²/day at the sensitive receptor sites for all sources.
- The predicted unmitigated and mitigated maximum daily dust deposition rates for the proposed Rietvlei Mine operations at the mine boundary do not exceeded the SANS residential limit of 600 mg/m²/day.
- The SANS residential dust fallout limit of 600 mg/m²/day was only predicted to be exceeded on-site, at and surrounding the northern topsoil stockpile.
- The SANS industrial dust fallout limit of 1200 mg/m²/day was only predicted to be exceeded on-site, at and surrounding the northern topsoil stockpile.

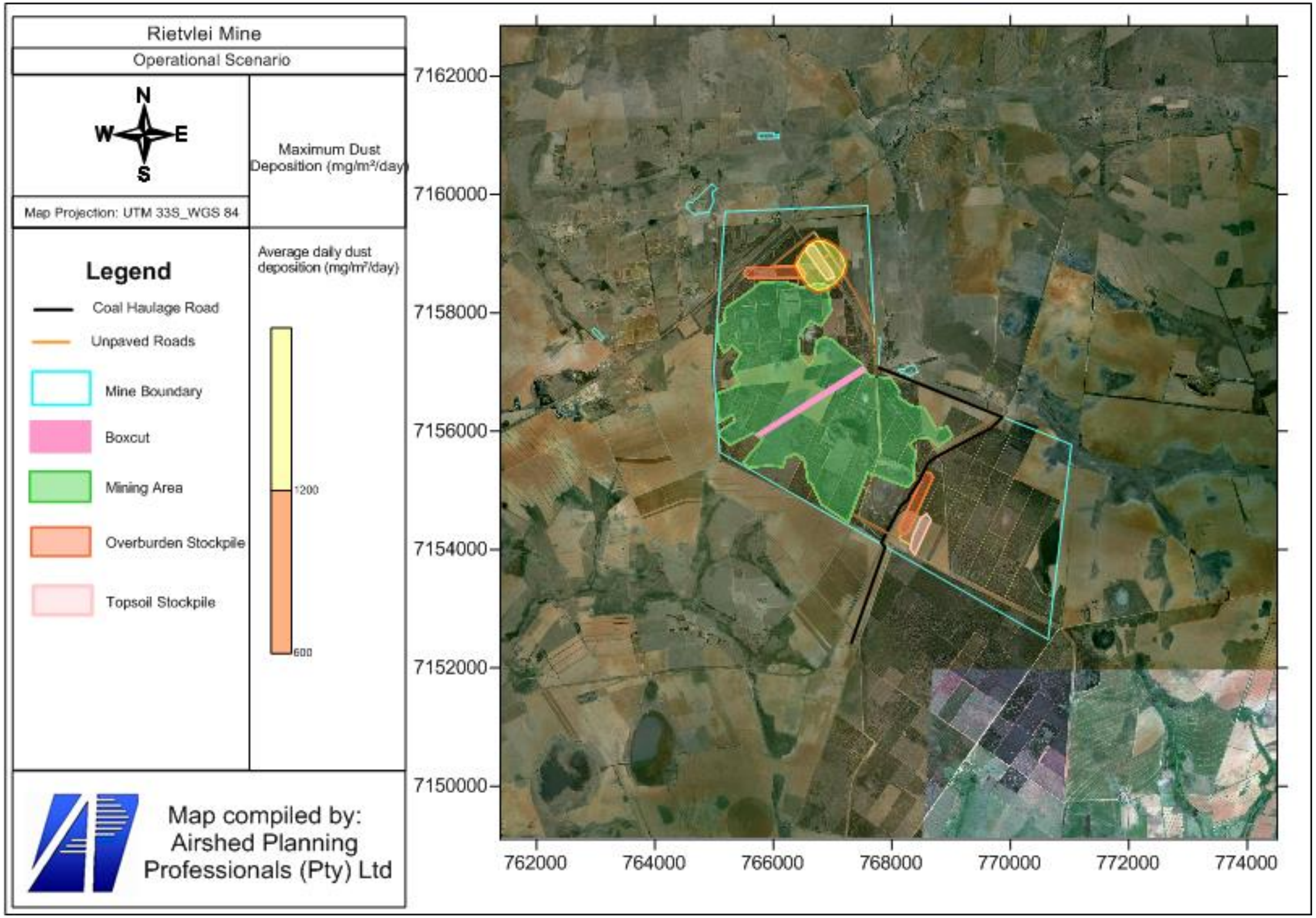

Figure 7-6: Maximum daily dust deposition rates (mg/m²/day) for all sources due to uncontrolled emissions during Rietvlei Mine operations

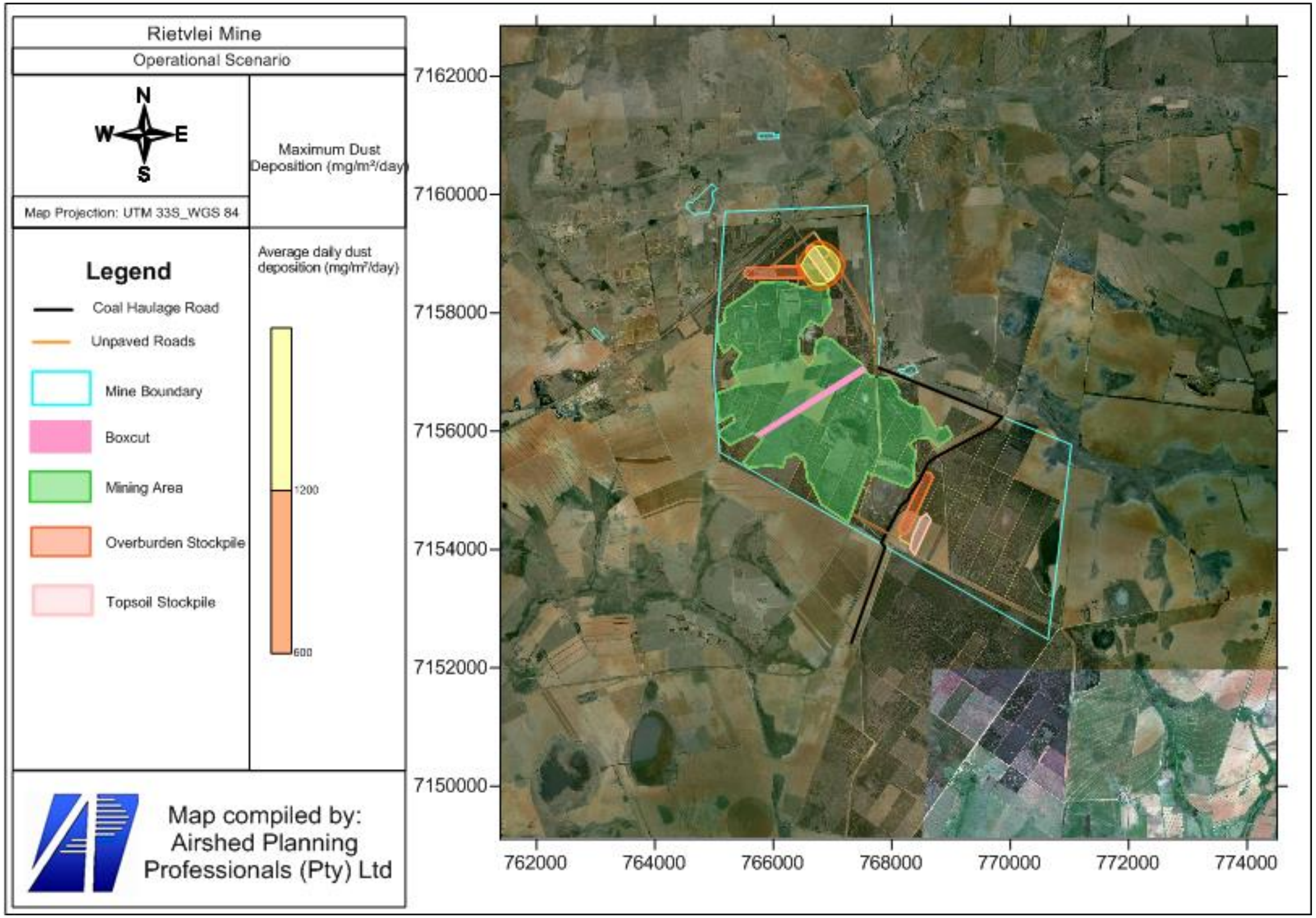

Figure 7-7: Maximum daily dust deposition rates (mg/m²/day) for all sources due to controlled emissions during Rietvlei Mine operations

8 CLOSURE PHASE

It is assumed that all mining activities and processing operations will have ceased by the closure phase of the project. The potentials for impacts during this phase will depend on the extent of demolition and rehabilitation efforts during closure.

Aspects and activities associated with the closure phase of the proposed mining operations at Rietvlei Mine are listed in Table 8-1.

Table 8-1: Activities and aspects identified for the closure phase of the proposed mining operations

Impact	Source	Activity
Generation of TSP and PM10	Unpaved roads	Vehicle entrainment on unpaved road surfaces
	Topsoil stockpiles	Topsoil recovered from stockpiles for rehabilitation and re-vegetation of surroundings
	Overburden stockpiles	Overburden removed from stockpiles for rehabilitation purposes
Gas emissions [(1)]	Blasting	Demolition of infrastructure may necessitate the use of blasting.
	Vehicles	Tailpipe emissions from vehicles utilised during the closure phase.

Notes:

[(1)] Gaseous emissions from tailpipes typically include: sulphur dioxide, oxides of nitrogen, carbon monoxide, hydrocarbons, lead (petrol powered vehicles only), potentially carbon dioxide.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

9.1.1 Baseline Characterisation: Meteorology

Predominant winds are from the north-west and east with strong wind speeds of up to 10m/s. Calm conditions (wind speeds below 1 m/s) occur 11.2% of the time. Day-time conditions show a similar pattern with winds predominantly from the north-westerly and easterly sectors, with an increase in frequency of winds from the north-westerly sector. Night-time conditions are characterised by winds from the north-easterly, easterly and south–easterly sectors. During the summer months, winds from the easterly, south easterly sectors dominate, with strong winds of up to 15 m/s occurring. During autumn, the strong winds of up to 8 m/s blow more frequently from the north-westerly, south easterly and easterly sectors. The winter months reflect dominancy of winds from the north-westerly sectors although there is a noticeably decrease in the frequency of winds from the south-easterly sector compared to the summer months. In spring, wind flow is predominant from the north-westerly and north-easterly sectors, with an increase in frequencies of occurrence being evident.

The Mpumalanga Highveld has been declared a priority area due to the concern for elevated PM_{10} and SO_2 concentrations. This is due to a range of industrial, power generation, domestic fuel burring and mining sources in the region, to name a few. The main pollutant of concern due to opencast coal mining operations is particulate matter, both as total suspended particulates (TSP) and as thoracic dust (PM_{10}) associated with health impacts.

9.1.2 Predicted Particulate Impacts

9.1.2.1 PM_{10}

Predicted impacts were screened using the NAAQS.

Since no baseline concentrations and fallout data exist for this region, it was not possible to provide a cumulative assessment. The cumulative concentrations (aggregate of baseline concentrations and proposed Rietvlei mine predicted concentrations) are therefore considered to be under-predicted. Due to the relatively high levels of particulate concentrations already experienced in the region, mitigation measures need to be considered and the effectiveness displayed.

For all the scenarios modelled, the predicted daily averaged PM_{10} ground-level concentrations only exceed the daily NAAQS limit of 75µg/m³ (2015) on-site but comply with the standard by not exceeding the limit more than four. The daily NAAQS limit of 75µg/m³ (2015) was not predicted to exceed at any of the sensitive receptors. The daily NAAQS limit of 75µg/m³ (2015) was predicted to exceed at a small portion of the mine boundary. Over an annual average exceedances were predicted for the annual 2015 NAAQS of 40 µg/m³ on-site at the stockpiles and portions of the open pit with and without mitigation in place. Over an annual average with and without mitigation in place no exceedances were predicted for the annual 2015 NAAQS of 40 µg/m³ at any of the sensitive receptors.

9.1.2.2 TSP

Maximum daily dust fallout levels for all the scenarios modelled were predicted to exceed the SANS residential limit of 600 mg/m²/day on-site at the north topsoil stockpile but not at the sensitive receptor sites or the mining boundary. With 75% control efficiency for the unpaved roads and 50% control efficiency for wind erosion, the impacts were reduced, although with higher control efficiencies, further reductions could be achieved.

9.2 Recommendations

9.2.1 Mitigation Recommendations

- Due to the generally high existing background particulate air concentrations in the region, it is recommended to control major contributing sources. Wind erosion of exposed areas should be kept to a minimum through watering programs and avoiding unnecessary disturbance of stabilised areas.

9.2.2 Monitoring Recommendations

- Dust fallout monitoring should continue to be carried out close to the sensitive receptors around the mine area. It is recommended that dust deposition sampling continue to be confined to sites within close proximity (< 2 km) to the proposed mine operations. Monitoring is undertaken using the American Society for Testing and Materials standard test method for the collection and analysis of dustfall (ASTM D-1739).

10 AIR QUALITY MANAGEMENT PLAN FOR RIETVLEI MINE

Even though the predicted impacts from the proposed Rietvlei Mine is regarded to be of low significance, with the location of the mine within the Highveld Priority Area, it is recommended that the project proponent committed itself to air quality management planning throughout the life of the mine. The dust management plan provides options on the control of dust at the main sources with the monitoring network designed as such to track the effectiveness of the mitigation measures.

As the main pollutant of concern in the current assessment was concluded to be dust in the form of TSP and PM_{10}, the management plan is focussed on the management and mitigation of particulates.

10.1 Site Specific Management Objectives

In order to define site specific management objectives, the main sources of pollution needed to be identified. Sources can be ranked based on source 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.

10.1.1 Source Ranking by Emissions

10.1.1.1 Construction Phase

Although no specific construction phase was modelled for this project, during the development of the proposed site, implementation of standard mining mitigation measures such as water sprays can be done to reduce the overall emissions (both TSP and PM10). Also, the implementation of dust abatement measures would restrict dust fall.

10.1.1.2 Operational Phase

The primary sources during operations are the unpaved roads and bulldozing sources as shown in Table 10-1. Unpaved roads were predicted to be the most significant source of both PM_{10} and TSP in this scenario, with a contribution of 38.92% to PM_{10} and TSP contribution of 45.93%. Bulldozing sources were predicted to be the second significant source of PM_{10} and TSP with source contribution of 24.80% and 28.75% respectively. Wind erosion was predicted to be the third most significant source of PM_{10} (18.35%) and TSP (13.71%). Blasting was predicted to the fourth most significant source of PM_{10} and TSP, while materials handling was predicted to be the least significant contributing source of PM10 and TSP.

Table 10-1: Synopsis of source contributions to PM_{10} and TSP for the unmitigated operations

Source	PM_{10} (tpa)	TSP (tpa)	PM_{10} %	TSP %
Unpaved Roads	69.39	243.42	38.92%	45.93%
Bulldozing	44.21	152.37	24.80%	28.75%
Wind Erosion	32.72	72.65	18.35%	13.71%
Blasting	31.30	60.18	17.55%	11.36%
Drilling	0.57	1.08	0.32%	0.20%
Materials handling	0.12	0.26	0.07%	0.05%
Total	**178.30**	**529.95**	**100.00**	**100.00**

tpa- tonnes per annum

Source ranking for the operations with mitigation for all the sources indicated that the bulldozing being the most significant source of both PM_{10} (30.83%) and TSP (37.36%). The unpaved sources were predicted to be the second significant source of PM_{10} and TSP with source contribution of 24.20% and 29.84% respectively. Wind erosion third, blasting fourth and drilling the fifth with materials handling predicted to be the least significant source of both PM_{10} and TSP (Table 10-2).

Table 10-2: Synopsis of source contributions to PM_{10} and TSP for the mitigated operations (75% for unpaved roads, and 50% for all the other sources)

Source	PM_{10} (tpa)	TSP (tpa)	PM_{10} %	TSP %
Bulldozing	22.10	76.18	30.83%	37.36%
Unpaved Roads	17.35	60.86	24.20%	29.84%
Wind Erosion	16.36	36.33	22.82%	17.81%
Blasting	15.65	30.09	21.83%	14.76%
Drilling	0.17	0.32	0.24%	0.16%
Materials handling	0.06	0.13	0.08%	0.06%
Total	**71.69**	**203.91**	**100.0**	**100.00**

tpa- tonnes per annum

10.1.2 Source Ranking by Impacts

Predicted impacts were screened using the NAAQS.

By taking all sources at the mine into account (for all the Scenarios), the predicted incremental PM_{10} concentrations do not exceed the NAAQS at any of the sensitive receptor areas located around the proposed mine.

Dust fallout levels were predicted to be well below the SANS residential limit of 600 mg/m²/day at the sensitive receptor sites during the operational phases of the proposed mine.

The main source of particulates resulting in on-site impacts (for both PM_{10} and TSP) during the operational phases of the mine is wind erosion from the stockpiles and bulldozing.

10.1.2.1 Closure Phase

The potential for impacts during the closure phase are dependent on the extent of demolition and rehabilitation efforts during closure. It was assumed that the potential for fugitive dust impacts due to these sources could be rendered negligible or of low environmental significance (and proven to be so) through comprehensive rehabilitation prior to closure being granted.

10.1.3 Target Control Efficiencies

10.1.3.1 Construction Phase

- Vehicle entrainment on unpaved roads – 75% control efficiency through effective water sprays on haul roads.

10.1.3.2 Operational Phase

- Vehicle entrainment on unpaved roads – 75% control efficiency through effective water sprays on haul roads.
- Wind erosion from topsoil stockpiles – 50% control efficiency through effective vegetation cover.

10.1.3.3 Closure Phase

- Vehicle entrainment on unpaved roads – 75% control efficiency through effective water sprays on water sprays
- Effective rehabilitation of mined out areas.

10.1.4 Identification of Suitable Pollution Abatement Measures

10.1.4.1 Vehicle Entrainment on Unpaved Haul Roads

Although vehicle entrained dust from unpaved road surfaces did not result in significant impacts on site during the operational phase predictions compared to the other sources, it is recommended that mitigation measures be considered on all unpaved haul roads

Three types of measures may be taken to reduce emissions from unpaved roads: (a) measures aimed at reducing the extent of unpaved roads, e.g. paving, (b) traffic control measures aimed at reducing the entrainment of material by restricting traffic volumes and reducing vehicle speeds, and (c) measures aimed at binding the surface material or enhancing moisture retention, such as wet suppression and chemical stabilization (EPA, 1987; Cowherd *et al.*, 1988; APCD, 1995). It is standard practice at most mines to utilise water trucks on the unpaved roads.

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 evaporation rates and traffic. It was estimated that water sprays resulting in at least 75% control efficiency would be a requirement to result in a significant reduction in ground level concentrations from all on-site haul roads. The amount of water needed to ensure 75% control efficiency on the various haul roads was calculated to be 0.058 litres/m²/hour.

The rate of watering required to ensure various control efficiencies, given site-specific evaporation rates and traffic rates, calculated on the basis of this model are illustrated in Figure 10-1. Average monthly evaporation rates, as averages for the Mpumalanga region, were used in the calculation (Schulze, 1997). As an example the watering rates required for 10 trucks per hour was included (return trips included).

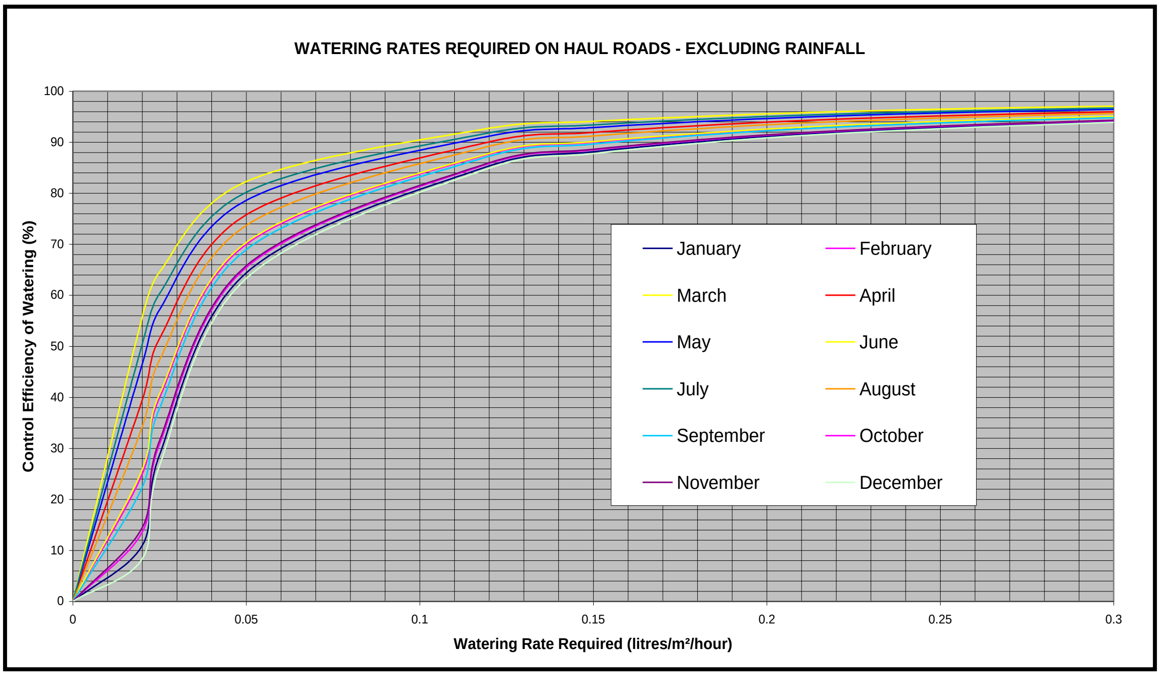

Figure 10-1: Watering rate required to ensure various control efficiencies for the haul roads given site-specific evaporation rates and traffic rates, using average evaporation rates for Mpumalanga

10.1.4.2 Wind Erosion

Wind erosion from the various stockpiles (topsoil, overburden etc) is a source of emissions. With no controls on the slopes and on the surfaces of the stockpiles, high impacts would be experienced. It is recommended that stockpiles be vegetated or covered up to 1 m from the top throughout the life of mine. Water sprays can also be used on uncovered stockpiles to reduce emissions.

It should be noted that the wind erosion equations are very sensitive to clay percentage, moisture content and particle size distribution of the material.

10.1.4.3 Materials Handling Operations

Materials handling operations have been identified as not such a significant source of emissions.

10.1.4.4 Blasting Operations

Although emissions from blasting would be significant during the construction phase, the duration of blasting would be only for a couple of minutes per day. It is however recommended that controlled blasting techniques be investigated since the visual reduction in dust emissions between a conventional blast and a controlled blast is significant.

10.1.5 Monitoring Requirements

10.1.5.1 Performance Indicators

Key performance indicators against which progress may be assessed form the basis for all effective environmental management practices. In the definition of key performance indicators careful attention is usually paid to ensure that progress towards their achievement is measurable, and that the targets set are achievable given available technology and experience.

Performance indicators are usually selected to reflect both the source of the emission directly and the impact on the receiving environment. Ensuring that no visible evidence of wind erosion exists represents an example of a source-based indicator, whereas maintaining off-site dustfall levels to below 600 $mg/m^2/day$ represents an impact- or receptor-based performance indicator. National Dust Control Regulations for dust fallout have been published as indicated in Section 2.

10.1.6 Specification of Source Based Performance Indicators

It is recommended that dust fallout in the immediate vicinity should be less than 1 200 $mg/m^2/day$ for unpaved roads associated with on-site activities.

The absence of visible dust plume at all tipping points would be the best indicator of effective control equipment in place. In addition the dust fall in the immediate vicinity of various sources should be less than 1 200 $mg/m^2/day$. Dust fall levels from all activities associated with proposed Rietvlei Mine should not exceed 600 $mg/m^2/day$ off-site.

10.1.7 Receptor based Performance Indicators

Based on the impacts predicted from the proposed mining operations on the surrounding environment and the limitations associated with the data used, it is recommended that the following be implemented:

- Continuation of the dust fallout network for the proposed operations and haul roads when these are in operation.
- Meteorological station

10.1.8 Dust fallout monitoring network

Since a dust fallout network does exist at the proposed Rietvlei Mine site, it is advisable that this be continued during operations. This will provide management with an indication of what the fugitive dust levels are once mining operations commence and will bring the mining operations in line with the Air Quality Act (no.39 of 2004). In addition, a dust fallout 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.

The dust fallout monitoring network included placing dust fallout buckets at the proposed open pit site and close to the unpaved road, the paved road, sensitive receptors, and proposed stockpiles. In Figure 4-1 the locations of dust buckets for a dust bucket network are represented by light blue circles in reference to proposed operations.

It is also recommended that a meteorological station be placed at the site to measure hourly average temperature, wind speed, wind direction, sigma theta (measure of horizontal stability of airflow) and relative humidity.

10.2 Record-keeping, Environmental Reporting and Community Liaison

10.2.1 Periodic Inspections and Audits

It is recommended that site inspections and progress reporting be undertaken at regular intervals (at least quarterly) during operations, with annual environmental audits being conducted. Annual environmental audits form part of an APCS and should occur at the Rietvlei Mine during its operation. Results from site inspections and off-site monitoring efforts should be combined to determine progress against source- and receptor-based performance indicators. Progress should be reported to all interested and affected parties, including authorities and persons affected by pollution.

Corrective action or the implementation of contingency measures must be proposed to the stakeholder forum in the event that progress towards targets is indicated by the quarterly/annual reviews to be unsatisfactory.

10.2.2 Liaison Strategy for Communication with I&APs

Stakeholder forums provide possibly the most effective mechanisms for information dissemination and consultation. EMPs should stipulate specific intervals at which forum meetings will be held, and provide information on how people will be notified of such meetings.

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12 APPENDIX A – PARTICULATE MATTER BACKGROUND INFORMATION

12.1 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).

12.2 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), 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 plays 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 from 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.

12.3 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, bioaerosols, 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 bioaerosols could lower feed efficiency, decrease growth, and increase morbidity and mortality. The study concurred the lack of information on the health effects and productivity problems of air contaminants on cattle and other livestock. 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 3).

13 APPENDIX B- MACRO – SCALE ATMOSPHERIC DISPERSION POTENTIAL

The macro-ventilation characteristics of the region are determined by the nature of the synoptic systems which dominate the circulation of the region, and the nature and frequency of occurrence of alternative systems and weather perturbations over the region.

13.1 Regional Climate

Situated in the subtropical high pressure belt, southern Africa is influenced by several high pressure cells, in addition to various circulation systems prevailing in the adjacent tropical and temperature latitudes. The mean circulation of the atmosphere over southern Africa is anticyclonic throughout the year (except near the surface) due to the dominance of three high pressure cells, viz. the South Atlantic HP off the west coast, the South Indian HP off the east coast, and the continental HP over the interior.

Five major synoptic scale circulation patterns dominate (Figure 13-1) (Vowinckel, 1956; Schulze, 1965; Taljaard, 1972; Preston-Whyte and Tyson, 1988). The most important of these is the semi-permanent, subtropical continental anticyclones which are shown by both Vowinckel (1956) and Tyson (1986) to dominate 70 % of the time during winter and 20 % of the time in summer. This leads to the establishment of extremely stable atmospheric conditions which can persist at various levels in the atmosphere for long periods.

Seasonal variations in the position and intensity of the HP cells determine the extent to which the tropical easterlies and the circumpolar westerlies impact on the atmosphere over the subcontinent. The tropical easterlies, and the occurrence of easterly waves and lows, affect most of southern Africa throughout the year. In winter, the high pressure belt intensifies and moves northward, the upper level circumpolar westerlies expand and displace the upper tropical easterlies equatorward. The winter weather of South Africa is, therefore, largely dominated by perturbations in the westerly circulation. Such perturbations take the form of a succession of cyclones or anticyclones moving eastwards around the coast or across the country. During summer months, the anticyclonic belt weakens and shifts southwards, allowing the tropical easterly flow to resume its influence over South Africa. A weak heat low characterises the near surface summer circulation over the interior, replacing the strongly anticyclonic winter-time circulation (Schulze, 1986; Preston-Whyte and Tyson, 1988).

Anticyclones situated over the subcontinent are associated with convergence in the upper levels of the troposphere, strong subsidence throughout the troposphere, and divergence in the near-surface wind field. Subsidence inversions, fine conditions with little or no rainfall, and light variable winds occur as a result of such widespread anticyclonic subsidence. Anticyclones occur most frequently over the interior during winter months, with a maximum frequency of occurrence of 79 percent in June and July. During December such anticyclones only occur 11 percent of the time. Although widespread subsidence dominates the winter months, weather occurs as a result of uplift produced by localized systems.

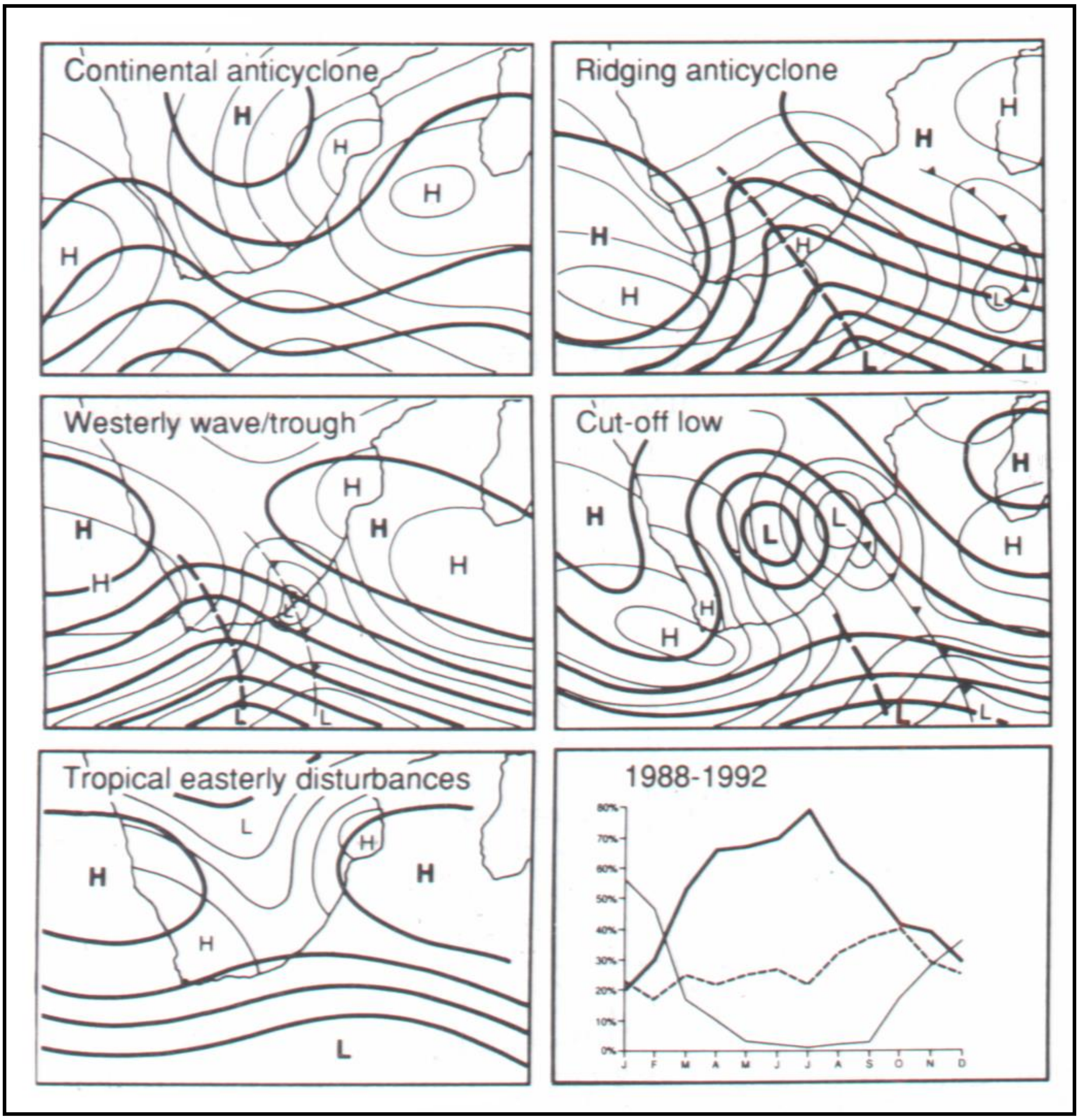

Figure 13-1: Major synoptic circulation types affecting southern Africa and their monthly frequencies of occurrence over a five year period (after Preston-Whyte and Tyson, 1988 and Garstang et al., 1996a)

Tropical easterly waves give rise to surface convergence and upper air (500 hPa) divergence to the east of the wave resulting in strong uplift, instability and the potential for precipitation. To the west of the wave, surface divergence and upper-level convergence produces subsidence, and consequently fine clear conditions with no precipitation. Easterly lows are usually deeper systems than are easterly waves, with upper-level divergence to the east of the low occurring at higher levels resulting in strong uplift through the 500 hPa level and the occurrence of copious rains. Easterly waves and lows occur almost exclusively during summer months, and are largely responsible for the summer rainfall pattern and the northerly wind component which occurs over the interior.

Westerly waves are characterised by concomitant surface convergence and upper-level divergence which produce sustained uplift, cloud and the potential for precipitation to the rear of the trough. Cold fronts are associated with westerly waves and occur predominantly during winter when the amplitude of such disturbances is greatest. Low-level convergence in the southerly airflow occurs to the rear of the front producing favourable conditions for convection. Airflow ahead of the front has a distinct northerly component, and stable and generally cloud-free conditions prevail as a result of subsidence and low-level divergence. The passage of a cold front is therefore characterised by distinctive cloud bands and pronounced variations in wind direction, wind speeds, temperature, humidity, and surface pressure. Following the passage of the cold front the northerly wind is replaced by winds with a distinct southerly component. Temperature decrease immediately after the passage of the front, with minimum temperatures being experienced on the first morning after the cloud associated with the front clears. Strong radiational cooling due to the absence of cloud cover, and the advection of cold southerly air combining to produce the lowest temperatures.

13.2 Regional Atmospheric Dispersion Potential

The impact of various synoptic systems and weather disturbances on the dispersion potential of the atmosphere largely depends on the effect of such systems on the height and persistence of elevated inversions. Elevated inversions suppress the diffusion and vertical dispersion of pollutants by reducing the height to which such pollutants are able to mix, and consequently result in the concentration of pollutants below their bases. Such inversions therefore play an important role in controlling the long-range transport, and recirculation of pollution.

Subsidence inversions, which represent the predominant type of elevated inversion occurring over South Africa, result from the large-scale anticyclonic activity which dominates the synoptic circulation of the subcontinent. Subsiding air warms adiabatically to temperatures in excess of those in the mixed boundary layer. The interface between the subsiding air and the mixed boundary layer is thus characterised by a marked elevated inversion. Protracted periods of anticyclonic weather, such as characterize the plateau during winter, result in subsidence inversions which are persistent in time, and continuous over considerable distances. The fairly constant afternoon mixing depths, with little diurnal variation, associated with the persistence of subsidence inversions, are believed to greatly reduce the dispersion potential of the atmosphere over the plateau, resulting in the accumulation of pollutants over the region.

Multiple elevated inversions occur in the middle to upper troposphere as a result of large-scale anticyclonic subsidence. The mean annual height and depth of such absolutely stable layers are illustrated in Figure 13-2. Three distinct elevated inversions, situated at altitudes of approximately 700 hPa (~3 km), 500 hPa (~5 km) and 300 hPa (~7 km), were identified over southern Africa. The height and persistence of such elevated inversions vary with latitudinal and longitudinal position. During winter months the first elevated inversion is located at an altitude of around 3 km over the plateau. In summer this inversion is known to increase in to 4 to 5 km over the plateau (Diab, 1975; Cosijn, 1996).

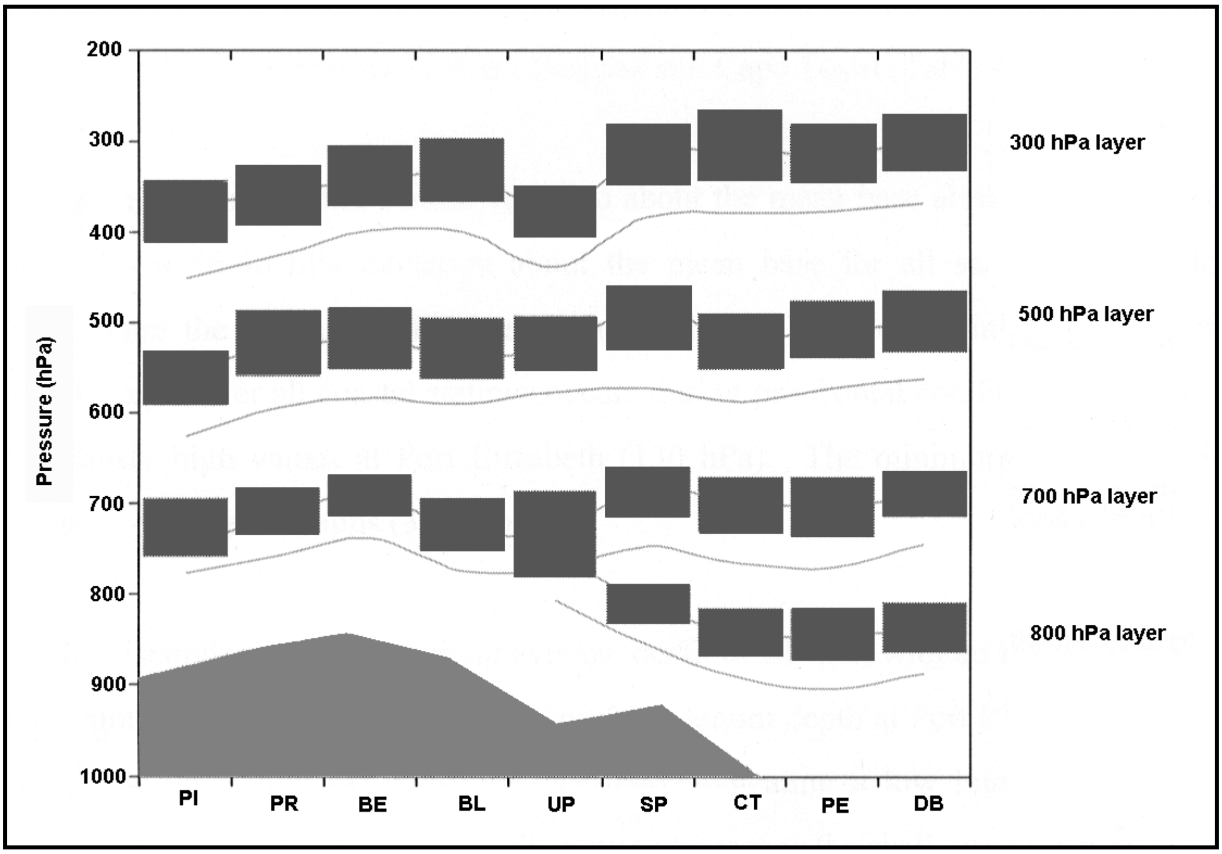

Figure 13-2: Mean annual stable layers (shaded) over Pietersburg (PI), Pretoria (PR), Bethlehem (BE), Bloemfontein (BL), Upington (UP), Springbok (SP), Cape Town (CT), Port Elizabeth (PE) and Durban DB). Upper and lower 95% confidence limits for the base heights

In contrast to anticyclonic circulation, convective activity associated with westerly and easterly wave disturbances hinders the formation of inversions. Cyclonic disturbances, which are associated with strong winds and upward vertical air motion, either destroy, weaken, or increase the altitude of, elevated inversions. Although cyclonic disturbances are generally associated with the dissipation of inversions, pre-frontal conditions tend to lower the base of the elevated inversion, so reducing the mixing depth. Pre-frontal conditions are also characterised by relatively calm winds. Over the interior due to the passage of a cold front, there is a tendency for the lowest mixing depths to coincide with the coldest air temperatures and rising pressure. Following the passage of the front, a gradual rise in the mixing depth occurs over the interior (Cosijn, 1996; Preston-Whyte and Tyson, 1988).

14 APPENDIX C- TECHNICAL DESCRIPTION OF EMISSIONS QUANTIFICATION

14.1 Materials Handling

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 emissions from material transfer operations:

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

where,

E = *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)*

14.2 Bulldozer Operations

The US-EPA provides an emissions equation specifically for activities from bulldozers since this equation takes silt content and moisture into account. This was taken from the Western Surface Coal Mining specifications for opencast mining activities.

The emissions from dozing of waste were calculated using the following equation:

$$E_{TSP} = \frac{2.6(s)^{1.2}}{M^{1.3}}$$

$$E_{PM10} = \frac{0.45(s)^{1.2}}{M^{1.4}} \cdot 0.75$$

Where:

E_{TSP}	=	Total Suspended Particulates emission factor (kg dust/hr)
E_{PM10}	=	Particulate emission factor (kg dust/hr) for particulates less than 10µm
s	=	Material silt content (%)
M	=	Material moisture content (%)

14.3 Grader Operations

The US-EPA provides an emissions equation specifically for grading activities:

$$E_{TSP} = 0.0034 \cdot S^{2.5}$$

$$E_{PM10} = 0.0034 \cdot S^{2.0}$$

Where:

E_{TSP}	=	Total Suspended Particulates emission factor (kg/VKT)
E_{PM10}	=	Particulate emission factor (kg/VKT) for particulates less than 10µm

S = mean vehicle speed in km/hr

14.4 Vehicle Entrained Dust from Unpaved 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:

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

Where,

E = *emissions in lb of particulates per vehicle mile 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.

14.5 Wind Blown Dust

Significant 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 area, 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 contents, whether due to precipitation or deliberate wetting, promote 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, which may be anticipated (Burger et al., 1997).

The calculation of emission rates for various wind speeds and stability classes representative of the simulation period was carried out using the ADDAS model. This model is based on the dust emission model by Marticorena and 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:

$$E_{(i)}=G_{(i)}10^{(0.134(\%clay)-6)}$$

For

$$G_{(i)}=0.261[P_a/g]u^{*3}(1+R)(1-R^2)$$

And

$$R=u^{*t}/u^*$$

where,

$E_{(i)}$ = *emission rate (g/m²/s) for particle size class i*

P_a = *air density (g/cm³)*

g = *gravitational acceleration (cm/s³)*

u_*^t = *threshold friction velocity (m/s) for particle size i*

u^* = *friction velocity (m/s)*

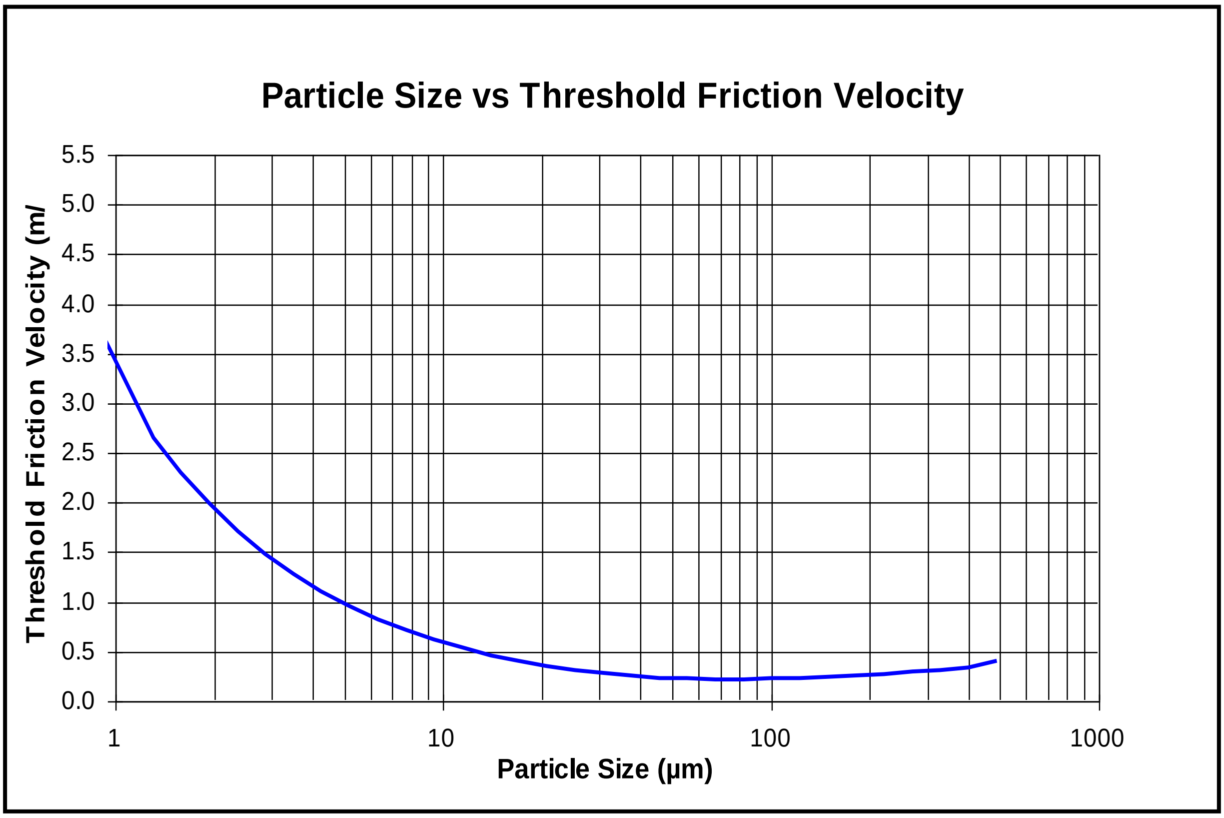

Figure 14-1: Relationship between particle sizes and threshold friction velocities

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 to initiate 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 by Marticorena and Bergametti (1995), is illustrated in Figure 14-1.

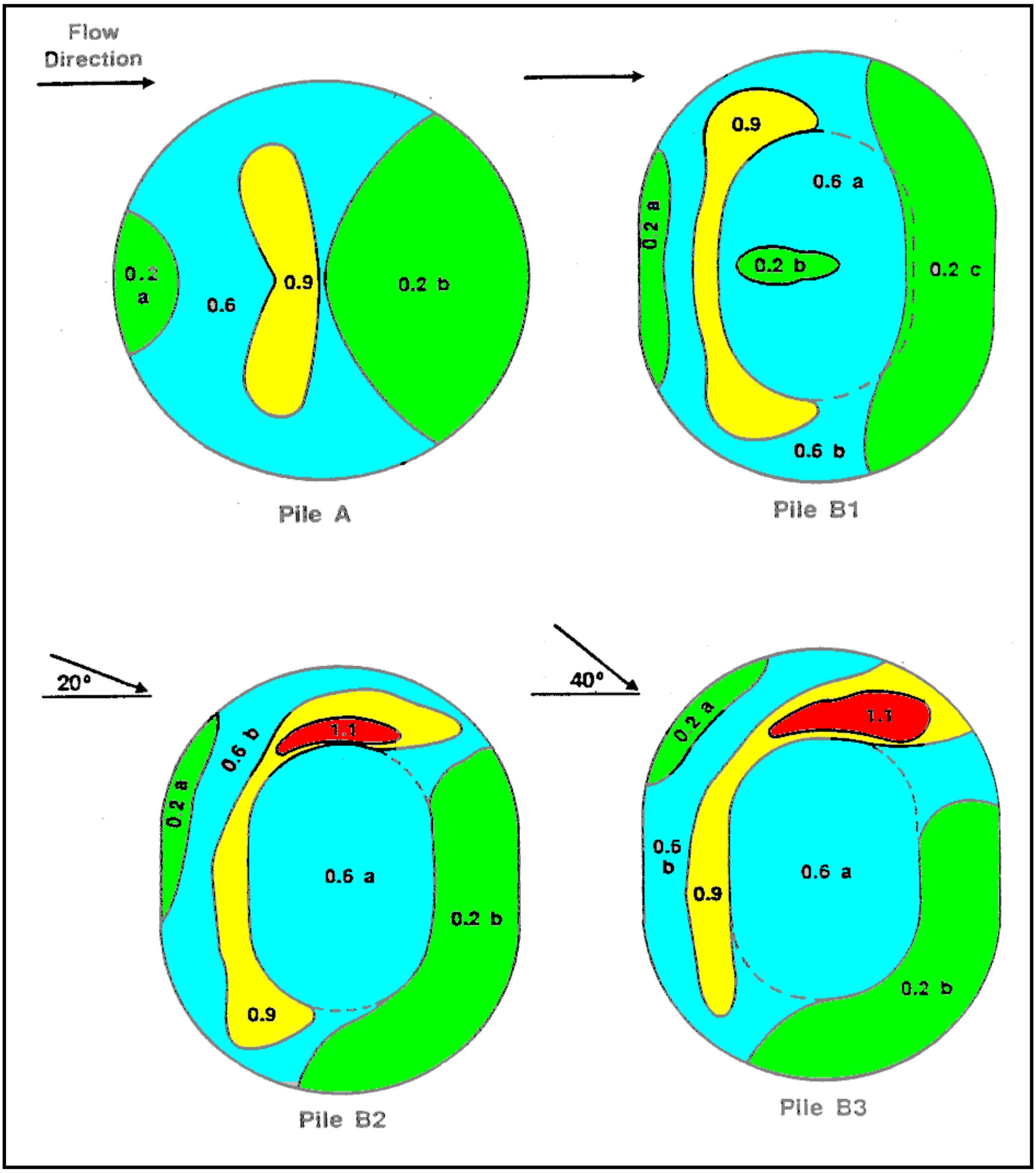

Figure 14-2: Contours of normalised surface wind speeds

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).

(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 area is based on the work of Cowherd et al. (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 area. 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 Figure 14-2 (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 (the higher the ratio, the greater the wind exposure potential).

15 APPENDIX D- CHECKLIST FOR DUST CONTROL (AFTER ENVIRONMENT AUSTRALIA, 1998).

Table 15-1: Checklist for Dust Control (After Environment Australia, 1998)

ISSUE	OUTPUTS	PERFORMANCE MEASURES	IMPROVEMENT
Information and Planning			
HAVE YOU, determined the sources of dust in the operations?	Potential sources of dust identified in the EIA	Comprehensive list of individual sources	Sources considered for each stage of the mine (i.e. exploration, construction, operation, decommissioning, rehabilitation and closure)
HAVE YOU attempted to characterise the types of dust and quantities produced (modelling)?	Estimates of dust types and levels to be produced Dust emission inventory and determination of dust emission factors	Estimates based on typical measured levels for a mining plant. Dust inventory is derived by analysing the mine plan to establish potential dust sources and estimate the level of dust-producing activity associated with each source. Emission factors are derived by assessing the quantifiable activities or aspects which generate dust, such as vehicle size, speed and distance travelled on haul roads.	Estimates, inventory and emission factors made for all potential sources for each stage of the mine (emission factors are only applicable when emissions are to be modelled).
DOES YOUR characterisation of the types and quantities of dust include diffuse dust sources?	All types and locations of dust emissions can be ranked and controls planned in a systematic manner	Quantitative estimates of dust emission rates from different classes of mining activity and land surface types	Use of models to produce estimates of dust types and levels across a wide range of operating and climatic conditions
HAVE YOU undertaken an impact assessment?	Identification of sensitive receptor areas Assessment of maximum levels to avoid impacts, significant concerns or discomfort	Assessment identifies dust levels likely to be experienced by workers and at key locations.	The potential health risk from dust is related to the size of dust particles. Mine dust lies in the range of 1-100 µ

ISSUE	OUTPUTS	PERFORMANCE MEASURES	IMPROVEMENT
HAVE YOU developed a draft management strategy, based on the impact assessment?	Incorporates input from the community and the regulatory authorities Addresses all environmental and social issues likely to arise from dust at the proposed project	Initial planning should include development of a draft management strategy which: • Identifies all the potential sources and risks • Sets out objectives for environmental protection and risk minimisation • Provides a framework for evaluating different options and choosing a design which reflects site conditions and environmental sensitivities	Consultation with key stakeholders during preparations of the draft management strategy
HAVE YOU devised approaches to mitigate impacts to acceptable levels?	Strategy incorporates "built in" design features to minimise the generation of dust at source	Strategy includes addressing the mitigation of dust	The EIA and mine plan for the project set out in a framework based upon: Mine design to avoid the generation of dust Systems design and management to minimise the generation of dust during operations Treatment of dust problems through active monitoring and response, and redesign of strategies if required.
Information and Planning Continued			
HAVE YOU considered the probable regulatory requirements?	Level to which targets in the strategy conform to standards and regulations taking into account estimates of inputs from all probable sources of dust.	Dust strategy describes relevant standards and regulations	
ARE THE target levels developed in	Documented agreement on maximum permissible levels	Maximum dust levels explained and agreed with the	Establishment of formal and frequent consultation with the local community early in the planning

ISSUE	OUTPUTS	PERFORMANCE MEASURES	IMPROVEMENT
consultation with the community?	between company and key community group/s	community	process.
DO THE provisions of the dust management plan also apply to the decommissioning, rehabilitation, and closure stages?	Smooth transition from operational to decommissioning stages, with low risk of exceedance of dust control targets.	Decommissioning, rehabilitation and closure plans for all include provisions for control of dust.	Plans incorporate provisions which must reflect the specific activities involved at the end of mining.
Management and Operation			
HAVE YOU prepared an operational dust management plan?	Dust management plan	The management plan: • sets out targets and management strategies for all issues identified in the impact assessment and in community consultations • must be integrated with other operational plans into an overall environmental management system	ISO 14001 accreditation may help to demonstrate the environmental commitment to regulators and other stakeholders.
IS the management plan known and understood by all staff including plant operators?	Staff awareness of the management plan and its contents	Relevant documentation must be available to staff, regulators and auditors.	Management plan available to staff, staff instructions on the control of dust, regular checks on effectiveness of operational systems, dust included in environmental awareness training seasons.
HAVE YOU selected appropriate options to minimise the generation of dust?	Few significant issues related to dust at site	Evidence of good design to reduce dust generation through mine design, choice of equipment, and work practices Consistent application of good design across all types of dust sources, including road transport outside the mining area.	The use of computer modelling to investigate the control measures needed to achieve targets.

ISSUE	OUTPUTS	PERFORMANCE MEASURES	IMPROVEMENT
HAVE YOU incorporated design features to mitigate the potential impacts from the dust generated at site?	Few significant issues related to dust at the site	Evidence of installation of engineering works, equipment modification etc to minimise dust Any significant dust sources identified via monitoring have been objectively evaluated and remedial action taken.	All reasonable measures taken to reduce from all fixed and mobile equipment
DO YOU have operational systems to control dust in all areas with dust potential?	Procedures described in the mine plan and EIA implemented correctly, and dust control targets achieved.	The EIA and related manuals will set out procedures for dust management in all relevant areas of the site	Documented procedures need to cover all mining activities.
Management and Operation Continued			
IS THERE documentation to demonstrate that the dust management plan is carried out properly?	Assurance to managers that dust control targets for the operation are being met.	Regular reports (monthly) of dust management activities and assessment against control targets and requirements of the management plan.	Standard operating procedures for staff working in dusty areas, operating dusty equipment, and involved in drilling and blasting activity, setting out responsibilities, and methods for limiting and reporting dust levels and incidents.
DO YOU have a system in place to incorporate improvement?	Continual improvement and reduced probability of recurrence of undesirable dust events	Evidence of review and update of systems and equipment where unsatisfactory dust levels have been recorded.	Assessment of the adequacy of dust control should be incorporated in annual environmental audits of the project.
Monitoring and Assessment			
IS THERE a monitoring regime in place which addresses all of the possible areas for environmental and social impact from dust identified at the	The level of performance of dust control and potential impacts on workers, the public and environment is well known to managers	Comprehensive monitoring regime which includes measurement of levels in worker areas and areas of the community sensitivity. Monitoring regime sets out:	Reporting and record keeping includes: Recording intervals

ISSUE	OUTPUTS	PERFORMANCE MEASURES	IMPROVEMENT
planning stage?		• Parameters to be monitored • Monitoring locations • Monitoring interval • Data and data analysis requirements for monitoring reports • Reporting interval	Location of attended and unattended monitoring instruments Comparison of monitoring results with those from modelling (if applicable)
ARE environmental and community targets set, and are the layout, techniques, frequency, quality and sensitivity of monitoring and sampling appropriate to these targets?	Low probability of community concern provided dust is controlled to within levels agreed by the community.	Control targets agreed with the community are set out in the management plan and monitoring regime and are used as key benchmarks to evaluate adequacy of performance in regular monitoring reports.	Tools for effective dust monitoring include: Baseline sampling Control site sampling Dust deposition gauges (provides long term data) High volume samplers (quantitative data over 24hr periods) Continuous particle monitors (provides data relevant to sort term events) Size-selective samplers (samples dust in size fractions) Personal exposure samplers (worn by workers)
IS monitoring undertaken in accordance with appropriate standards?	High level of assurance or the reliability of dust monitoring results	Evidence that monitoring techniques accord with appropriate standards	Measures outlined in the South African National Standards, SANS 1929:2004 are recommended.

ISSUE	OUTPUTS	PERFORMANCE MEASURES	IMPROVEMENT
Monitoring and Assessment Continued			
DOES monitoring include meteorological data?	Proactive management of site activities can be undertaken to avoid significant dust events in periods of bad weather.	Routine collection of data on predicted rainfall, temperature and wind velocity	The erection of a site specific meteorological is highly recommended.
ARE data collected in accordance with the requirements of the monitoring regime?	Low risk of regulatory non-compliance or of community concerns regarding dust.	Monthly and annual reports of dust data, which cross refer to monitoring requirements	
ARE the data analysed and regularly reported to the regulatory authorities?	Assurance that all regulatory requirements for dust are being met continuously	Regular reports (i.e., monthly) provided, where deemed necessary.	Dust control performance is reported against community-agreed targets in public reports.
ARE non-compliance issues or abnormalities in the data routinely recorded?	Management aware of any areas of poor performance Management provides an ongoing measure of effectiveness of the current system and past improvements	Register of non-compliance and unplanned events, indicates time of event, time of action, type of action, result and interaction with authorities.	Regulatory authority advised immediately of all non-compliance and sign cant unplanned events.
IS THERE a system in place for significant dust events or issues to be addressed to reduce prospects of recurrence?	Reduced risk of recurrence of significant dust events	Evidence that entries in the register of non-compliance and unplanned events are investigated properly and appropriate remedial action is identified and implemented promptly.	Standard deadline set for completion of actions to remedy dust events. Number of entries in the register and speed of actioning improvements can be used as reporting criteria to staff, management, regulators, and the community.
IS liaison with the community maintained in relation to dust issues?	Good community relationships maintained	Documentation of regular community liaison that addresses issues of dust.	Community meetings / stakeholder forum held regularly with dust standing as an agenda item. Special meeting held immediately after a significant

ISSUE	OUTPUTS	PERFORMANCE MEASURES	IMPROVEMENT
			event raising community concern
IS a complaints register maintained and are complaints investigated?	Areas of poor dust control are addressed quickly so that the risk of recurrence is minimised Good community relationships must be maintained.	Documented complaints register which records details of complaints and any follow-up action.	Register records date, time, and type of event, which is the subject of the complaint; follow-up action, risk of recurrence. Reporting back to the complainant

16 APPENDIX E:- EVALUATION OF SUSPENDED PARTICULATE SAMPLERS

Suspended particle samplers can be *filter-based* or *non-filter-based, intermittent* or *continuous* and *off-line* or *near real time*.

16.1 Filter-based Monitors

Filter-based monitors include various *off-line* samplers, such as stacked filter units (SFU) and sequential air samplers, and certain continuous *real-time* monitors such as the Tapered Element Oscillating Microbalance (TEOM) and the beta gauge or beta-attenuation mass (BAM) monitors.

16.1.1 Filter-based, Off-line Samplers (SFUs, Sequential Samplers)

Stacked filter units and sequential air samplers are most frequently used when elemental, ionic and/or carbon analyses are required of the measured particulates. Filters are required to be weighed prior to their being loaded in the sampler for exposure in the field. Following exposure the filters are removed are reweighed in a lab to determine the particulate concentration. The filters may then be sent for elemental (etc.) analysis. Teflon-membrane filters are commonly used for mass and elemental analysis.

Sequential air samplers with sequential dichotomous configurations splits the PM10 sample stream into its fine (PM2.5) and coarse (particles between 2.5 and 10 µm in size) fractions - collecting the fine and coarse mode particulates simultaneously on two different filters. Certain of these systems (e.g. Partisol-Plus Air Samplers, Figure 16-1) have capacities of up to 16 filter cassettes with an automatic filter exchange mechanism. (Filter changes can be triggered on a temporal basis or based on wind direction.) Once the 16 filters have been exposed, the filters would require collection and replacement.

Figure 16-1: Partisol-Plus Sequential Air Sampler

Key disadvantages of *off-line* filter-based samplers such as the SFU and sequential air sampler include: the labour intensive nature of this monitoring technique and the large potential which exists for filter contamination due to the level of filter handling required. Real-time measurements are also not possible through the application of these samplers making it impossible to identify pollution episodes on a timely basis.

16.1.2 Filter-based, On-line Samplers (TEOM, BAM)

The TEOM is operates by continuously measuring the weight of particles deposited onto a filter. The filter is attached to a hollow tapered element which vibrates at its natural frequency of oscillation - as particles progressively collect on the filter, the frequency changes by an amount proportional to the mass deposited. As the airflow through the system is regulated, it is possible to determine the concentration of particulates in the air. The filter requires changing periodically, typically every 2 to 4 weeks, and the instrument is cleaned whenever the filter is changed. Different inlet arrangements are used to configure the instrument. TEOMs can monitor PM10, PM2.5, PM1 and TSP continuously. Data averages and update intervals include: 5-minute total mass average (every 2 seconds), 10-minute rolling averages (every 2 seconds), 1-hour averages, 8-hour averages, 24-hour averages (etc.). The TEOM has a minimum detection limit of 0.01 $\mu g/m^3$.

Beta attenuation monitors collect particulates on a filter paper over a specified cycle time. The attenuation of beta particles through the filter is continuously measured over this time. BAMs give real-time measurement of either TSP, PM10 or PM2.5 depending on the inlet arrangement. At the start of the cycle, air is drawn through a glass fibre filter tape, where the particulates deposit. Beta particles that are emitted from either a C14 or a K85 sources are attenuated by the particles collecting on the filter. The radiation passing through the tape is detected by a scintillator and photomultiplier assembly. A reference measurement is made through a clean portion of the filter, either during or prior to the accumulation of the particles - the measurement enables baseline shifts to be corrected for.

Application of filter-based, on-line samplers such as either the BAM or TEOM monitors has several distinct advantages including:

- continuous, near-real-time aerosol mass monitoring,
- self-contained, automated monitoring approach requiring limited operator intervention following installation,
- a choice of averaging times from 1 minute to 24 hours,
- low labour costs, minimal filter handling and a reduction in the risk of filter contamination, and
- non-destructive monitoring methods providing the potential of supplying samples which may be submitted for chemical analysis.

The TEOM is US-EPA approved (EQPM-1090-079) as an equivalent method for measuring 24-hour average PM10 concentrations in ambient air quality. It represents the only continuous monitor which meets the California Air Resources Board acceptance criteria for 1-hour mass concentration averages. TEOM instrumentation also has German TÜV approval for TSP measurements. Not all beta gauges are US-EPA approved, with only the Andersen (FAG-Kigelfischer, Germany) and Wedding beta monitor having been approved.

The performance of the TEOM ad BAM monitors are compared in Table 16-1. The TEOM tends to perform better than BAMs in many respects, particularly with regard to the precision of measurements made. An additional advantage of the TEOM (14000 series) is the optional inclusion of the ACCU system. This system allows for conditional sampling by time/date, particulate concentration and/or wind speed and direction. The application of the TEOM in combination with the ACCU system could therefore allow for the assessment of an operation's contribution to particulate concentrations occurring at a site on an on-line real-time basis.

Table 16-1: Comparison of TEOM and BAM performance

	TEOM	BAM
Principle of operation	*Measured mass* on a filter based upon inertia (as fundamental as gravimetric method).	*Inferred mass* on a filter based upon the strength of a radioactive beam.
	Measures *only mass* (represents a true mass measurement)	Do *not* measure mass but rather the transmission of beta rays
Advantages and disadvantages	Performs well under varying humidity conditions. Samples and measures at a defined filter face velocity and conditioning temperature to ensure standardized data under low humidities	Can produce erroneous measurements under changing humidity conditions
	Not sensitive to particulate composition since it makes a mass-based measurement.	Sensitive to interferences (site/season specific) arising due to: particle composition, particle distribution across the filter, radioactive decay and the effect of air density in the radioactive beam.
Precision (measured by standard deviation)	Standard deviation for hourly data: ± 1.5-2.0 µg/m³. (Precision of ±5 µg/m³ for 10-minute averaged data.)	Beta monitors with strong source: standard deviation for hourly data: ± 15-20 µg/m³. Beta monitors with weak source: hourly data not acceptable.

TEOMs have been found to typically under-predict actual particulate concentrations by a consistent amount (typically 18% to 25%). In the US TEOM results are typically multiplied by a factor of 1.3 to determine actual concentrations (this single factor is made possible by the consistency or high precision of the instrument). TEOMs tend to be less effective in environments with elevated nitrate concentrations or high potentials for the adsorption of volatile compounds on particles. Beta attenuation monitors perform poorly in areas with soils that have a radioactive component.

A common disadvantage of the TEOM and BAM monitors is that they all require electricity to operate thus limiting the potential sites for the location of such monitors. A further disadvantage of the TEOM and BAM monitors are that they are relatively costly to purchase. Despite the relatively high costs of purchasing continuous real-time monitors such as the TEOM and beta gauge monitors, significant savings can be achieved in the operation of such monitors due to the low labour costs and the minimal filter handling required by these techniques.

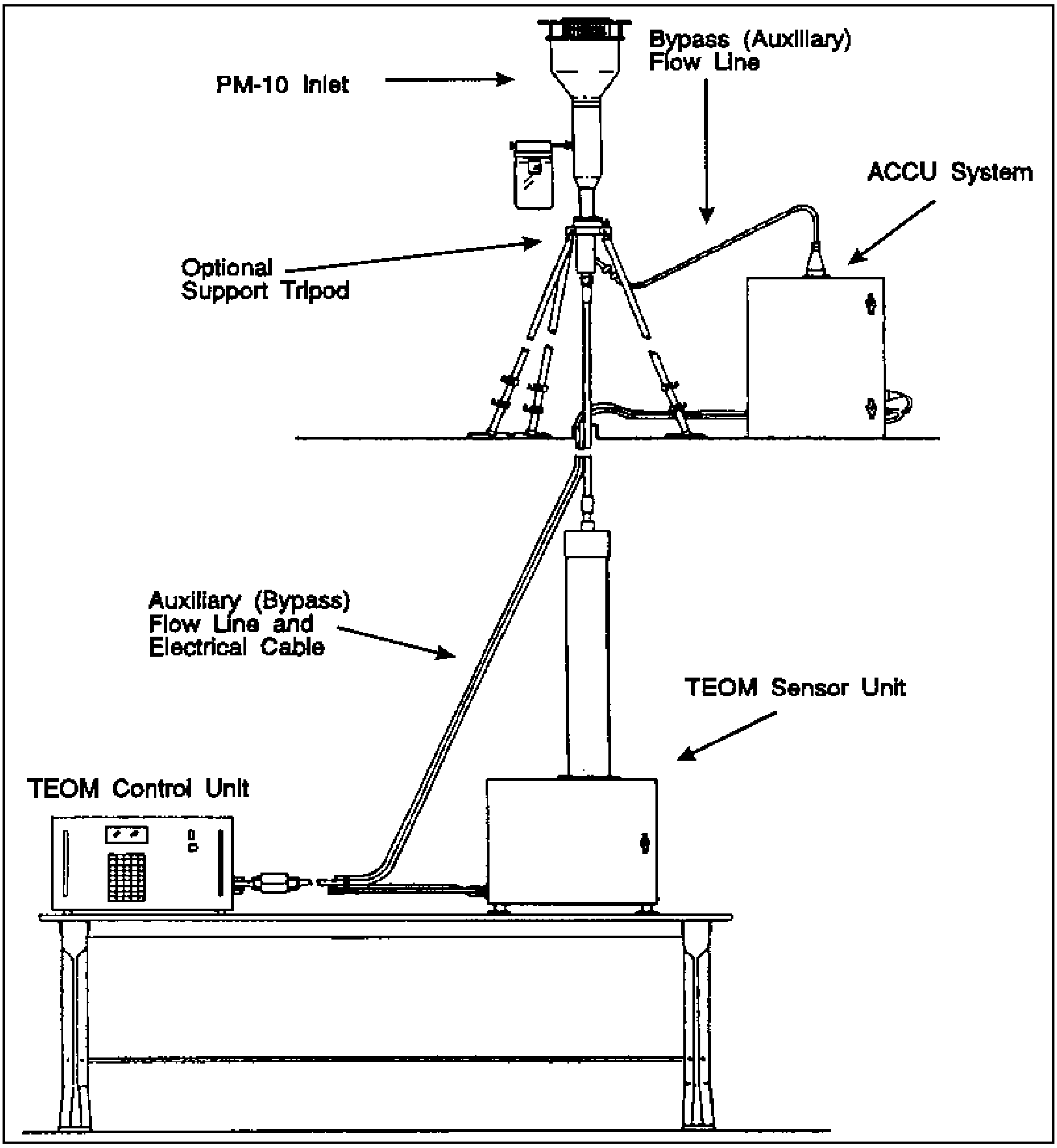

Figure 16-2: TEOM sampler linked to the ACCUTM conditional sampling system

16.2 Non-filter-based Monitors

Locally-supplied, real-time but non-filter based monitors include the TSI DustTrak, the DustScan Sentinel Aerosol Monitor and the Topas Dust Monitor. Various of these monitors can be solar-powered negating the need for selecting a site with power access. Such monitors measures particle concentrations corresponding to various size fractions, including PM10, PM2.5 and PM1.0, and comprise many of the benefits of the TEOM and BAM monitors including:

- continuous, near-real-time aerosol mass monitoring,
- a choice of averaging times from 1 minute to 24 hours,
- limited operator intervention, and
- minimal filter handling.

16.3 Data Transfer Options

Although most analysers have internal data storage facilities, logging is usually carried out by means of a dedicated data logger (PC or specialised data logger). Data transfer may be undertaken in various ways:

- downloaded intermittently from the instrument - PC link cable required
- real-time, continuous transfer via telemetry - telemetry control unit required
- near real-time, intermittent transfer via radio link - requires transmitter & license to use frequency
- continuous download via satellite

In selecting the data transfer option possible future accreditation requirements must be taken into account, e.g.: (i) raw data is to be kept for minimum of 3 years, and (ii) all manipulations of data must be recorded.

16.4 Sampler and Data Transfer Recommendations

The most suitable sampler type depends on ietvlei Mine mining operation are expected to include: on-going compliance evaluation, on-going estimation of contribution to airborne particulate concentrations, and evaluation of the effectiveness of dust control measures implemented at the plant.

Given the above objectives, and noting that international reference methods are likely to be the preferred approach during the promulgation of South African regulations for air quality monitoring it is recommended that the Rietvlei Mine invest in the purchase of a filter-based, on-line monitor (e.g. TEOM, BAM). Real-time, continuous transfer of the measured concentrations (via telemetry, satellite, etc.) would contribute significantly to the use of such measurements to trigger rapid responses to pollution episodes.

Should the TEOM or BAM be considered too costly, investment in one of the non-filter based automatic monitors (e.g. DustTrak, DustScan, Topas). These instruments provide an indication of the range of particulate concentrations and despite possibly not being the preferred method for compliance monitoring, would provide the mine with a means of tracking progress made through emission reduction measure implementation.