1 Introduction

Turquoise Moon Iron Ore Mining Project (Turquoise Moon) is located in the north-western part of the Limpopo Province, approximately 30 km from the Botswana border. The project includes farms located along the N11 between Mokopane and the Botswana border, near to the town of Marnitz, approximately 60 km north of Lephalale. The proposed project will be an opencast iron ore mine.

The mining activities will include drilling and blasting, loading, hauling and off-loading of ore and waste rock, crushing and screening and a processing plant. Waste rock will be taken to the waste dumps with a tailings storage facility (TSF) handling the waste from the processing plant. No agglomeration, reduction, melting or pig casting will take place on-site with the concentrate to be transported to an off-site facility for further processing.

Airshed Planning Professionals (Pty) Ltd was appointed by Metago Environmental Engineers (Pty) Ltd (Metago) to conduct an air specialist study assessing the potential impacts from the proposed operation on the surrounding environmental and human health.

1.1 Geographical Setting

The nearest towns to the proposed mine are Lephalale, approximately 70 km to the southwest and Mokopane, 140 km to the southeast (Figure 1-1). The main sensitive receptors in close proximity to the proposed Turquoise Moon Mine are farms and scattered homesteads.

The topography in the area is fairly flat ranging from 890m to around 930m (eastern part).

1.2 Process Description

Mining operations were assumed to follow conventional open pit mining methods. This includes drilling and blasting of ore bearing rock and excavation and loading of both ore and waste rock onto haul trucks. Waste rock will be dumped onto the two proposed waste rock dumps (Figure 1-2).

From the process description supplied, ROM will be tipped directly into a Primary Gyratory Crusher and transported from the crusher to an open stockpile via conveyor belt (1 076 tph, 6 200 hours per year). The stockpile will have a total capacity of 21 000 tons but a live capacity of 7 000 tons meaning supply for 8 hours of Plant Feed at 872 tph.

From the primary crusher, crushed ore will be delivered to two secondary crushers via conveyor systems at a rate of 872 tph. Screening will reduce the ROM top size to a nominal -35 mm particle. From the secondary screens, the material will go to a tertiary crusher comprising of a High Pressure Grinding Roll (HPGR) in a closed circuit with a sizing screen reducing the particles to -6 mm. The non-magnetic fraction of the material (approximately 6%) will be stockpiled to either go to the Mine Waste Dump or used for the Tailings Storage Facility (TSF) wall construction.

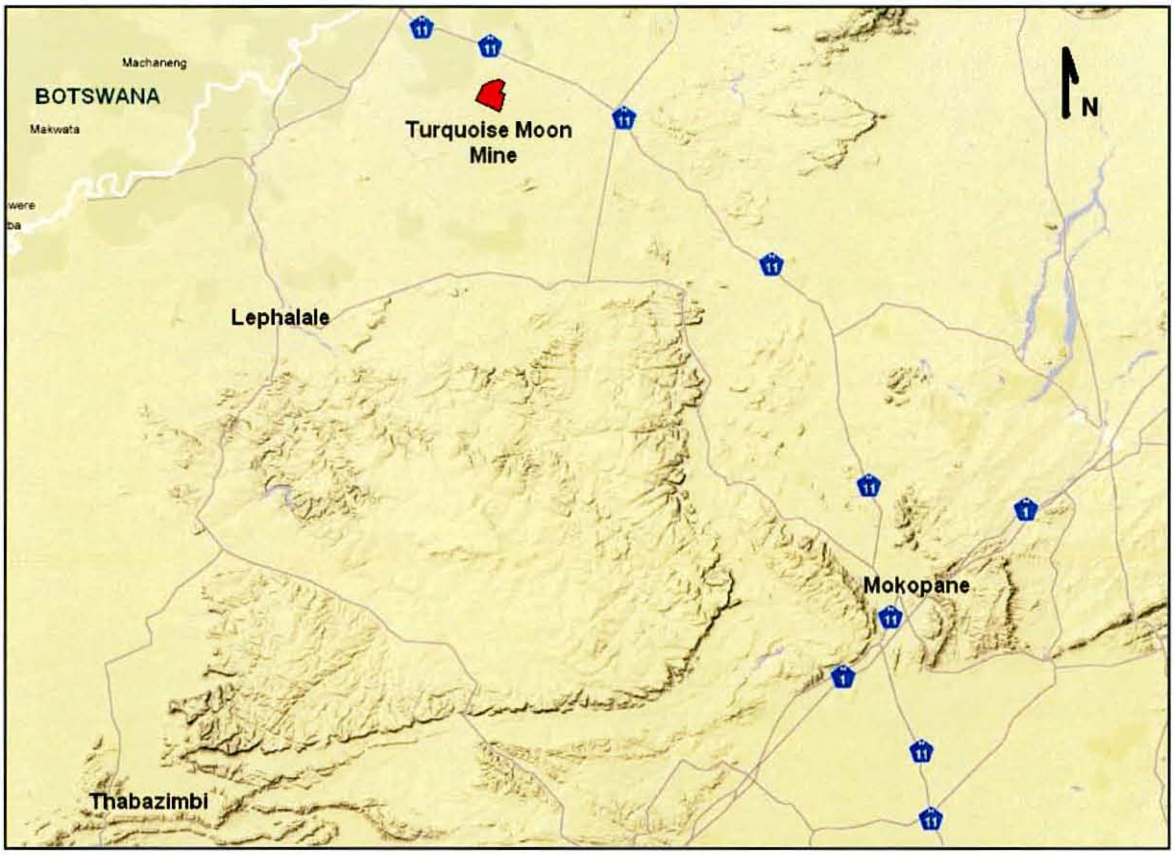

Figure 1-1: Geographic location of Turquoise Moon Mine (after Google Earth 2011)

From the tertiary screens the material will undergo further grinding in a closed circuit with wet screening to reduce the particle size to 1 800 µm. The slurry from this process will be fed to a drum Rougher Low Intensity Magnetic Separator where the magnetic fraction is directed to another milling application whilst the non-magnetic fraction report to a different mill before going to the Wet High Intensity Magnetic Separator (WHIMS) to isolate paramagnetic hematite in the magnetic product. The non-magnetic product from this stage will go to the TSF.

The magnetic product from the Cleaner Magnetic Separator stage is milled down to 45 µm before being combined with the WHIMS magnetic product. The combined product is then dewatered via a conventional thickener before pumped to a pelletising facility off-site for further processing.

The mining and processing operational hours will be 24 hours per day, 7 days per week including three shifts of eight hours each. Maintenance will mainly be done on weekdays with planned maintenance downtimes schedule for one 8-hour dayshift per week.

1.3 Study Scope

The Terms of Reference as set out in the Scoping Report should achieve the following objectives:

- to qualify the ambient air quality baseline;
- to quantify all proposed emission sources in an emissions inventory;

- to determine the relevant meteorological conditions in and adjacent to the project area including wind speeds and direction;
- to model the spatial dispersion of emissions to air;
- to assess the potential incremental and cumulative off-site impacts of the emissions including potential effects on cattle and game;
- to compare these estimated impacts to relevant guideline standards which act as a guide for human health impacts; and
- to have input, together with Metago, other specialists and the technical project team, into project alternatives and the management measures going forward.

1.3.1 Terms of Reference

Following the scope of work, the Terms of Reference includes both a baseline assessment and impact assessment.

2.1 Baseline Assessment

- Determine the regional climate and site-specific atmospheric dispersion potential, including:
  - Analysis of meteorological data.
  - Characterisation of ambient air quality and dustfall levels in the region based on observational data recorded to date in the region.
  - Preparation of hourly average meteorological data for the dispersion model.
- Identification of the potential sensitive receptors within the vicinity of the sites.
- Identification of existing sources of dust emissions in the area.
- Specific reference to the new Air Quality Act of 2004 and national government projects currently being initiated that will have a direct impact on the mining operations.
- Collate and analyse all monitoring data available from the mining operations within the region.

2.2 Impact Assessment for the Mine

- Quantification of all sources of atmospheric emissions, including all *routine* and *upset* sources of emissions. The emissions inventory include all point and non-point sources of emissions for the following phases:
  - Construction phase;
  - Operational phase; and
  - Closure and decommissioning phase.
- Selection of an appropriate atmospheric dispersion model for application for each individual division.
- Formatting and preparation of topographical, meteorological, land use, source and emissions data for input to the dispersion model.

- Dispersion simulations of ambient PM_{10} concentrations and dust fallout from all the identified mining activities for selected averaging periods. Analysis of dispersion modelling results from all mining operations, including:
    - Determine zones of maximum incremental ground level impacts (concentrations and dust fallout); and
    - Determine zone of maximum predicted cumulative ground level impacts (concentrations and dust fallout).
- Evaluation of potential for human health and environmental impacts.
- Recommendation of mitigation and management measures including:
    - Estimation of emission control efficiencies required for each significant source;
    - Identification of suitable pollution abatement measures able to realise the required dust control efficiencies, 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; and
    - Recommendations pertaining to record keeping, environmental reporting and community liaison.

1.4 Interested and Affected Party Concerns

The main concerns from the public relating to air quality are listed in Table 1-1. The table provides comments and relevant sections of the report where these concerns are addressed.

1.5 Report outline

The overall structure of the document reflects this approach:

- Section 2 of the report provides a description of the study approach followed.
- Section 3 provides the legislation and regulatory requirements.
- Section 4 describes the site specific dispersion potential of area in the vicinity of the mine.
- Section 5 reports on the Construction Phase emissions and qualitative impacts assessment.
- Section 6 is on the Impact Assessment including the emissions inventory, dispersion modeling results and compliance evaluation.
- Section 7 provides a qualitative description on the closure options proposed.
- Section 8 concludes the report with site specific recommendations.
- Section 9 provides and management measures.
- Section 10 provides a list of all the references.
- Section 11 includes Appendix A, the technical background on the emissions quantification methodology.
- Section 12 provides a summary of health research on particulate concentrations.

Table 1-1: Summary of I&AP concerns related to Air Quality

Issue Raised	By whom and when	Comment & Section of report where addressed
There will be an increase in dust pollution	Louis Smuts, telephonic discussion, 22 July 2010. P. Aucamp, social scan, 21 July 2010.	Mining operations will result in an increase in dust emissions. These can however be mitigated to only impact within the mine boundary. Predicted impacts are discussed in Section 6.3 with mitigated impacts discussed in Section 9.
Concerned about dust pollution associated with the proposed mining activities and an increase in dust pollution	Ronald Jackson, social scan, 20July 2010.	
Air quality in the area will decrease.	Rudolf Scheepers, social scan, 21 July 2010.	Impacts from mining operations are generally localised due to the low level of emission releases. Impacts are discussed in Section 6.3 with mitigated impacts in Section 9.
I am concerned about the possibility of acid rain. In addition to this, dust fallout will affect cattle grazing.	Eli Stroh, social scan, 22 July 2010.	Acid rain is associated with SO_2 emissions. Since the mine will not pelletise ore on-site, SO_2 emissions will be restricted to vehicle tailpipe emissions. These are regarded as insignificant sources of SO_2. Dust fallout impacts were predicted to be localised and mainly impacting within the mine property, especially when mitigated (See Sections 6.3 and 9).
Mine dust will cause medical problems.	P.G Ras, comment received by email, 20 September 2010.	Ambient air quality standards are there to protect human health, from the young to the old. All predicted impacts were screened against the NAAQS. Mitigated impacts will be restricted to the mine property as indicated in Section 9.
How will the dust at households be mitigated?	Riaan De Beer, comments received at focused scoping review meeting, 13 November 2010.	Predicted PM_{10} concentrations and dust fallout are mainly limited to the mine property and with mitigation as discussed under Section 9, there should not be significant off-site impacts. Should there be a concern for impacts at houses, dust fallout buckets could be installed to collect dust on a monthly basis. In addition, PM_{10} monitoring can be done.
What is the health risk to humans of the dust?		See Section 3 on ambient air quality standards and Appendix C for a discussion on health related implications from particulates.
What level of PM_{10} dust is expected? What is the PM dust currently? What will be the cumulative PM_{10} count?		Predicted PM_{10} GLC are provided in Section 6.3 (unmitigated) and Section 9 (mitigated). Current ambient background concentrations are not known. The Waterberg AQMP mainly focussed on the area around Lephalale and is not regarded representative of the area around Turquoise Moon. Cumulative

Issue Raised	By whom and when	Comment & Section of report where addressed
		impacts are difficult to assess with the lack of current background data and at least one year of baseline monitoring is required. Ambient monitoring as recommended under Section 9 should be conducted even before the mine commences and will provide information on the current levels of pollution.
How will the dust from blasting be mitigated?		Mitigating blasting dust generation is difficult. Alternative blasting methods should be investigated by the mine.
Predict the dust from the access and haul roads on all structures and areas that will be impacted upon-including all sensitive receptors adjacent all access roads		The access road and all on-site haul roads were assessed. See Section 6 for emissions quantification of road dust and predicted impacts and Section 9 for the mitigated option.
How will the impact of dust towards human health be mitigated? What suppression methods are envisaged? How many l/sqm/hour is needed for 70% dust suppression? How many l/sqm/hour is needed for 90% dust suppression?		The mitigation options are provided in Section 9 with the calculated amount of water required to ensure 75% mitigation provided in Section 9.3.1. 90% control efficiency can be achieved through the combination of water with chemical surfactants.
What are the square meters needed for all dust producing areas that will need to be suppressed during each year of operations		The main impacting dust generating sources were identified and recommendations on mitigation measures provided in Section 9.
How much water is needed for dust suppression in each year of the LOM? Where will the water for the dust suppression be sourced? What water quality would be used for dust suppression? What other dust suppressant will be used? How often will it be used on different surfaces? What would be the long term impact of poor water quality used in dust suppression to rehabilitation/ human health and the environment?		Section 9 provides recommendations on dust suppression options for the mine.
What is the seasonal difference in dust pollution and dust control?		The dispersion model provides the worst-case scenario i.e. the highest days throughout the year. Based on the wind roses the spring months is likely to result in the highest dust emissions from wind dependant sources (see Section 4).
What is the cumulative dust impact?		This could not be determined due to lack of background data. The DEA classified the entire Waterberg District Municipality a potentially poor area based on existing ambient data primarily from the Lephalale region (see Section 4.2.2).

Issue Raised	By whom and when	Comment & Section of report where addressed
Depletion of quantity and quality of natural pasture and grazing for animal consumption due to air pollution, dust, acid rain and outfall of heavy metals and phosphates. The un-palatability and avoidance of grazing due to dust outfall and heavy metal lead outfall from low speed (30-55 km/hour) tourist vehicles in the Kruger National Park has been proved significantly by science. Heavy duty hauling trucks and wind storms running across the stock piles, and fast racing (uncontrollable taxis) will create far more outfall than tourist vehicles. Acid rain, phosphates and heavy metals are amongst the chemicals that are potentially hazardous in effecting body growth, animal bone structure and trophy development. Trophy development is the major marketing produce of game ranching.	Deon Furstenburg, Agricultural Research Council, 24 January 2011	All the referenced information on dust impacts on animals and vegetation is reported on in Appendix C, Section 13.2 and 13. Since no thresholds exist for either vegetation (only dust fall limit exist) or animals, it is assumed that the human health thresholds (Section 3) would apply. Acid rain is associated with SO_2 emissions. Since the mine will not pelletise the ore on-site, SO_2 emissions will be restricted to vehicle exhaust. These are regarded as insignificant sources of SO_2. Dust fallout impacts were predicted to be localised and mainly impacting within the mine property, especially when mitigated (See Sections 6.3 and 9).
How will you be able to correctly investigate the impact that blasting activities will have on the surrounding air quality if the specialist study is conducted prior to any blasting activities having taken place? Specific information on the material will be blasted is needed	Simon Van Niekerk at Koedoesrand focused scoping review meeting, 13 November 2010.	Blasting, although a significant source of dust emissions, are very short lived. Blasting is an instantaneous event, and the visible dust takes about 10 minutes to dissipate under low wind conditions (from personal witnessing at Sishen Iron Ore Mine).
Any modelling of air quality impacts from blasting is inadequate and does not show a true picture		It is correct that Gaussian plume models, as the one used in this study, cannot compute real-time events. Ambient PM_{10} air quality standards are only applicable to 24-hour averages and therefore the significance from short-term events cannot be determined, even should a model be used that can compute for 5-minute intervals.

2 Methodology Approach

In assessing atmospheric impacts from the proposed mining and processing operations on sensitive receptors and the surrounding environment, emissions need to be quantified, atmospheric dispersion modelling conducted and predicted air pollutant concentrations evaluated.

The steps undertaken in the impact assessment include emissions quantification for all proposed sources at Turquoise Moon operations, dispersion modelling and impact evaluation.

2.1 Baseline Characterisation

Meteorological characteristics of a site govern the dispersion, transformation and eventual removal of pollutants from the atmosphere. Pollution concentrations fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth, and to shifts in the wind field. Spatial variations, and diurnal and seasonal changes, in the wind field and stability regime are functions of atmospheric processes operating at various temporal and spatial scales. No on-site weather station exists and meteorological data for the period 2009 were obtained from the South African Weather Services Unified Model (UMD) for a location on-site (28.1942°E; -23.2389°S). The UMD hourly average wind speed, wind direction, temperature and rainfall for the year 2009 were used to inform the local dispersion potential of the site.

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.

A comprehensive baseline assessment requires ambient monitoring data for a period of at least one year to account for seasonal variation. No dust fallout or PM_{10} monitoring are being conducted at the proposed mine site. The only available background information is the baseline as reported on in the Waterberg Air Quality Management Plan, published June 2009 (GES, 2009) and the general ranking of the District by the Department of Environmental Affairs (DEA).

In addition, all existing sources of air pollution in the region were identified and qualitatively described based on the associated pollutants and potential to contribute to the background ambient concentrations and dust fallout levels at the project area.

2.2 Impact Assessment

The main objective of the air quality assessment is to determine the possible impacts from the mining operations on the surrounding environment and human health. In the absence of any specific tasks required to complete the impact assessment, the following basic steps were conducted.

The three main phases of the mining process were evaluated, namely (i) Construction Phase; (ii) Operational Phases; and (iii) Closure and Post Closure Phase. Closure refers to the phase when all mining operations have ceased and rehabilitation occur with post closure assuming all rehabilitation is in place.

2.2.1 Emissions Inventory

In the quantification of fugitive dust emissions, emission factors were used that associate the quantity of a pollutant to the activity associated with the release of that pollutant. Due to the absence of locally generated emission factors, use was made of the comprehensive set of emission factors published by the US Environmental Protection Agency (US.EPA) in its AP-42 document compilation of Air Pollution Emission Factors. The US.EPA AP-42 emission factors are of the most widely used in the field of air pollution. In addition, reference was made to the Australian National Pollutant Inventory (NPi) emission factors. Empirically derived predictive emission factor equations are available for vehicle-entrained dust from roadways, pushing (dozing) operations, dust erosion from open areas, and for materials handling operations. Single-valued emission factors are also available for general surface preparation and topsoil stripping which is applicable to construction activities. The US.EPA emission factors facilitate the quantification of various particle size fractions. This is important given that ambient air quality standards make a distinction between Total Suspended Particulates (TSP), thoracic particulates (PM_{10}), and respirable particulates ($PM_{2.5}$). TSP is usually of interest in terms of dust deposition (nuisance) impacts, whereas PM_{10} needs to be considered for health risk purposes. PM_{10} and $PM_{2.5}$ represent particles of a size that would be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung.

2.2.2 Selection of dispersion model

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 (Trinity Consultants, 2004). 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 preprocessor for the AERMOD. Input data can come from hourly cloud cover observations, surface meteorological observations and twice-a-day upper air soundings. Output includes surface meteorological observations and parameters and vertical profiles of several atmospheric parameters.

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

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. 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.

2.2.3 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 UMD from the SAWS for the period 2009 were used as input to the dispersion model.

2.2.4 Source Data Requirements

The AERMOD model is able to model point, area, volume and line sources. Material transfer points (truck loading and off-loading, tipping and conveyor transfer points) were modelled as volume sources, with all roads as area sources. The waste rock dumps (WRDs) and TSF were included as area sources with all opencast operations (i.e. drilling, blasting and excavation) as in-pit sources.

2.2.5 Modelling Domain

The dispersion of pollutants emanating from all mining and processing operations was modelled for an area covering 20 km by 20 km with a 400 m grid resolution. This does not limit the predicted impacts and should this area have been found too small to indicate the affected areas, a larger modelling domain would have been selected. Mining activities, as proposed for Turquoise Moon, are all near-surface releases and therefore likely to impact near-field to the relevant sources.

Aside from the mine boundary included as a receptor area, all nearby farm houses and homesteads were included as discrete receptor. This was to allow for the evaluation of predicted impacts from the proposed mine at each of these locations. Figure 2-1 provides the location of the discrete receptors.

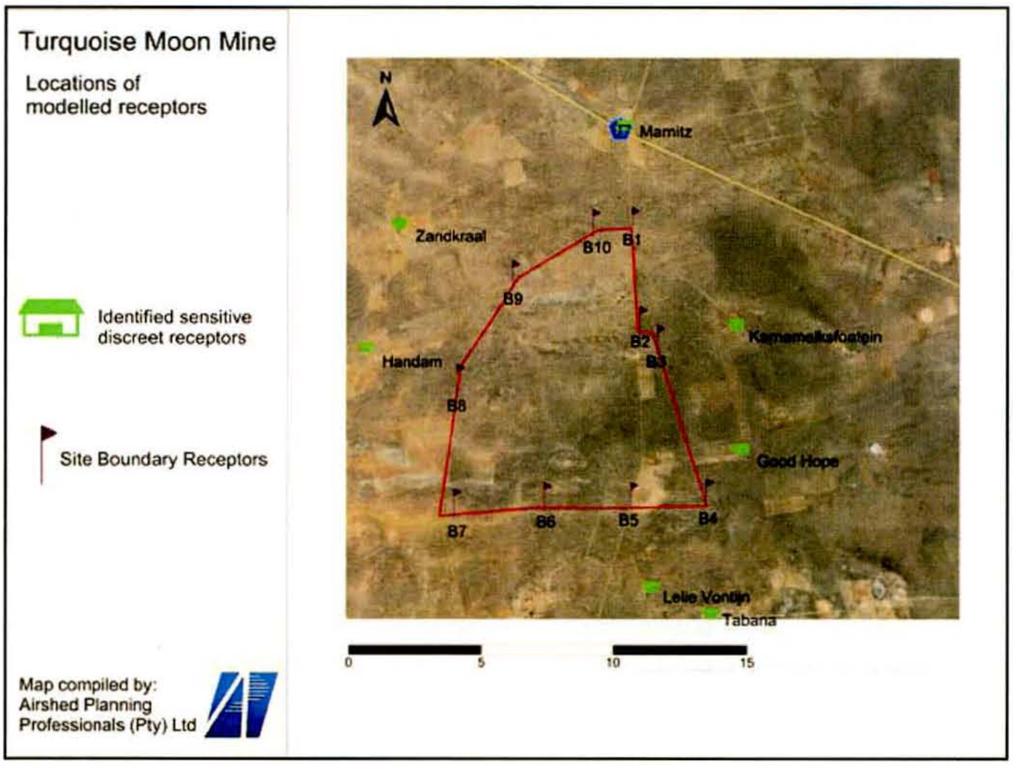

Figure 2-1: Farm houses included in the dispersion model as discrete receptors

2.3 Assumptions and Limitations

In interpreting the study findings it is important to note the limitation and assumptions on which the assessment was based. The most important assumptions and limitations of the air quality impact assessment are summarised as follows:

- Available on-site meteorological data were not available for the site and use was made of calculated UMD as provided by the SAWS. During the project scoping phase, 2009 was the most recent meteorological year. The potential exist for variations in the meteorological parameters between years. However, historical meteorological data for Lephalale indicate consistent north-easterly winds for this region (GES, 2009). This can be updated to cover a longer meteorological period with the update of the model, once the mine is operational.

- No ambient monitored concentration data or dust fallout data are available for the site. A general description of the air quality within the greater Waterberg District was obtained from the Waterberg Air Quality Management Plan compiled in 2009. The design of a dust monitoring system forms part of this study.

- Emissions were based on the process description and mine layout plan as provided.

- Since it is a proposed mine, no site specific particle size fraction data for the various sources were available and use was made of information obtained from existing iron ore mines in the region. Particle size distribution was provided for the TSF and is assumed to present a worst-case scenario. The surface of TSFs at other iron ore mines tend to harden if undisturbed and it is likely that the predicted windblown dust from the TSF followed a conservative approach. Once the mine is operational, particle size distribution should be determined for the various wind dependent sources and the dispersion model simulations updated.

- Routine emissions for the proposed operations were simulated. Blasting is regarded as non-routine (*upset*) event, occurring only intermittently for short durations. Blasting was accounted for in the modelling, simulated as if occurring for an hour every day.
- Dispersion models don't contain all the features of a real system but contain the feature of interest for the management issue or scientific problem to be solved (MFE, 2001). Gaussian plume and puff models are regarded to have an uncertainty range of between -50% to 200%. It has generally been found that the accuracy of off-the-shelf dispersion models improve with increased averaging periods. The accurate prediction of instantaneous peaks are the most difficult and are normally performed with more complicated dispersion models specifically fine-tuned and validated for the location. The duration of these short-term, peak concentrations are often only for a few minutes and on-site meteorological data are then essential.
- The dispersion model (AERMOD) cannot compute real time mining processes, therefore average mining process throughputs were utilised. Even though the nature of open pit mining operations (pit utilisation and roads) change over the life of mine, the proposed open pit mining area was modelled to reflect the worst-case condition (i.e. resulting in the highest impacts). For example, retention of dust generated within the open pit will result in up to 50% reduction in TSP emissions and 5% of PM_{10} emissions according to the NPi but was modelled as if at surface without any pit retention.
- The impact assessment was limited to airborne particulates (including TSP and PM_{10}). Mechanical operations such as associated with mining give rise to particles mainly in the TSP and PM_{10} fraction whereas combustion sources result in the finer $PM_{2.5}$ fraction. For this reason, the main focus of this study was on TSP and PM_{10}.
- The construction, closure and post-closure phases were assessed qualitatively.
- It was assumed that all processing operations will have ceased by the closure phase. The potential for impacts during this phase will depend on the extent of demolition and rehabilitation efforts during closure and on features which will remain. Information regarding the extent of demolition and/or rehabilitation procedures were limited and therefore not included in the emissions inventory or the dispersion modelling.

2.4 Metago Methodology for Assessing the Significance of Impacts

Impacts were assessed based on consideration of the impact severity/ , spatial scale and duration of impacts, which together determines the impact consequence (Table 2-1). The probability of the impacts were considered in the determination of significance.

Table 2-1: Impact Assessment Criteria (Metago)

Criteria for ranking of the SEVERITY of environmental impacts	**H**	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints.
	L	Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	L+	Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	M+	Moderate improvement. Will be within or better than the recommended level. Nor observed reaction.
	H+	Substantial improvement. Will be within or better than the recommended level. Favourable publicity.
Criteria for ranking the DURATION of impacts	**L**	Quickly reversible. Less than the project life. Short term
	M	Reversible over time. Life of the project. Medium term.
	H	Permanent. Beyond closure. Long term.
Criteria for ranking the SPATIAL SCALE of impacts	**L**	Localized – Within the site boundary.
	M	Fairly widespread – Beyond the site boundary. Local
	H	Widespread – Far beyond site boundary. Regional/ national.
PROBABILITY (of exposure to impacts	**H**	Definite/ Continuous
	M	Possible/ frequent
	L	Unlikely/ seldom

3 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.

Listed activities pertain to industrial processes such as smelting. Since the pelletising of iron ore will occur off-site, Minimum Emission Standards associated with Listed Activities do not apply to the proposed Turquoise Moon project.

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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.

3.1 Ambient Air Quality Standards and Dust fallout Limits

3.1.1 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 3-1: National ambient air quality standards for PM_{10}

Pollutant	Averaging Period	Limit Value (µg/m³)	Frequency of Exceedance	Compliance Date
PM_{10}	24 hour	120	4	Immediate – 31 Dec 2014
	24 hour	75	4	1 Jan 2015
	1 year	50	0	Immediate – 31 Dec 2014
	1 year	40	0	1 Jan 2015

3.1.2 Dust fallout limits

In the South African context, widespread dust deposition impacts occur as a result of windblown mine tailings material and other fugitive dust sources. It is for this reason that the SABS Technical Committee on air quality standards has recommended the establishment of target levels and alert thresholds for dust fall. The SANS four-band scale is presented in Table 3-2. Proposed target, action and alert thresholds for ambient dust deposition are given in Table 3-3. No margin of tolerance is granted for operations that result in dust fall rates in Band 4 ALERT.

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[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.

The Draft National Dust Control Regulations was published on the 27th of May 2011 (Government Gazette, Notice 309 of 2011). According to these regulations the dust fall at the boundary or beyond the boundary of the premises where it originates cannot exceed 600 mg/m^2/day in residential and light commercial areas; or 1 200 mg/m^2/day in areas other than residential and light commercial areas. This will be based on the measuring reference method ASTM 01739 averaged over 30 days.

Table 3-2: Bands of dustfall rates proposed for adoption

Band Number	Band Description Label	30 Day Average Dustfall Rate (mg/m^2-day)	Comment
1	RESIDENTIAL	D < 600	Permissible for residential and light commercial
2	INDUSTRIAL	600 < D < 1 200	Permissible for heavy commercial and industrial
3	ACTION	1 200 < D < 2 400	Requires investigation and remediation if two sequential months lie in this band, or more than three occur in a year.
4	ALERT	2 400 < D	Immediate action and remediation required following the first exceedance. Incident report to be submitted to relevant authority.

Table 3-3: Target, action and alert thresholds for ambient dustfall

Level	Dustfall Rate (mg/m^2-day)	Averaging Period	Permitted Frequency of Exceedence
TARGET	300	Annual	
ACTION RESIDENTIAL	600	30 days	Three within any year, no two sequential months.
ACTION INDUSTRIAL	1 200	30 days	Three within any year, not sequential months.
ALERT THRESHOLD	2 400	30 days	None. First exceedance requires remediation and compulsory report to authorities.

3.1.3 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 C, Section 13.2 and 13.3, respectively.

3.2 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 Waterberg District Municipality developed an Air Quality Management Plan in 2009 (GES, 2009).

4 Local Weather Conditions and Background Concentrations

4.1 Regional Dispersion Potential

The meteorological characteristics of a site impact on the rate of emissions from fugitive sources, and 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, determines the general path pollutants will follow, and the extent of crosswind spreading (Shaw and Munn, 1971; Pasquill and Smith, 1983; Oke, 1990). Pollution concentration levels therefore fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth, and to shifts in the wind field.

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

The analysis of hourly average meteorological data is necessary to facilitate a comprehensive understanding of the ventilation potential of the site, and to provide the input requirements for the dispersion simulations. A comprehensive data set for at least one year of detailed hourly average wind speed, wind direction and temperature data are needed for the dispersion simulations. Meteorological data were obtained from the SAWS UMD for the year 2009 for a location on-site.

4.1.1 Local Wind field

Wind roses comprise 16 spokes, which represent the directions from which winds blew during the period. The colours reflected the different categories of wind speeds, the grey area, for example, representing winds of 1 m/s to 3 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. For the current wind roses, each dotted circle represents a 5% frequency of occurrence. The number given in the centre of the circle gives the frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s.

Figure 4-1 provides period wind roses for the Turquoise Moon site, with Figure 4-2 providing the seasonal wind roses for the same site. The prevailing wind field for this area is north-easterly with very little airflow from the northwest and southeast. Highly infrequent winds occur from the southwest. During daytime, frequent winds occur from the northeast with strong, but limited winds from the southwest. Night-time conditions indicate a more frequent flow from the northeast with a decrease in wind velocity and an increase in calm conditions. Wind speeds are moderate, in general, not exceeding 10 m/s.

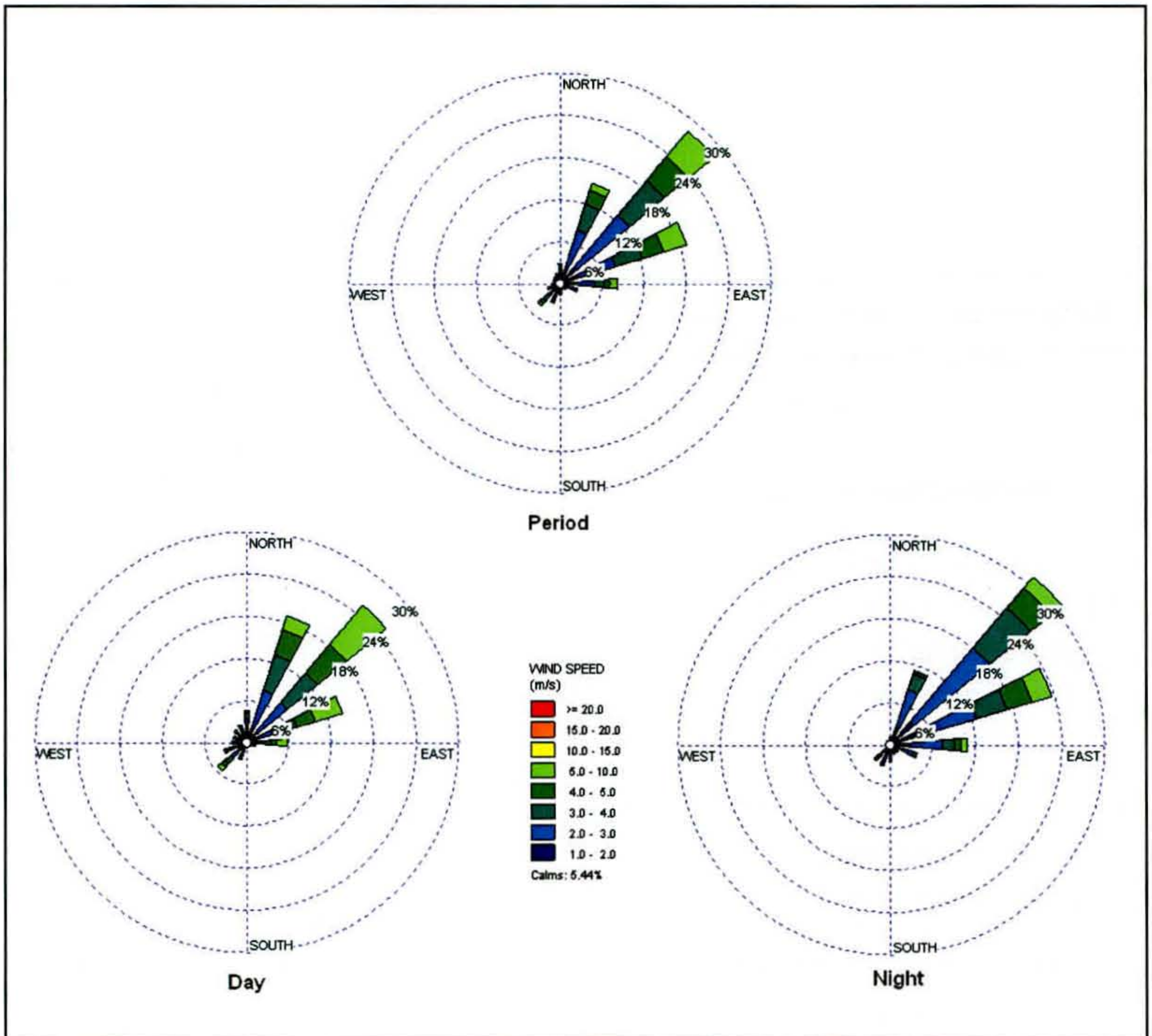

Figure 4-1: Period, day-time and night-time wind roses for Turquoise Moon site.

There is not much variation between the seasons as depicted in Figure 4-2. Spring months do however reflect stronger winds in general, with more frequent winds from the northeast during the summer and spring months. An increase in south-westerly flow during the winter and autumn months are evident.

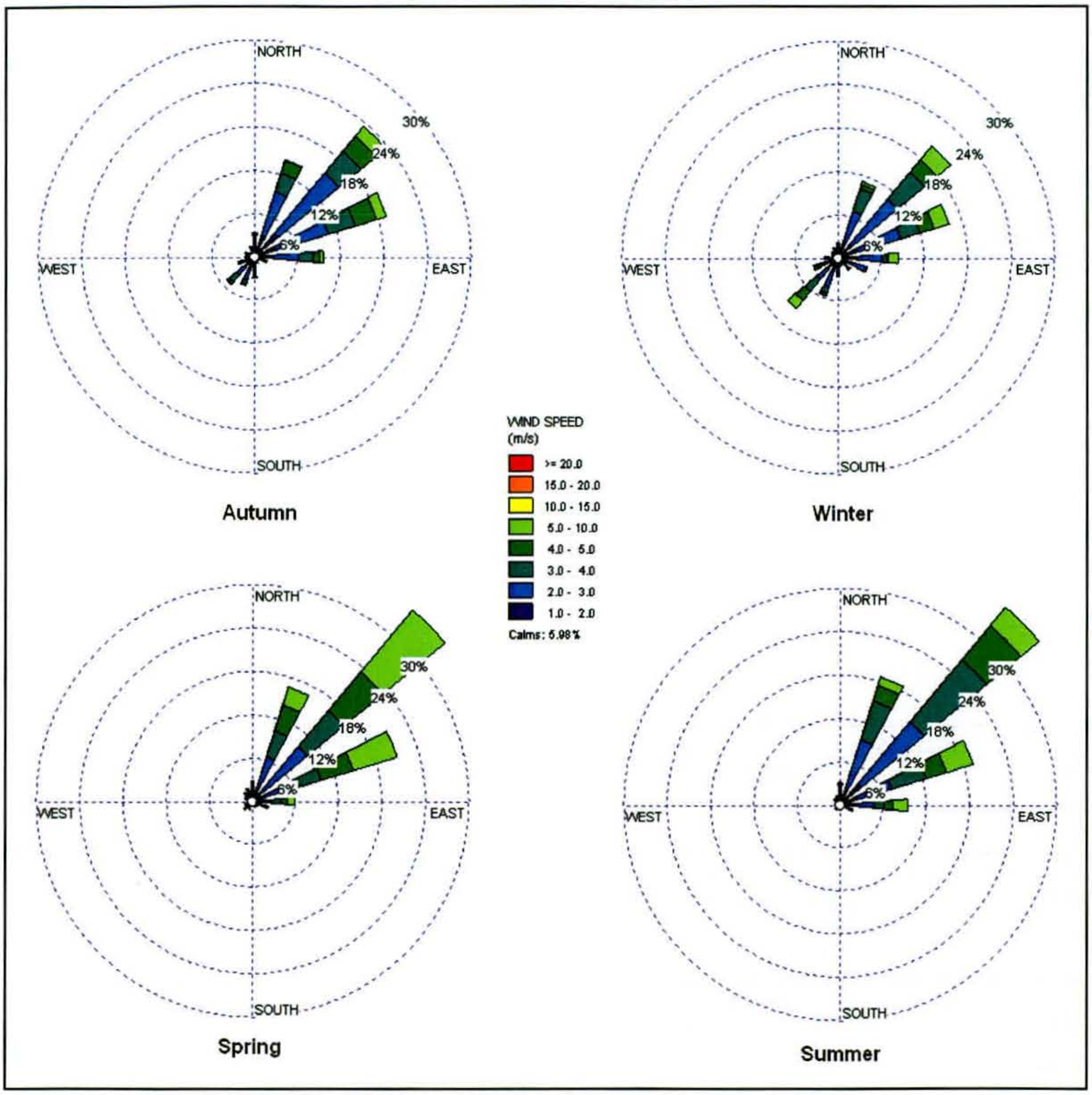

Figure 4-2: Seasonal wind roses for the Turquoise Moon site.

Wind speeds between 1-4 m/s dominated with exceedances of 10 m/s occurring less than 1% of the time for 2009. Figure 4-3 provides a graph indicating the percentage time wind speeds fell within certain wind speed categories.

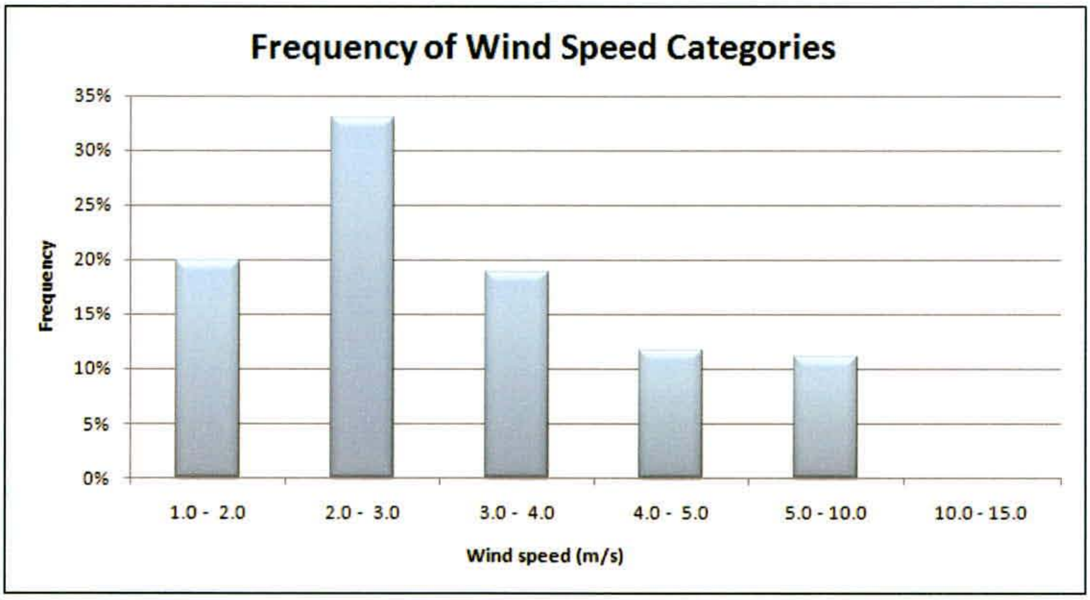

Figure 4-3: Frequency of wind speeds at the Turquoise Moon site for 2009

4.1.2 Temperature Profiles

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 diurnal temperature profile for the Turquoise Moon site is given in Figure 4-4.

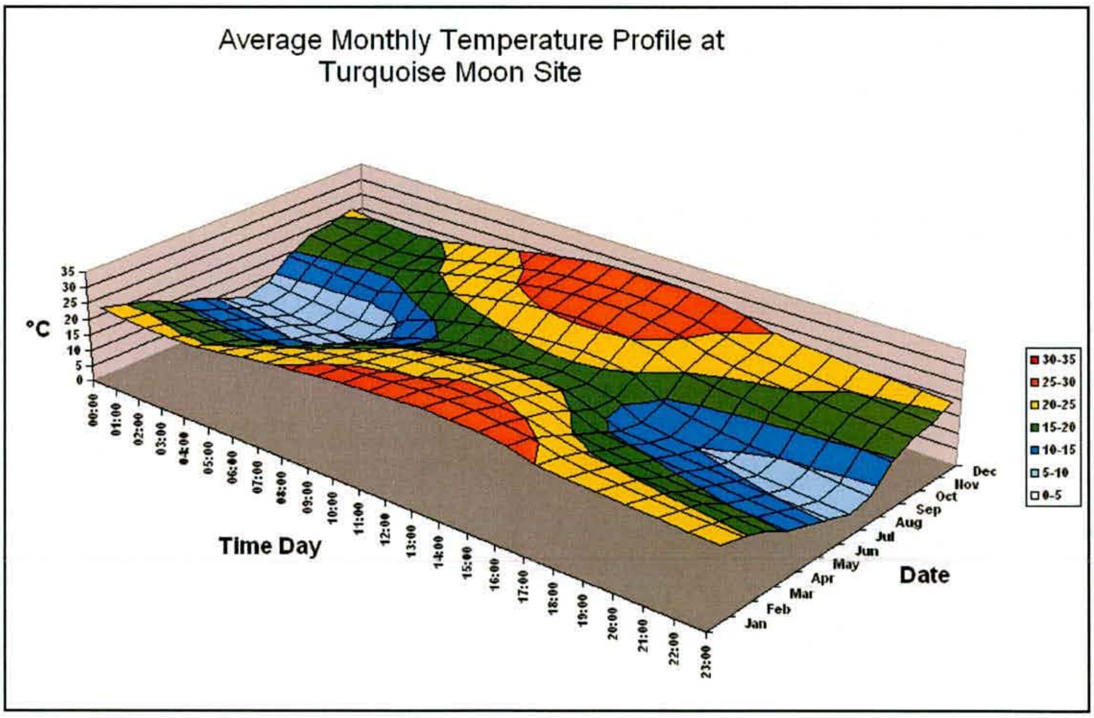

Figure 4-4: Diurnal temperature profile for the Turquoise Moon site

Annual maximum, minimum and mean temperatures for Turquoise Moon are given as 37.8°C, 0.4°C and 18.9°C, respectively, based on 2009 UMD records. Average daily maximum temperatures range from 30.3°C in December to 19.9°C in June, with daily minima ranging between 20.9°C in January and 4.6°C in July (Table 4-1).

Table 4-1: Minimum, maximum and mean temperature for Turquoise Moon (2009)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	20.9	18.9	16.5	12.7	10.0	7.9	4.6	6.0	12.5	16.7	17.4	19.6
Average	24.5	23.0	20.9	18.1	15.8	13.0	11.0	13.0	18.7	21.6	22.4	24.6
Maximum	28.7	27.7	25.6	24.7	23.2	19.9	18.5	21.5	25.8	27.9	28.1	30.3

4.1.3 Rainfall and Evaporation

Rainfall represents an effective removal mechanism of atmospheric pollutants and is therefore frequently considered during air pollution studies. Evaporation is a function of ambient temperature, wind and the saturation deficit of the air. Evaporation rates have important implications for the design and implementation of effective dust control programmes.

Monthly rainfall and evaporation data (converted to Lake estimates) were sourced from the Marnitz station and are shown in Figure 4-5. Annual rainfall trends indicate summer rainfall (November to February) and dry winter months (July and August). Total annual rainfall was 421 mm with the total evaporation for the year at 1651 mm.

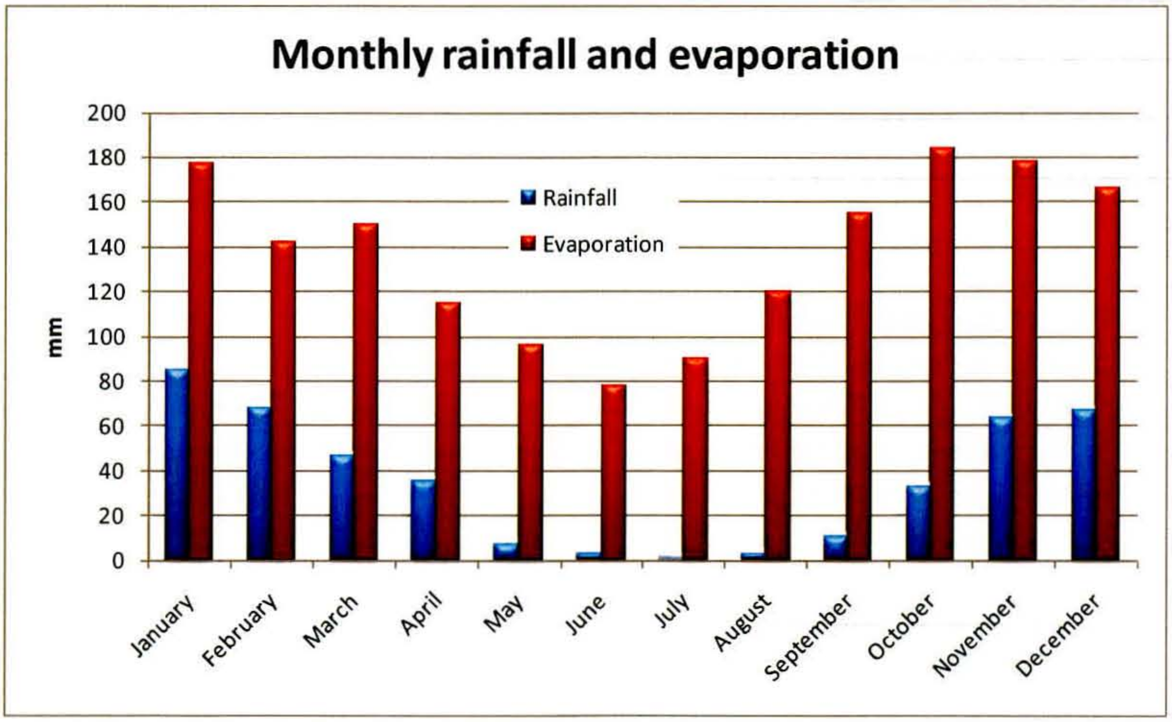

Figure 4-5: Monthly rainfall and evaporation data

4.1.4 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 ranges in depth from a few metres (i.e. stable or neutral layers) during nighttimes 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 1 000 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.

Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table 4-2.

Table 4-2: Atmospheric stability classes

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

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

For elevated releases, the highest ground level concentrations would occur during unstable, daytime conditions. In contrast, the highest concentrations for ground level non-wind dependent releases would occur during weak wind speeds and stable (night-time) atmospheric conditions.

4.2 Baseline Air Quality of the region

4.2.1 Sources of Air Pollution in the Region

The main sources of emissions within the Waterberg District are confined to the Lephalale region in the form of Matimba Power Station and Grootegeluk Colliery. Other regional sources that may have an influence on the ambient air quality around the Turquoise Moon Project include Moropule Power Plant, located approximately 130 km to the northwest at Palapye in Botswana. In addition, agricultural activities, fugitive sources, vehicle entrainment on roads, household fuel combustion and biomass burning also contribute to background air quality. To a lesser extent, sources such as vehicle tailpipe emissions impact on the proposed site and surroundings. In addition to the existing sources, a range of projects have been approved for development within the north-western part of Limpopo. These include Medupi Power Station (currently under construction) and Grootegeluk Colliery expansion.

Power generation and domestic fuel burning give rise to SO_2, NO_2 and PM_{10} emissions whereas coal mining, agricultural activities and vehicles on roads primarily result in particulate emissions. The main source of particulate emissions within proximity to the proposed project is agricultural activities in the form of land tilling.

4.2.2 Ambient Air Quality

According to the Waterberg District Air Quality Management Plan of 2009, limited air quality monitoring data are available (GES, 2009). Ambient monitoring is restricted to the Lephalale area as undertaken by Eskom, Exxaro and Anglo Coal. Given the distance from Turquoise Moon to the main contributing sources around Lephalale (~70 km), the available information is not regarded representative of the area.

The baseline assessment conducted as part of the Air Quality Management Plan for the Waterberg does not provide any measured, simulated PM_{10} or dust fallout data for the area around Turquoise Moon. The background particulate concentrations and dust fallout are therefore not known.

The DEA has conducted an initial assessment of the current air quality status of metropolitan and district municipalities in South Africa based on available data (Government Gazette, 11 September 2007 No. 30284). The municipalities were rated as having poor, potentially poor or acceptable air quality. According to this rating, the Waterberg District Municipality is regarded as potentially poor due to industrial activities. This implies that the potential exists for exceedances of the NAAQ Limits.

5 Construction Phase

The construction phase 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.

5.1 Emission Estimation

A list of all the potential dust generation activities expected during the construction phase is provided in Table 5-1.

Table 5-1: Typical fugitive dust impacts and associated activities during construction

Impact	Source	Activity
TSP and PM_{10}	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
	Site development	Clearing of vegetation and topsoil
		Levelling of proposed transportation route areas

If 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 5-1, for emissions quantification and dispersion simulations. Due to the lack of detailed information, emissions from the construction activities were instead estimated on an area wide basis. This approach estimates construction emissions for the entire affected area without regard to the actual plans of the individual construction project.

In the quantification of releases from the construction phase, use was made of emission factors published by the US.EPA (EPA, 1996). The approximate emission factors for construction activity operations are given as:

$$ETSP = 2.69 \text{ Mg/hectare/month of activity}$$

This emission factor is most applicable to construction operations with (i) medium activity levels, (ii) moderate silt contents, and (iii) semi-arid climates and applies to TSP. Thus, it will result in conservatively high estimates when applied to PM_{10}. Also, because the derivation of the factor assumes that construction activity occurs 30 days per month, it is regarded as conservatively high for TSP as well (EPA, 1995). The emission factor does not provide an indication of which type of activity during construction would result in the highest impacts thus not providing information to develop an effective dust control plan. For example, secondary dust sources during construction might be far more significant than the actual on-site construction operations. Such secondary sources may include vehicle activity on off-site roads, quarry operations and stockpiles located away from the actual site (EPA, 1995).

The total TSP generated during the proposed construction phase when applying the above mentioned emission factor is 751.30 tons of TSP per month (**9 015.6** tpa). This is assuming that all construction activities would take place simultaneously and over the entire area. This is unlikely to be the case. The construction period was given to last for 24 months.

5.2 Qualitative assessment of the potential impacts

Dispersion modelling was regarded not representative of the actual activities that will result in dust emissions during the construction phase at Turquoise Moon Mine. It is not anticipated that the various construction activities would result in higher off-site impacts than the operational phase mining activities. The temporary nature of the construction activities, and the likelihood that some of these activities would concur with the first operational mining months would reduce the significance of the potential impacts.

According to the EPA of South Australia on recommended separation distances from various activities, a buffer zone of 300 m from the nearest sensitive receptor is required when quarry type operations occur without blasting. A distance of 500 m is required where blasting occurs. Thus, the land clearing operations should be a minimum of 300 m away from any homesteads.

5.2.1 Significance rating of construction activities

The significance of the construction operations can be summarised as follows:

- Un-mitigated: Construction operations with no mitigation in pace will most likely results in off-site impacts over the 24-month duration of the construction phase. The spatial scale is likely to stretch beyond the mine boundary and may exceed the PM_{10} NAAQSs and dust fallout limits.

- Mitigated: Mitigation in the form of water sprays could result in 60% reduction in dust generated from the construction operations (EPA, 1996). This could reduce the spatial extent to fall within the mine boundary with impacts off-site falling within the PM_{10} standards and relevant dust fallout limits.

6 Operational Phase

The Operational Phase includes open pit mining with overburden/ waste stockpiles (WRDs), topsoil stockpiles and a tailings storage facility (TSF). Support functions include a mining contractor area, an explosives magazine and a processing plant with primary, secondary and tertiary crushing and screening, grinding, wet milling and magnetic separation facilities.

This section covers the emissions quantification, dispersion modeling, results and impact assessment for the proposed operational phase.

6.1 Emissions Inventory

Emissions from the proposed Turquoise Moon mine will be restricted to fugitive releases (non-point releases). Examples of fugitive emissions include dust from the two waste rock dumps (WRDs), the tailings storage facility (TSF), drilling and blasting, crushing and screening operations, material transfer points and vehicle entrainment on unpaved and paved roads.

Particulates are the main pollutant of concern from mining operations and include Total Suspended Particulates (TSP) and thoracic particles (PM_{10}).

6.1.1 Source Inventory

The establishment of an emissions inventory forms the basis for assessing the impact from source emissions on the receiving environment. The establishment of an emissions inventory comprises the identification of sources of emission, and the quantification of each source's contribution to ambient air pollution concentrations.

Typically, plant emissions may be obtained from the following four methods:

- Direct measurements of pollutants;
- mass balance;
- fuel analysis or other engineering calculations; and/or
- emission factors.

Point source emissions are preferably measured but can also be quantified through mass balance, engineering calculations and emission factor application. Fugitive dust emissions are quantified through emission factor application and emission equations. The most readily available emission factors are those published by the US.EPA. Also, the Australian Government has in its National Pollution Inventory (NPI) emissions estimation technique manuals for mining operations primarily based on the US.EPA techniques. No local emission factors for mining operations exist, but site specific information was used as input to these equations as far as possible.

Fugitive dust, generated from materials handling operations, drilling, wind erosion, crushing/ screening and vehicle-entrainment from unpaved roads, is classified as *routine* emissions and is fairly constant throughout the year. *Upset* conditions may, for example, arise due to blasting operations.

All sources of emission associated with Turquoise Moon project are summarised in Table 6-1.

The run of mine (ROM) was given as 6.5 million tons per annum and the waste material also at 6.5 million tons per annum. The Life of Mine is estimated at 30 years and operations will be for 24 hours per day, seven days per week.

6.1.2 Emissions quantification

6.1.2.1 Drilling Operations

Fugitive dust emissions as a result of in-pit drilling operations were quantified using the Australian NPI single value emission factors for drilling (Table 11-2, Appendix A). The area to be drilled per day is 2000 m² covering 12 rows in the ore, and 6 rows in the waste rock. Drill holes will be 3 m apart for the ore and 4.3 m apart for the waste rock. This results in a total of 203 drill holes per day for both ore and waste rock. Drilling duration will be 18 hours per day, seven days per week. The drill rigs will be equipped with vacuum packs to reduce water requirements resulting in an estimated 60% control of dust emissions. Should this prove not sufficient it can be increased to 80% control efficiency by applying additional water sprays. Emissions calculated to result from drilling activities are summarised in Table 6-3.

6.1.2.2 Blasting Operations

Fugitive dust emissions as a result of in-pit blasting operations were quantified using the Australian NPI emission factor equation for blasting (Equation 2, Appendix A). It was indicated that during the operational phase an average area of 2 000 m² will be blasted per event and the hole depth will be 6.1 m in the ore and 11.1 m in the waste rock. Blasting will be done at most twice a day during mid day. The average moisture of material being blasted was assumed at 4% based on generic data from the US.EPA.

No mitigation was applied to blasting emissions. Emissions calculated to result from blasting activities are summarised in Table 6-3. With an increase in pit depth, pit retention would result in a decrease in particulate emissions. According to the Australian NPi, TSP can be reduced by 50% and PM_{10} up to 5% due to the effects if in-pit dispersal.

Table 6-1: Summary of all air pollution sources at the proposed Turquoise Moon Mine

Source	Activity	Activity rates	Section where discussed
In-pit	Drilling of ore bearing rock	Two drills per day; 12 rows in ore and 6 in waste. ore holes will be 6.1 m deep and 11.1 in waste. Drill area = 2 000 m²/day Total number of holes = 203/day (ore and waste)	6.1.2.1
	Blasting of ore bearing rock	Maximum of 2 blasts per day at mid day. Blast area = 2 000 m²/day Moisture of ore and waste = 4% (assumption)	6.1.2.2
	Excavation of ore and waste rock	Ore loading to truck = 742 tph Waste loading to truck = 742 tph	6.1.2.3
	Truck activity within pit	Haul truck average weight = 103.5 tons Number of trucks = 9 Silt content = 8.4% (assumed) Total haul road length = 2.49 km Haul road width = 10 m (assumed)	6.1.2.5
Haul roads	Truck activity on unpaved haul roads between open pit and WRD and ROM storage pile		6.1.2.5
Access unpaved road	Vehicle activity on unpaved access road	Light duty vehicles = 76/day Number of busses = 24/day Silt content = 6% (assumed) Total road length = 13.55 km Road width = 6.5 m (assumed)	6.1.2.5
Materials handling	Loading and off-loading i.e. tipping	Off-loading of ROM at Stockpile = 742 tph Off-loading of waste rock at Stockpile = 742 tph	6.1.2.3
	Conveyor transfer points	Transfer from Primary crusher onto conveyor = 742 tph Transfer from Secondary crusher onto conveyor = 742 tph Transfer from Tertiary crusher onto conveyor = 742 tph	6.1.2.3
Crushing and Screening	Primary, Secondary and Tertiary crusher and screen	Primary crushing and screening of ROM = 742 tph Secondary crushing and screening of ROM = 742 tph	6.1.2.4

Source	Activity	Activity rates	Section where discussed
		Tertiary crushing and screening of ROM = 742 tph (enclosed)	
Waste rock dump, ROM storage pile and TSF	Wind erosion from stockpiles	ROM storage pile area = 4 347 m² Waste Rock Dump 1 area = 1 158 002 m² Waste Rock Dump 2 area = 1 496 508 m² Tailings Storage Facility area = 2 656 767 m² Particle size distribution provided for TSF and assumed for WRDs and ROM storage pile	6.1.2.6

6.1.2.3 Materials Handling

Materials handling points at the proposed operation include a front end loader (FEL) moving material between the ROM stockpile and crusher, loading of ore and waste to trucks, tipping of ore and waste from trucks and conveyor transfer points. The US.EPA AP42 predictive equation (Equation 1, Appendix A) was used to estimate emissions from material transfer operations.

The material volumes used in the calculation of materials handling emissions were based on the annual throughput of 6.5 million tons of ore and 6.5 million tons of waste rock. The moisture content of ore and waste was assumed to be 4% based on generic data from the US.EPA. Water sprays with a general control efficiency of 60% (NPI, 2001) were applied in the estimation of mitigated emissions. Emissions from materials handling points were calculated using the hourly average wind speed of 3.47 m/s from the UMD for the site for 2009. Expected materials handling emissions are summarised in Table 6-3.

6.1.2.4 Crushing and Screening Operations

Crushing and screening plants represent significant dust-generating sources if uncontrolled. Dust fallout in the vicinity of crushers also give rise to the potential for re-entrainment of dust by vehicles or by wind at a later date. The large percentage of fines in the deposited material enhances the potential for it to become airborne. Fugitive dust emissions due to the crushing and screening operations at the mine were quantified using US.EPA single valued emission factors for such operations (Table 11-1, Appendix A).

Primary, secondary and tertiary crushing and screening emissions were quantified. Emissions were estimated for high moisture ore (moisture in excess of 4%) volumes provided in Table 6-1. Tertiary crushing and grinding would result in similar emissions. Mitigated emissions were calculated assuming a control efficiency of 60% through the application of water sprays (NPI, 2001). Estimated emissions from crushing and screening operations are summarised in Table 6-3.

6.1.2.5 Vehicle Entrained Dust from Unpaved Roads

Vehicle-entrained dust emissions have been found to account for a great portion of fugitive dust emissions from mining operations. The following activities were included:

- In-pit haulage of ore and waste;
- Transport of ore from open pit to the ROM storage pile;
- Transport of waste from open pit to the waste dumps; and
- Passenger cars (public and mining personnel) and busses using the access road to site.

Fugitive dust emissions from ***unpaved haul roads*** and the ***access road*** were calculated using the US.EPA predictive emission factor equation (Equation 8, Appendix A). Haulage of the material volumes as given in Table 6-1 was applied to the unpaved haul roads. For the access road, the number of staff vehicles and company busses were accounted for in addition to the public vehicles as per the traffic specialist study. It has been calculated that the haul trucks would travel a total of 54.5 km per day between the pit and ROM storage pile and WRDs. The haul roads were taken to be 10 m wide. Passenger cars and buses transporting people to site will mainly utilise the access road. This road was taken to be 6.5 m wide with a length of 13.55 km. Cars and busses will travel between certain hours i.e. between 6AM – 9 AM, 3PM – 6 PM and 11PM-1AM. Public vehicles passing through the mine site were given for morning hours and late afternoon hours. The percentage road surface silt content (material less than 75 µm in diameter) on the access road was taken as the average from the on-site soil samples (7.1%) whereas the maximum of 12% was applied to the haul roads (haul roads have higher silt content according to the US.EPA AP42 documentation). It was assumed that water trucks will be used on-site to suppress dust from unpaved haul roads and within the pit. Water can result in a control efficiency of 75% and was assumed as the minimum mitigation scenario. When used in combination with chemical suppressants an efficiency of 90% can be achieved. Estimated fugitive dust emissions rates due to vehicle-entrained dust from the unpaved access and haul roads are provided in Table 6-3.

6.1.2.6 Windblown dust emission quantification

Wind erosion is a complex process, including three different phases of particle entrainment, transport and deposition. It is primarily influenced by atmospheric conditions (e.g. wind, precipitation and temperature), soil properties (e.g. soil texture, composition and aggregation), land-surface characteristics (e.g. topography, moisture, aerodynamic roughness length, vegetation and non-erodible elements) and land-use practice (e.g. farming, grazing and mining) (Shao, 2008).

Windblown dust generates from natural and anthropogenic sources. For wind erosion to occur, the wind speed needs to exceed a certain threshold, called the threshold velocity. This relates to gravity and the inter-particle cohesion that resists removal. Surface properties such as soil texture, soil moisture and vegetation cover influence the removal potential. Conversely, the friction velocity or wind shear at the surface, is related to atmospheric flow conditions and surface aerodynamic properties. Thus, for particles to become airborne, the wind shear at the surface must exceed the gravitational and cohesive forces acting upon them, called the threshold friction velocity (Shao, 2008).

Saltation and suspension are the two modes of airborne particles in the atmosphere. The former relates to larger sand particles that hop and can be deposited as the wind speed reduces or changes. Suspension refers to the finer dust particles that remain suspended in the atmosphere for longer and can disperse and be transported over large distances. It should be noted that wind erosion involves complex physics that is not yet fully understood (Shao, 2008).

Airshed has developed an in-house wind erosion model called ADDAS (Burger et al., 1997; Burger, 2010). This model, developed for specific use by Eskom in the quantification of fugitive emissions from its ash dumps, is based on the dust emission model proposed 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). This model is discussed in Appendix A (Section 11.1.5).

The proposed Turquoise Moon operations consist of the ROM Storage pile, the TSF and two WRDs (Figure 1-2). For the current assessment, particle size distribution for the TSF were provided with particle size distribution for the waste rock dumps and ROM storage pile taken from similar iron ore processes. The particle size distribution for the TSF, WRDs and ROM are provided in Table 6-2.

Table 6-2: Particle size distribution for the dumps at Turquoise Moon operations

Tailings		ROM		Waste Rock Dumps	
Size (Microns)	Fraction	Size (Microns)	Fraction	Size (Microns)	Fraction
2.5	0.003	0.008	0.033	1	0.375
4	0.009	1	0.290	2	0.050
10	0.108	2	0.052	5	0.092
25	0.384	5	0.119	7	0.036
30	0.107	7	0.061	10	0.033
38	0.033	10	0.070	15	0.028
45	0.137	15	0.082	30	0.044
63	0.170	30	0.142	45	0.046
75	0.032	45	0.079	75	0.092
90	0.010	75	0.072	150	0.204
106	0.007				

6.2 Synopsis of Particulate Emissions from Quantified Turquoise Moon Operations

A synopsis of the TSP and PM_{10} emissions from quantifiable Turquoise Moon operations is given in Table 6-3. The contribution of each source group to total emissions is also reflected in this table.

The most significant dust generating sources at the proposed mine were quantified. Off these, the source groups attributing most to dust generation were windblown dust and vehicle entrainment on the unpaved roads. Windblown dust accounted for 60% of the PM_{10} and 48% TSP emissions whereas vehicle entrained dust from unpaved access and haul roads accounted for 24% and 37% of PM_{10} and TSP emissions, respectively. Materials handling operations were the lowest contributing source group at less than 2% PM_{10} and TSP emissions.

With 60% control efficiency on the crushers and screens, and 75% controls on the roads, the overall emissions reduce by 23% for PM_{10} and 33% for TSP as indicated in Table 6-4.

Table 6-3: Total annual TSP and PM_{10} unmitigated emissions from quantified Turquoise Moon sources and contribution of each source group to total PM emissions

Source Group	PM_{10} Emissions (tpa)	TSP Emissions (tpa)
Drilling and Blasting	154.92	297.56
Crushing and Screening	247.65	679.25
Materials handling operations	41.49	104.63
Vehicle entrainment from road surfaces	680.30	2 611.47
Windblown dust from TSF, WRDs and ROM SP	1 665.94	3 401.01
TOTAL	**2 790.30**	**7 093.91**

	Source Contributions to Total PM_{10} Emissions (%)	Source Contributions to TSP Emissions (%)
Drilling and Blasting	5.6	4.2
Crushing and Screening	8.9	9.6
Materials handling operations	1.5	1.5
Vehicle entrainment from road surfaces	24.4	36.8
Windblown dust from TSF, WRDs and ROM SP	59.7	47.9
TOTAL	**100.0**	**100.0**

Table 6-4: Total annual TSP and PM_{10} mitigated emissions from quantified Turquoise Moon sources and contribution of each source group to total PM emissions

Source Group	PM_{10} Emissions (tpa)	TSP Emissions (tpa)
Drilling and Blasting	154.92	297.56
Crushing and Screening	99.06	271.70
Materials handling operations	41.49	104.63
Vehicle entrainment from road surfaces	170.08	652.87
Windblown dust from TSF, WRDs and ROM SP	1 665.94	3 401.01
TOTAL	**2 131.49**	**4 727.76**

	Source Contributions to Total PM_{10} Emissions (%)	Source Contributions to TSP Emissions (%)
Drilling and Blasting	7.3	6.3
Crushing and Screening	4.6	5.7
Materials handling operations	1.9	2.2
Vehicle entrainment from road surfaces	8.0	13.8
Windblown dust from TSF, WRDs and ROM SP	78.2	71.9
TOTAL	**100.0**	**100.0**

6.3 Impact Assessment

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 as provided in Table 3-1 and the dust fallout limits as set out in Table 3-2. In addition, dust fallout was also screened against the European threshold for vegetation impact (Section 3.1.3)

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 99.73th 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 (2009).

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 include as discrete receptors as discussed in Section 2.2.5.

Two scenarios were evaluated, namely:

- Unmitigated – assuming no controls in place at any of the dust generating sources, except for drilling where it formed part of the type of drill techniques and equipment (i.e. estimated 60% control of dust emissions); and
- Mitigated – assuming water sprays at the crushers and screens resulting in 60% control efficiency and water sprays on the roads ensuring 75% control efficiency.

6.4 Dispersion Modelling Results

6.4.1 PM_{10} Ground Level Concentrations

The isopleths plots are provided in Figures 6-1 and 6-2 for PM_{10} highest daily and annual averages without mitigation, respectively. Figures 6-3 and 6-4 provides highest daily and annual average plots for PM_{10} with assumed mitigation in place. Predicted GLCs at each of the discrete receptors are provided in Table 6-5. The mine boundary receptors and farm locations are provided in Figure 2-1. Plots for individual source groups are provided in Appendix B.

- Unmitigated scenario: Figure 6-1 indicates the area of highest predicted daily PM_{10} GLCs. The NAAQ limit of 75 $\mu g/m^3$ is exceeded for a distance of up to 5 km to the south and east-northeast. The only exceedances of the NAAQ limit at the sensitive receptors are at Karnemelksfontein and Lelie Vontijn, for daily averages and at the northern, eastern and southern mine boundary receptors (Table 6-5). Figure 6-5 provides the area where the NAAQ limit of 75 $\mu g/m^3$ is exceeded for more than the allowable four days per year. This zone stretches outside the mine boundary to the east and south for up to 3 km, indicating a zone of non-compliance. Over an annual average, predicted annual average PM_{10} GLCs comply with the NAAQS (Figure 6-2).
- Mitigated scenario: With mitigation in place on crushing and screening activities and on the roads, the predicted impacts reduce over a daily average to only exceed the NAAQ limit of 75 $\mu g/m^3$ for a small area at the mine boundary (Figure 6-3). This results in compliance with the NAAQS off-site as shown in Figure 6-6 except for two boundary locations (Table 6-5). The annual average footprint as shown in Figure 6-4 also reduces significantly, remaining to be within compliance outside of the mine boundary.

Table 6-5: Predicted PM_{10} impacts at each of the sensitive receptors (figures in bold indicate exceedances of the NAAQ Limit and NAAQ Standards)

Receptor	Highest Daily PM_{10} concentration (µg/m^3)		Frequency of exceedance of NAAQS for daily average of 75 µg/m^3		Annual Average PM_{10} concentration (µg/m^3)	
	Unmitigated	Mitigated	Unmitigated	Mitigated	Unmitigated	Mitigated
Marnitz	40.1	14.2	1	0	2.7	1.0
Zandkraal	34.8	9.5	0	0	2.0	0.6
Handam	49.9	13.7	0	0	3.7	1.2
Karnemelksfontein	**77.6**	24.4	2	0	5.7	1.9
Good Hope	65.4	33.2	1	0	3.4	1.3
Lelie Vontijn	**75.3**	25.3	2	0	3.3	1.2
Tabana	48.9	15.9	0	0	2.4	0.9
Mine boundary receptors						
B1	**279.0**	**84.9**	**41**	3	21.9	6.0
B2	**194.3**	**156.0**	**23**	**4**	14.8	5.5
B3	**136.5**	**95.4**	**21**	3	13.2	4.6
B4	**88.0**	26.6	**2**	0	3.4	1.3
B5	**238.1**	**85.4**	**23**	**4**	18.1	6.5
B6	**215.0**	**76.7**	**56**	2	**39.7**	14.1
B7	70.4	28.7	1	0	12.2	4.2
B8	**79.0**	21.0	2	0	8.7	2.7
B9	**79.0**	22.6	2	1	6.7	2.2
B10	**77.5**	21.7	2	0	7.4	2.2

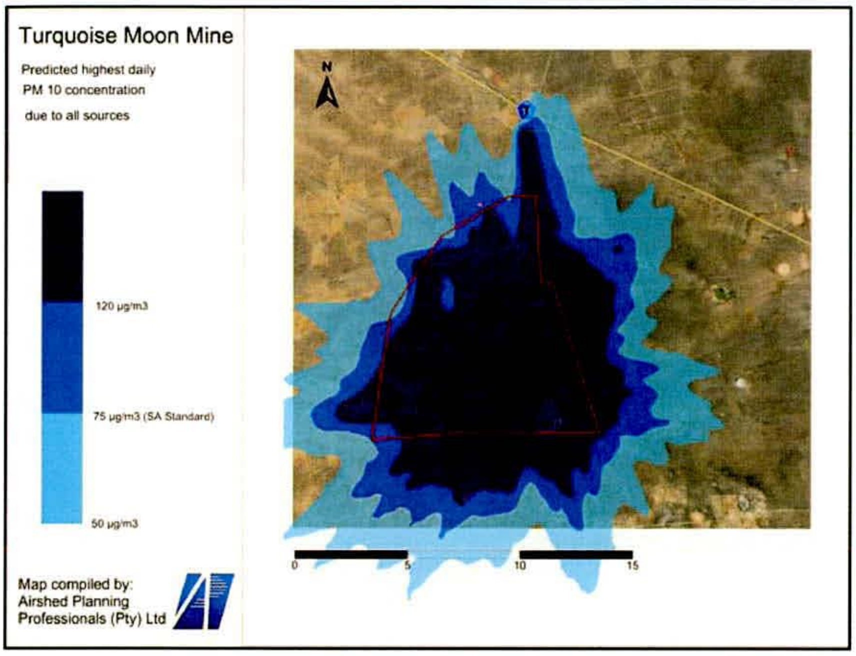

Figure 6-1: Highest daily predicted PM_{10} GLC (µg/m³) due to all sources at Turquoise Moon (without mitigation)

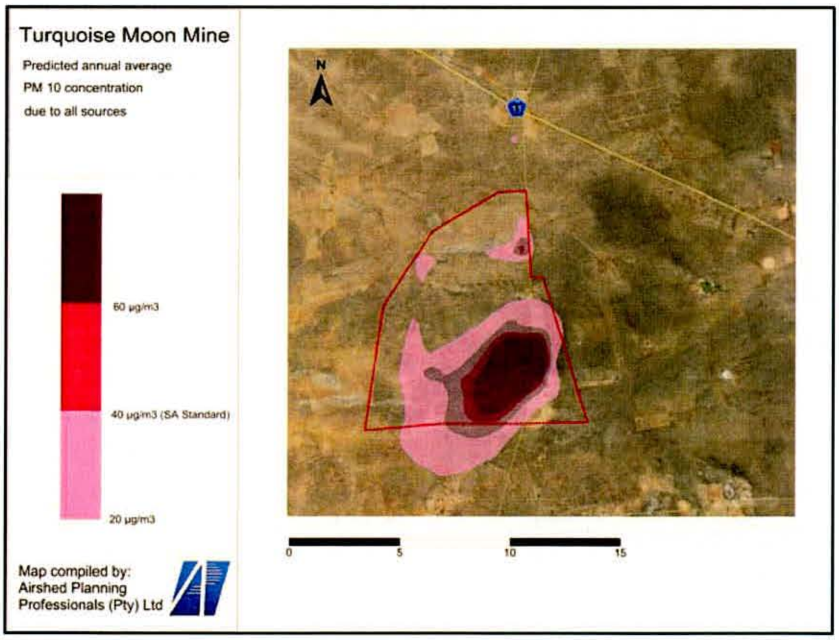

Figure 6-2: Annual average predicted PM_{10} GLC (µg/m³) due to all sources at Turquoise Moon (without mitigation)

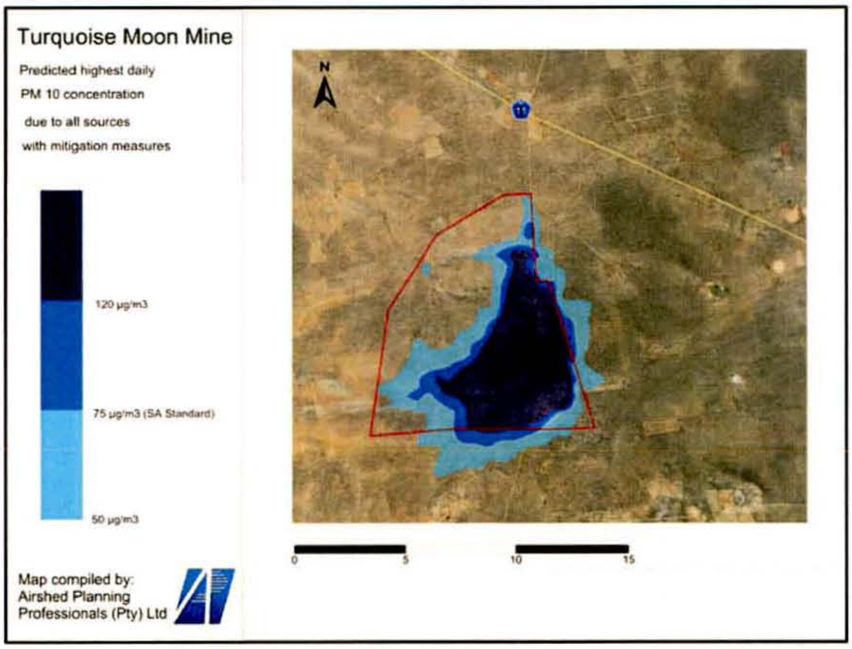

Figure 6-3: Highest daily predicted PM_{10} GLC ($\mu g/m^3$) due to all sources at Turquoise Moon (with mitigation)

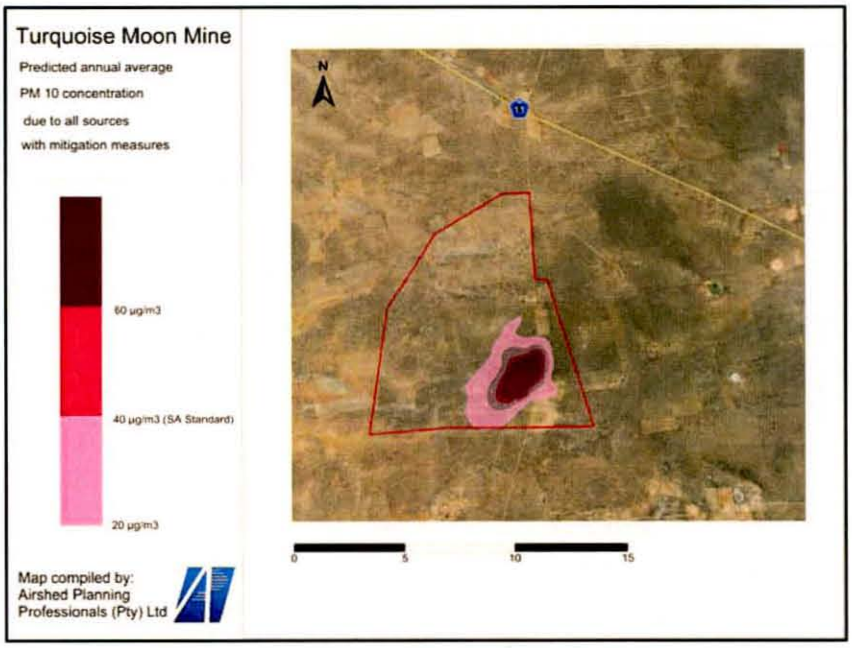

Figure 6-4: Annual average predicted PM_{10} GLC ($\mu g/m^3$) due to all sources at Turquoise Moon (with mitigation)

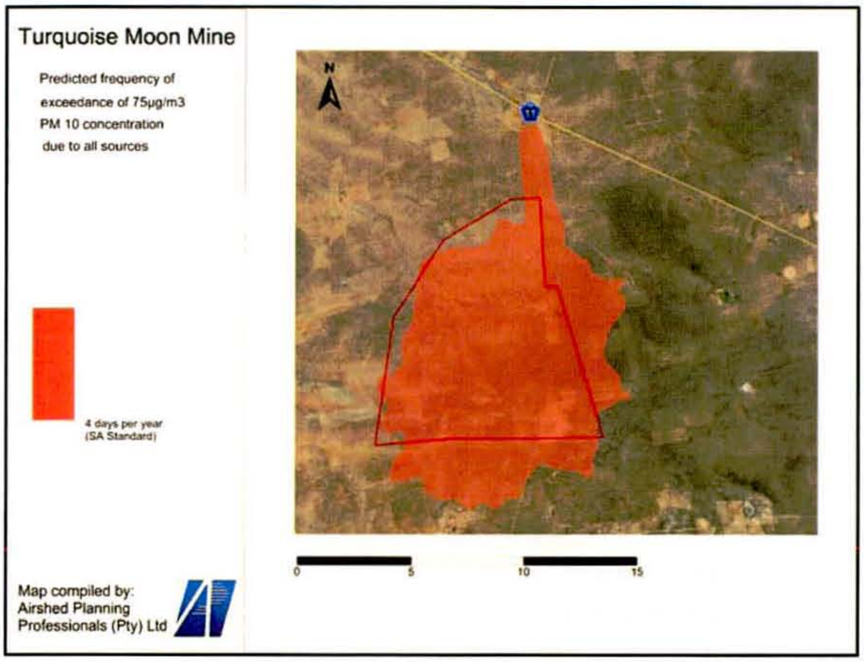

Figure 6-5: Predicted highest daily average frequency of exceedance due to Turquoise Moon operations for the year 2009 (without mitigation)

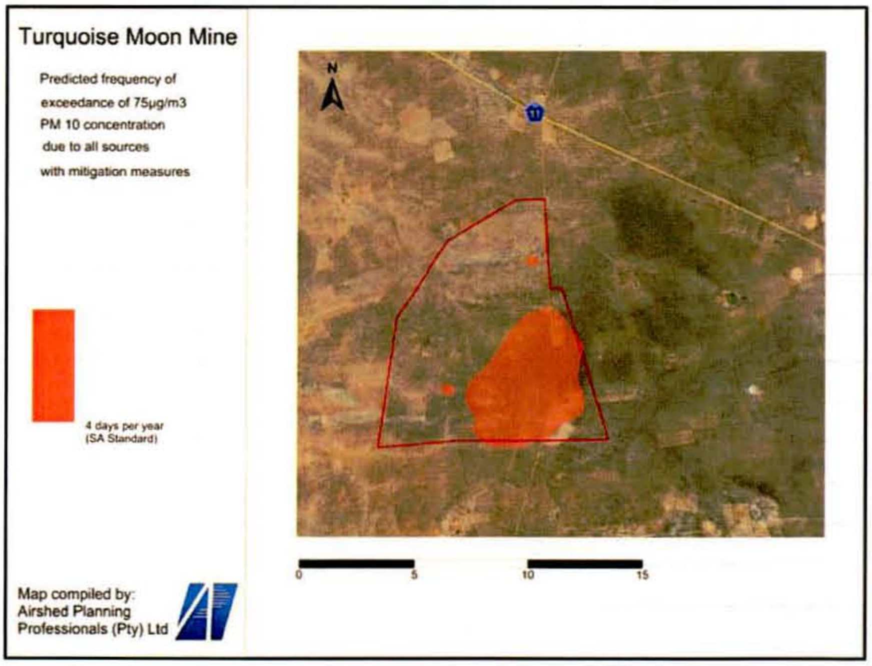

Figure 6-6: Predicted highest daily average frequency of exceedance due to Turquoise Moon operations for the year 2009 (with mitigation)

6.4.2 Dust Fallout Rates

Figure 6-7 provides the dust fallout rates for the year 2009 and Table 6-6 at the sensitive receptors, for the unmitigated scenario. Dust fallout is already low without mitigation and even lower when mitigation is applied as indicated in Figure 6-8.

- Unmitigated scenario: The majority of dust fall occurs within the site boundary. The area around the road has higher dust fallout. The predicted dust fallout rate at the mine boundary is below 600 mg/m^2/day, the proposed maximum dust fall rate for residential areas. It also does not exceed the limit for vegetation (400 mg/m^2/day).
- Mitigated scenario: With mitigation in place on crushing and screening activities and on the roads, the predicted dust fallout rates reduce to fall completely within the mine boundary, not exceeding any of the dust fall limits.

Table 6-6: Predicted dust fall impacts at each of the sensitive receptors

Receptor	Daily average dust fall (mg/m^2/day)	Daily average dust fall (mg/m^2/day)
	Unmitigated	**Mitigated**
Marnitz	0.9	0.3
Zandkraal	0.2	0.1
Handam	1.5	1.2
Karnemelksfontein	1.8	1.5
Good Hope	7.3	5.3
Lelie Vontijn	2.8	1.4
Tabana	0.6	0.3
Mine boundary receptors		
B1	39.5	10.0
B2	9.2	7.7
B3	10.2	7.2
B4	12.0	9.5
B5	24.3	12.2
B6	63.1	44.9
B7	8.6	5.9
B8	9.1	7.0
B9	5.8	1.5
B10	7.8	2.1

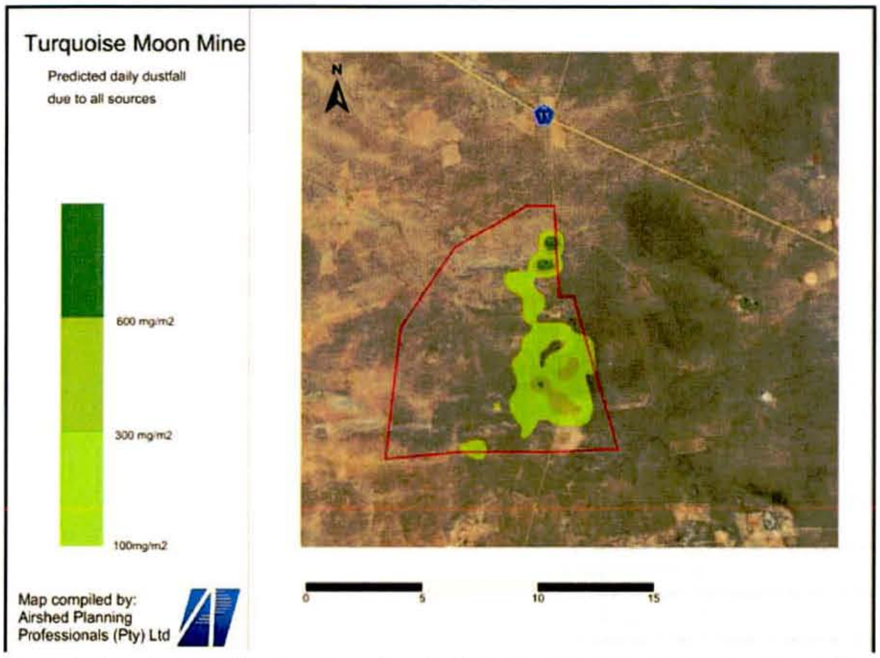

Figure 6-7: Total daily dust fallout rates (mg/m²/day) due to all sources at Turquoise Moon operations (without mitigation)

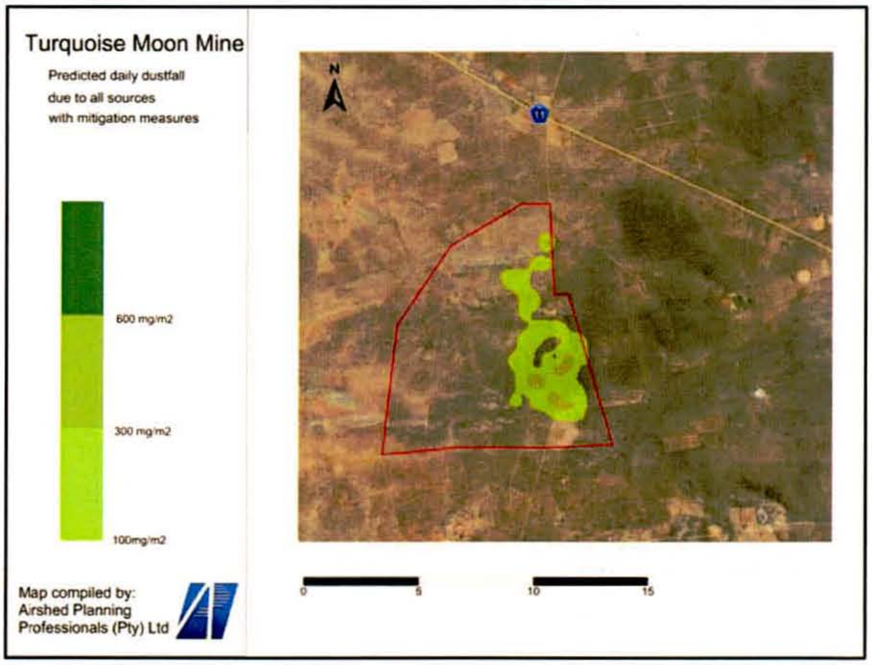

Figure 6-8: Total daily dust fallout rates (mg/m²/day) due to all sources at Turquoise Moon operations (with mitigation)

6.4.3 Significance rating of operational phase activities

6.4.3.1 Significance of PM_{10} ground level concentrations

The significance of the operational phase operations can be summarised as follows:

- Un-mitigated: Operations with no mitigation in place will most likely result in off-site impacts exceeding the NAAQS at the mine boundary and at the farms located on the eastern and southern side of the mine. These impacts will occur for the Life of Mine.

- Mitigated: With mitigation in place at the crushing and screening operations and on roads, the predicted impacts are likely to decrease such to comply with the NAAQS off-site, specifically at the nearby farms. These impacts will be restricted to the mine property exceeding only at two locations along the mine boundary. Further mitigation on the unpaved roads to ensure 90% control efficiency will reduce the impacts to be retained within the mine boundary.

6.4.3.2 Significance of Dust fall rates

The significance of the operational phase operations can be summarised as follows:

- Un-mitigated: Operations with no mitigation in place are predicted to fall within the SANS residential dust fall limits at the mine boundary and beyond. It is also below the European vegetation limit.

- Mitigated: With mitigation in place (crushing and screening operations of in 60% control efficiency and roads with 75% control), the predicted dust fallout rates are even lower.

7 Closure and Post-Closure Phase

For the sake of this discussion, closure is regarded as the phase where all mining operations cease and rehabilitation takes place. Post-closure is with rehabilitation already in place. It is assumed that all mining activities will have ceased in 30 years from the start of opencast mining. The potential for impacts during this phase will depend on the extent of rehabilitation efforts during closure.

Aspects and activities associated with the closure phase of the mining operations at the proposed Turquoise Moon mine are listed in Table 7-1.

Table 7-1: Activities and aspects identified for the closure phase of mining operations.

Impact	Source	Activity
Generation of TSP and PM_{10}	Topsoil stockpiles	Topsoil recovered from stockpiles for rehabilitation and re-vegetation of surroundings.
	Plant site/s	Infrastructure removal at processing plant site.
	Unpaved roads	Vehicle entrainment on unpaved road surfaces for rehabilitation. Once that is done, vehicle activity should cease.
	Blasting	Demolition of infrastructure may necessitate the use of blasting.
Gas emissions (1)	Vehicles	Tailpipe emissions from vehicles utilised during the closure phase. Once that is done, vehicle activity should cease.

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

7.1.1 Significance rating of closure and post closure phase

The significance the closure phase is likely to be the same as impacts expected from windblown dust sources. As indicated in Figure 12-14 in Appendix B, the predicted impacts from windblown dust is likely to only impact off-site under conditions of high wind speed with no mitigation in place. If rehabilitation as indicated takes place i.e. rock cladding on the side wall of the TSF and paddocks of vegetation and pools on the surface, the impacts should be limited to be within the mine boundary. TSFs at other iron ore mines tend to harden if undisturbed with little dust emanating from it.

8 Conclusions

An air quality impact assessment was undertaken to assess the possible impacts of all dust generating sources at the proposed Turquoise Moon mining operation. PM_{10} GLCs and dust fallout rates for the proposed operations were assessed in order to identify all possible detrimental impacts on the surrounding environment and human health.

Two scenarios were assessed namely (i) unmitigated and (ii) mitigated. Unmitigated assumed no controls to be applied on any of the activities. Mitigated assumed dust suppression in the form of water sprays on all the roads to achieve 75% control efficiency and at the crushers and screens to achieve 60% control efficiency.

8.1 Main Findings

8.1.1 Emissions Inventory

From the emissions quantification, windblown dust from the two WRDs and the TSF are the main contributing sources to both PM_{10} (60%) and TSP (48%) emissions for the unmitigated scenario. Dust emanating from unpaved haul roads and the access road is the second most significant source group contributing 24% to PM_{10} and 37% to TSP. Crushing and screening, third on the list, adds 9% and 10% to PM_{10} and TSP, respectively. With mitigation in place, the overall emissions will reduce by 24% and 33% for PM_{10} and TSP, respectively. This is when no mitigation is applied.

With mitigation in place, the source ranking remains unchanged but there is a 24% reduction in the overall PM_{10} emissions and 33% reduction in TSP.

8.1.2 Predicted PM_{10} impacts

Construction Phase

Construction operations were only qualitatively assessed. The main dust generating activities during construction include clearing of vegetation and topsoil, loading and unloading of topsoil, wind erosion from topsoil storage pile and vehicle entrainment on unpaved road surfaces. Calculations indicate TSP emission rates 1.3 times higher than that of the operational phase. This is based on the assumption that all construction activities will occur simultaneously and over the entire area. This is very unlikely and it is expected that the impacts will be similar or lower than that of the operational phase, for the unmitigated scenario.

With water sprays in place at most of the construction activities, the emissions could be halved ensuring impacts to be restricted to the mine property.

Operational Phase

PM_{10} daily impacts from the proposed operations are significant in close proximity to the mine with no mitigation in place. Predictions indicate that the NAAQ limit of 75 µg/m³ will be exceeded for more than 4 days per year implicating non-compliance with the AQA. The impact area stretches approximately 3 km to the east and south of the mine boundary and includes two farm dwellings. With mitigation in place, the predicted impacts reduce to be within compliance outside of the mine boundary.

Figure 8-1 provides the source contributions to the highest daily PM_{10} and annual average GLCs when no mitigation is applied. From this graph it is evident that the main contributing sources over daily averages are the roads, materials handling (specifically crushing and screening) and dust from the WRDs and TSF. This is also illustrated in Appendix B, Figures 12-14, 12-17, 12-19 and 12-20 for the unmitigated scenario. Over an annual average, the crushing and screening (materials handling) operations are the main contributors. Blasting, even though high over a few minutes, is a small contributor when averaged over a day.

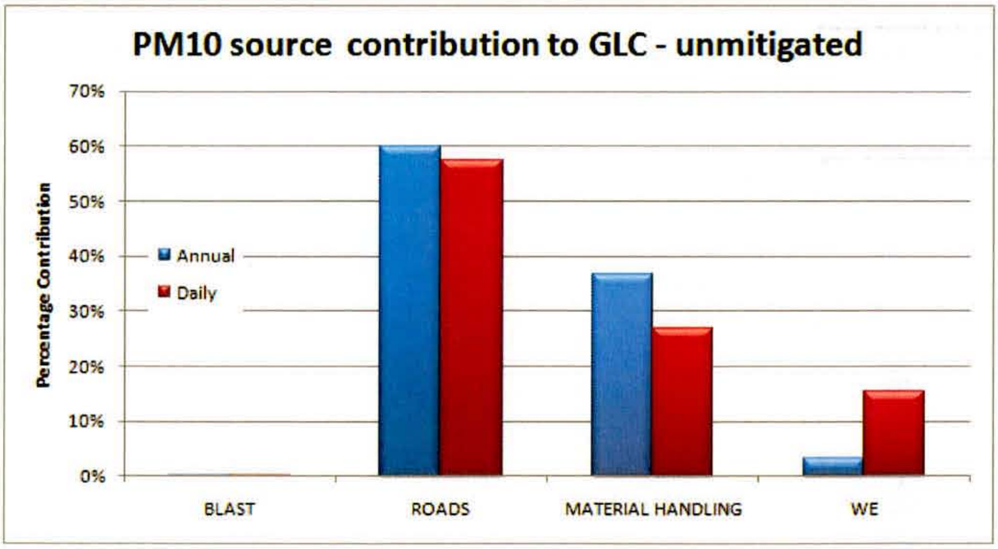

Figure 8-1: Source contributions to average daily PM_{10} and annual predicted GLCs (unmitigated)

With mitigation in place on the roads and crushing/ screening operations, the source contributions to predicted GLCs change slightly with a lower contribution from the vehicles and materials handling as shown in Figure 8-2.

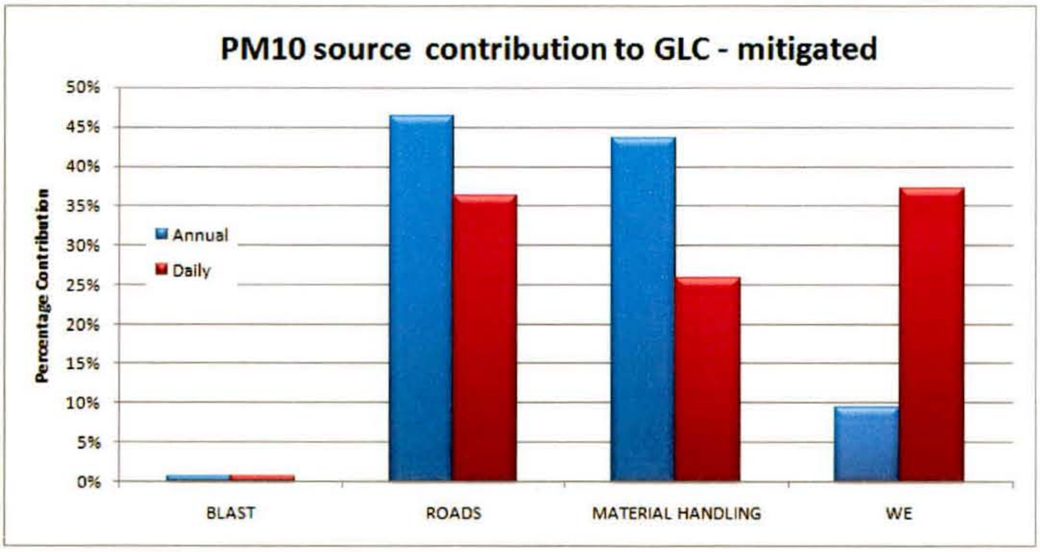

Figure 8-2: Source contributions to average daily PM_{10} and annual predicted GLCs (mitigated)

8.1.3 Predicted dust fallout

Dust fallout rates as predicted is high on-site (>600 mg/m²/day) and near the source of emissions. Outside the mine boundary and at the various farms the dust fallout is well below the SANS residential limit and even below the European limit for vegetation (400 mg/m^2/day). With mitigation in place, this reduces to an even smaller area.

Figure 8-3 provides the source contributions to the dust fallout rates. From this graph it is evident that the main contributing source group is the roads, with blasting second.

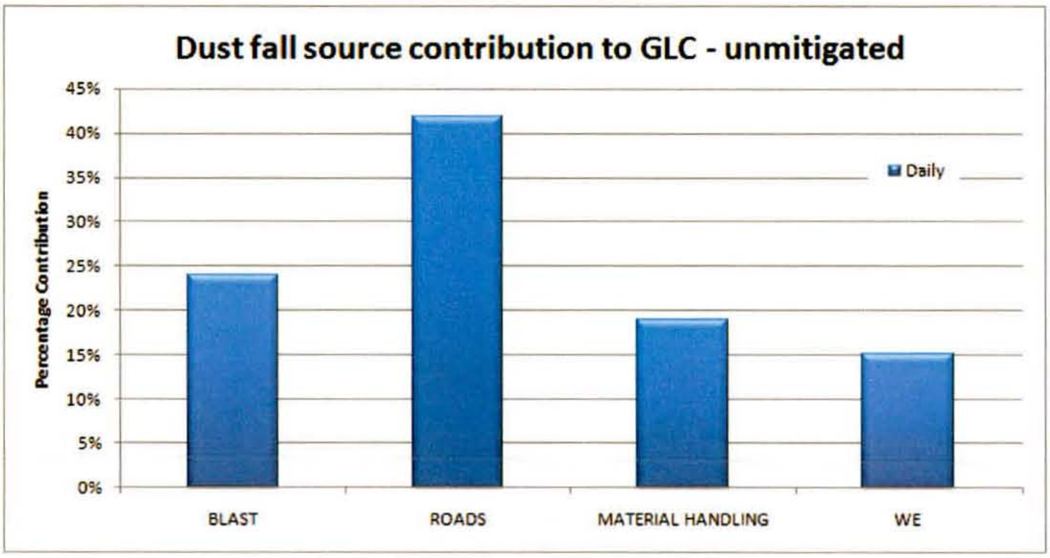

Figure 8-3: Source contributions to average daily predicted dust fallout rates (unmitigated)

With mitigation in place as depicted in Figure 8-4, blasting becomes the most significant source contributing to dust fallout.

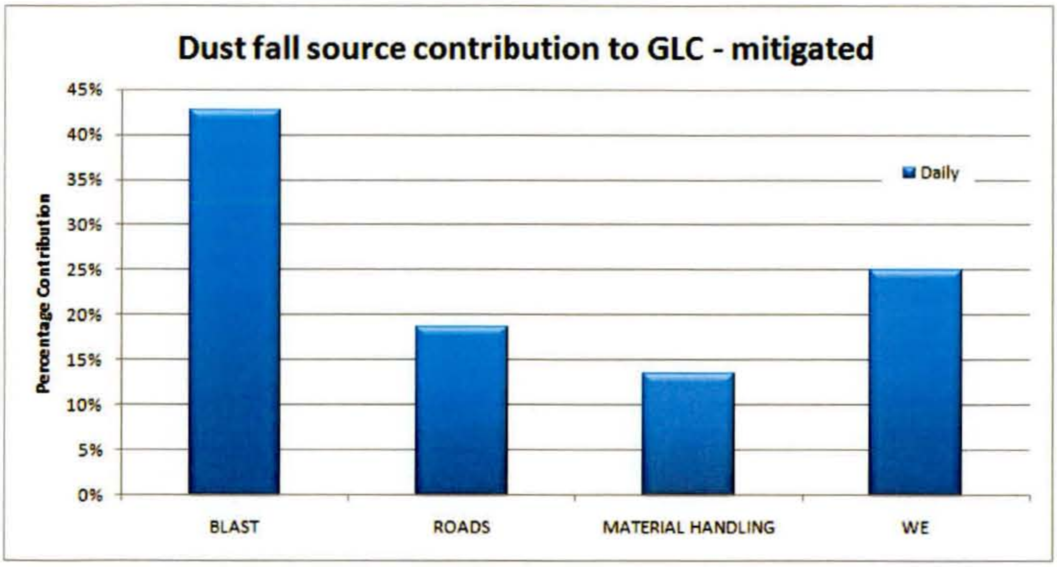

Figure 8-4: Source contributions to average daily predicted dust fallout rates (mitigated)

8.2 Main Conclusion

It can be concluded that the proposed Turquoise Moon Project will have high PM_{10} impacts at the mine boundary with no mitigation in place. With the recommended mitigation measures applied, the predicted impacts will be retained on-site resulting in compliance off-site. Dust fallout is generally low and within the acceptable SANS limit for residential areas and the European limit for vegetation.

9 Dust Management Plan

In the light of the potential non-compliance without mitigation in place and the concerns raised by the I&APs, 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. The sources need to be ranked according to sources strengths (emissions) and impacts. Once the main sources have been identified, target control efficiencies for each source can be defined to ensure acceptable cumulative ground level concentrations.

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.

9.1 Source ranking

As concluded, the main source of both emissions and predicted GLCs are as follows:

- fugitive dust emissions from unpaved roads surfaces (over daily and annual averages);
- windblown dust from WRDs and the TSF (only over daily averages); and
- crushing and screening operations (only over annual averages).

9.2 Target controls for the Main Sources

The proposed target controls on the various sources are provided below.

9.2.1 Construction Phase

- Vegetation removal and construction of infrastructure – 60% control efficiency through effective water sprays.
- Vehicle entrainment on temporary unpaved roads – 75% control efficiency through effective water sprays on haul roads.

9.2.2 Operational Phases

- Vehicle entrainment on unpaved access and haul roads – a minimum of 75% control efficiency through the application of water sprays on the haul roads and 90% control efficiency on the access road through the application of chemicals.

- Windblown dust from WRDs and TSF – at least 80% vegetation cover and/ or rock gladding/ due to natural binding on the side slopes of the TSF to ensure 60% control efficiency and general vegetation cover on the WRDs to ensure the same control efficiency.
- Crushing and Screening operations – at least 60% control efficiency through the application of water sprays.

The reduction in the area of impact for highest daily PM_{10} GLCs is provided for the unmitigated option (Figure 9-1) and the mitigated option (Figure 9-2). Only 75% control efficiency for roads and 60% on materials handling were assumed.

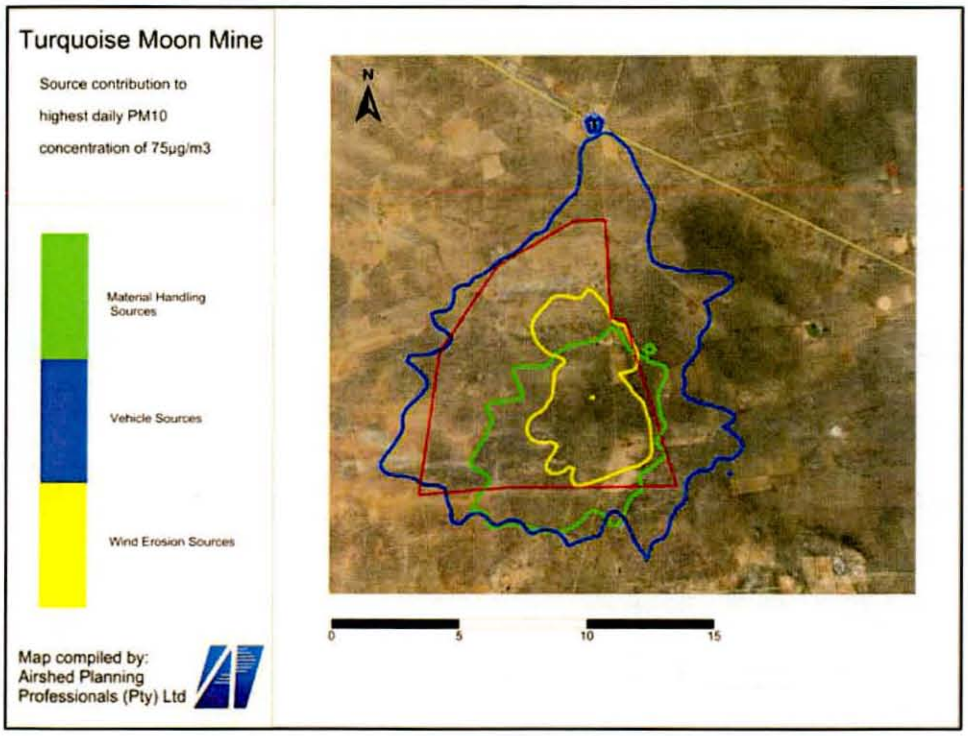

Figure 9-1: Predicted source contributions to highest daily PM_{10} concentration (without mitigation)

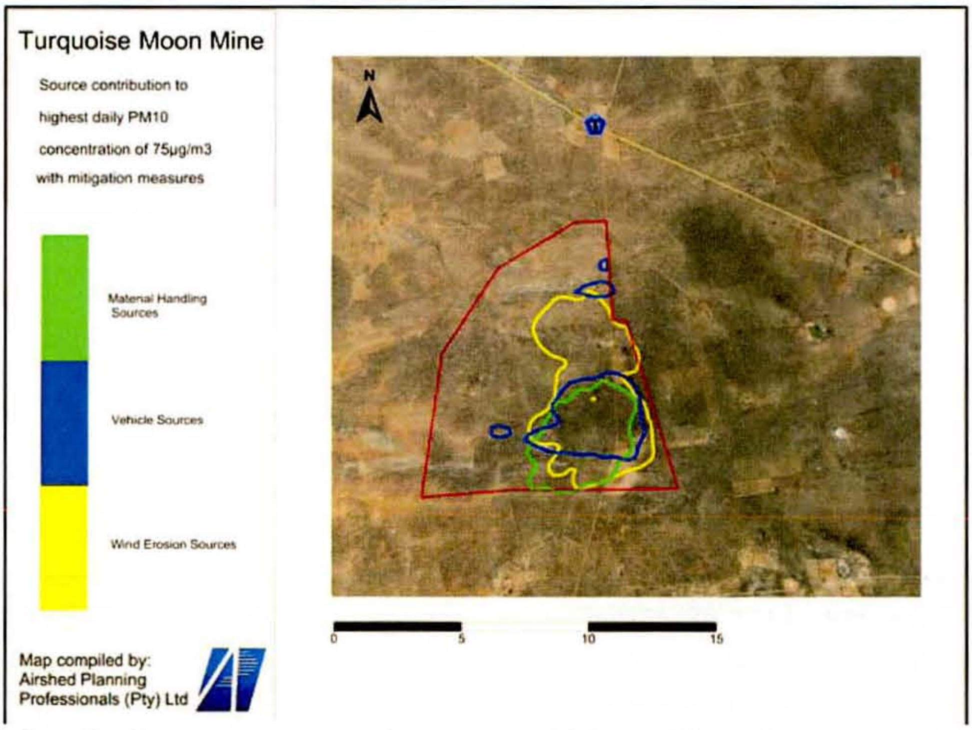

Figure 9-2: Predicted source contributions to highest daily PM_{10} concentration (with mitigation)

9.2.3 Closure and Post-closure Phase

The potential for impacts during the closure phase is dependent on the extent of demolition and rehabilitation efforts during closure and on features which remain (viz. the WRDs and TSF). As indicated in Section 7, the closure option of rock gladding and vegetation pockets and pools should result in a reduction in the potential for windblown dust resulting in negligible impacts. The potential also exists for the TSF material to bind naturally. This will have to be assessed once the TSF is in place.

9.3 Identification of Suitable Pollution Abatement Measures

9.3.1 General

The mine layout plan provided indicate the majority of dust generating sources centralised within a specific boundary. Adherence to this plan will limit the potential for off-site impacts. Drastic changes to the proposed plan will have adverse effects on the off-site PM_{10} concentrations and dust fallout rates.

9.3.2 Unpaved 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; Cowhert et al., 1988; APCD, 1995).

The main dust generating factors on unpaved road surfaces include:

- Vehicle speeds
- Number of wheels per vehicle
- Traffic volumes
- Particle size distribution of the aggregate
- Compaction of the surface material
- Surface moisture
- Climate

When quantifying emissions from unpaved road surfaces, most of these factors are accounted for. Vehicle speed is one of the significant factors influencing the amount of fugitive dust generated from unpaved roads surfaces. According to research conducted by the Desert Research Institute at the University of Nevada, an increase in vehicle speed of 10 miles per hour resulted in an increase in PM_{10} emissions of between 1.5 and 3 times. A similar study conducted by Flocchini et.al. (1994) found a decrease in PM_{10} emissions of 42±35% with a speed reduction from 40 km/hr to 24 km/hr (Stevenson, 2004). The control efficiency obtained by speed reduction can be calculated by varying the vehicle speed input parameter in the predictive emission factor equation given for unpaved roads. An evaluation of control efficiencies resulting from reductions in traffic volumes can be calculated due to the linear relationship between traffic volume, given in terms of vehicle kilometres travelled, and fugitive dust emitted. Similar affects will be achieved by reducing the truck volumes on the roads. Thus, by increasing the payload of the truck, fewer trips will be required to transport the same amount of material.

Water sprays on unpaved roads is the most common means of suppressing fugitive dust due to vehicle entrainment at mines, but it is not necessarily the most efficient means (Thompson and Visser, 2000). Thompson and Visser (2000) developed a model to determine the cost and management implications of dust suppression on mine haul roads using water or other chemical palliatives. The study was undertaken at 10 mine sites in Southern Africa. The model was first developed looking at the re-application frequency of water required for maintaining a specific degree of dust palliation. From this the cost effectiveness of water spray suppression could be determined and compared to other strategies. Factors accounted for in the model included climate, traffic, vehicle speed and the road aggregate material. A number of chemical palliative products, including hygroscopic salts, lignosulponates, petroleum resins, polymer emulsions and tar and bitumen products were assessed to benchmark their performance and identify appropriate management strategies. Cost elements taken into consideration included amongst others capital equipment, operation and maintenance costs, material costs and activity related costs. The main findings were that water-based spraying is the cheapest dust suppression option over the short term. Over the longer term however, the polymer-emulsion option is marginally cheaper with added benefits such as improved road surfaces during wet weather, reduced erosion and dry skid resistance (Thompson and Visser, 2000).

An empirical model, developed by the US.EPA (EPA, 1996), was used to estimate the average control efficiency of certain quantifies of water applied to a road. The model takes into account rainfall, evaporation rates and traffic. Water sprays resulting in at least 75% control efficiency would be a requirement to result in a significant reduction in ground level concentrations and dust fall rates. Should only water be applied, the amounts needed to ensure 75% control efficiency on the main and in-pit haul roads (assuming 8.53 trucks/hour) are 0.17 l/m²-hour excluding mitigation due to rainfall and only accounting for evaporation (Section 4.1.3). Considering the effect of rainfall (Section 4.1.3), the watering rate was calculated to be 0.14 l/m²-hour based on annual rainfall of 421 mm. Watering rates for a variety of control efficiencies are presented in Figure 9-3.

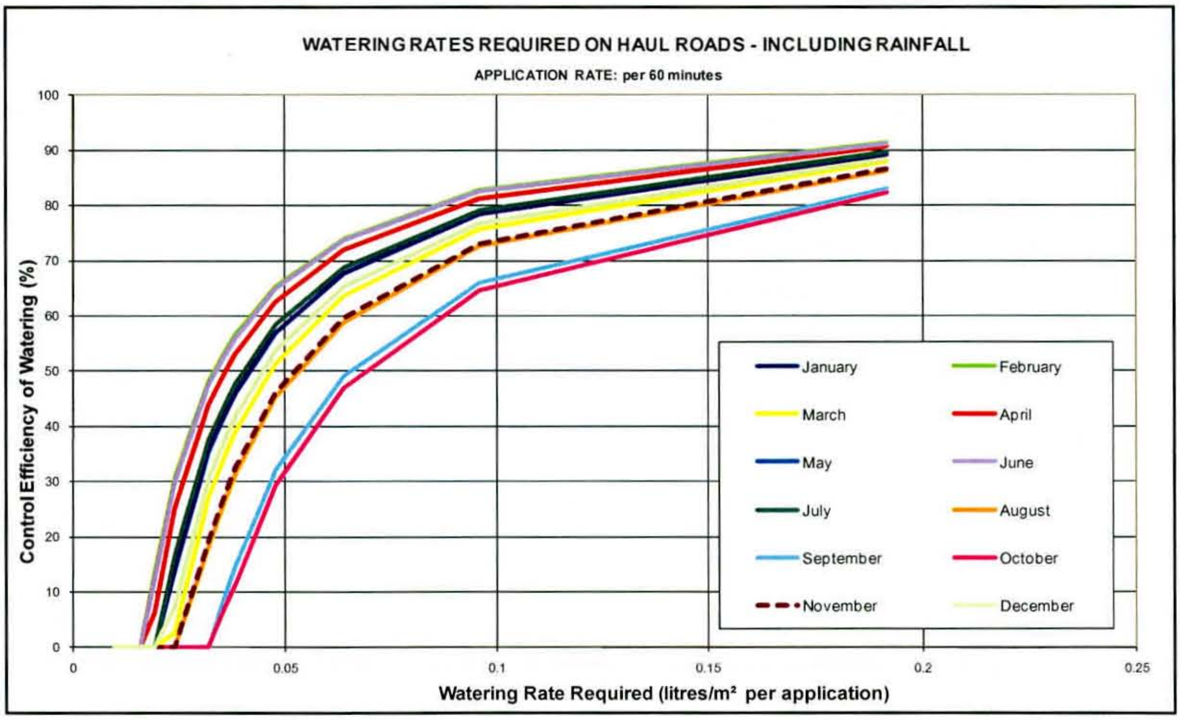

Figure 9-3: Required watering rates on haul roads for various mitigation efficiencies

Chemical suppressant has been proven to be affective due to the binding of fine particulates in the road surface, hence increasing the density of the surface material. In addition, dust control additives are beneficial in the fact that it also improves the compaction and stability of the road. The effectiveness of a dust palliative include numerous factors such as the application rate, method of application, moisture content of the surface material during application, palliative concentrations, mineralogy of aggregate and environmental conditions. Thus, for different climates and conditions you need different chemicals, one chemical might not be as effective as another under the same conditions and each product comes with various advantages and limitations of each own. In general, chemical suppressants are given to achieve a PM_{10} control efficiency of 80% when applied regularly on the road surfaces (Stevenson, 2004).

There is however no cure-all solution but rather a combination of solutions. A cost-effective chemical control programme may be developed through establishing the minimum control efficiency required on a particular roadway, and evaluating the costs and benefits arising from various chemical stabilization practices. Appropriate chemicals and the most effective relationships between application intensities, reapplication frequencies, and dilution ratios may be taken into account in the evaluation of such practices.

Spillage and track-on from the surrounding unpaved areas may result in the deposition of materials onto the chemically treated or watered road resulting in the need for periodic "housekeeping" activities (Cowherd et al., 1988; EPA, 1996). In addition, the gradual abrasion of the chemically treated surface by traffic will result in loose material on the surface which would have to be controlled. The minimum frequency for the reapplication of watering or chemical stabilizers thus depends not only on the control efficiency of the suppressant but also on the degree of spillage and track-on from adjacent areas, and the rate at which the treated surface is abraded. The best way to avoid dust generating problems from unpaved roads is to properly maintain the surface by grading and shaping for cross sectional crowing to prevent dust generation caused by excessive road surface wear (Stevenson, 2004).

One of the main benefits of chemical stabilisation in conjunction with wet suppression is the management of water resources (MFE, 2001). It is therefore recommended that water be used in combination with chemical surfactants to reduce the amount of water required to achieve control efficiencies in excess of 75% on the access and main surface haul roads at Turquoise Moon Mine.

9.3.3 Wind erosion

The second most significant impacting source over short term averages is wind erosion from the WRDs and TSF. With no controls on the slopes and on the surfaces of these dumps and piles, high impacts can be experienced off-site. Wind erosion is governed by particle size distribution, binding forces between particles and roughness elements on the surface. It is understood that WRDs comprises various particle sizes, from ultrafine to large boulders. The latter acting both as a screen against the force of the wind and reducing the wind speed over the dump surface, thereby limiting the potential for erosion. The TSF, on the other hand, comprises of very fine particles prone to wind erosion. The wet surface will reduce the potential for windblown dust but the side walls remain a potential source if not mitigated. It is recommended that the walls of TSF be vegetated or rock gladded up to 1 m from the top throughout the life of mine to ensure an increase in both binding agents and roughness elements. It is possible that the surface of TSF, as at other iron ore mines, will harden if undisturbed and reduce the potential for dust generation. This should be verified once the mine is operational. The cover or natural binding should be of such a nature to ensure at least 60% control efficiency. This should be an on-going process.

Various methods have been researched and proposed for TSF controls, specifically. These range from vegetation cover, to rock cladding to wind screens. As indicated in Section 6.1.2.6, any approach that either binds the particles together and make it more resistant to wind erosion, or reduce to the force of the wind will result in a reduction in windblown dust emissions. This section provides a brief discussion on various windblown dust control methods.

Surface treatment techniques which may be implemented to reduce dust generation include: wet suppression, chemical stabilisation, covering of surface with less erodible aggregate material and the vegetation of open areas. Wet suppression (the use of sprinklers) can achieve results in the short term, but will require constant maintenance and management to remain effective.

Rock cladding or armouring of the sides of tailings dams has been shown in various international studies to be effective in various instances in reducing wind erosion of slopes. Cases in which rock cladding has been found to be effective in this regard generally involve rock covers of greater than 0.5 m in depth (Ritcey, 1989; Jewell and Newson, 1997). The application of a 300 mm layer of fine rock was found to be the most successful of the non-vegetative measures, resulting in an erosion control efficiency of 90% *if the base is levelled and compacted.* (Wind erosion is considered to be reduced by 100% through the addition of such a rock cover.) It should be noted that the control efficiency is only anticipated to be ~ 60% if the base is not compacted. It was estimated that the addition of a geofabric or a layer of filter stone beneath the fine rock layer (on a compacted based) would provide an additional control efficiency of only 2% to 3%. The coarse rock layer, on a compacted base, was observed to reduce erosion by 50% to 60% with only marginally better results being obtained from the more expensive commercial ballast rock when compared to the cheaper coarse dump rock. The addition of a geofabric layer under the coarse rock was given as improving the erosion reduction to at least 90% (Smith, 1995; Blight and Smith, 1996).

In addition, **screens** could be installed on the crest of the tailings dam walls mainly to act as wind breaks and to reduce the potential for dust deposition on the vegetated side walls, hence curbing the growth of the grass. The workable surface (disturbed surface) of the tailings dam should be kept as small as possible to reduce the exposed surface.

Vegetal cover retards erosion by binding the residue with a root network, by sheltering the residue surface and by trapping material already eroded. Sheltering occurs by reducing the wind velocity close to the surface, thus reducing the erosion potential and volume of material removed. The trapping of the material already removed by wind and in suspension in the air is an important secondary effect. Vegetation is also considered the most effective control measure in terms of its ability to also control water erosion. In investigating the feasibility of vegetation types the following properties are normally taken into account: indigenous plants; ability to establish and regenerate quickly; proven effective for reclamation elsewhere; tolerant to the climatic conditions of the area; high rate of root production; easily propagated by seed or cuttings; and nitrogen-fixing ability. The long-term effectiveness of suitable vegetation selected for the site will be dependent on (a) the nature of the cover, and (b) the availability of aftercare. It is for this reason that careful attention is paid to the preparation of the surface prior to establishing vegetation. Multi-layer covers are frequently being used to ensure the best results (Dixon, 1997; Jewell and Newson, 1997; Ritchey, 1989). Vegetation has proved to be an effective erosion control measure on horizontal surfaces and low- to intermediate-angled slopes. Vegetation has not proved entirely successful on some of steeper slopes with such slopes being gradually denuded of grass as erosion progresses. Greig (1981), having conducted a study of the vegetation on 27 tailings dams in the Central Witwatersrand area, concluded that in general the ratio of grass cover to tailings exposure was 1 to 2 or greater and that this grass cover ratio approaches that of the natural veld. He noted that there was no evidence of problems from wind or water erosion from horizontal surfaces grassed up to fifteen years previously. Erosion losses from grassed slopes measured by Blight (1989) was found to be in the order of 100 t/ha/year compared to uncontrolled slopes from which losses of up to 500 t/ha/year were recorded.

The **spraying** of dump surfaces with various substances (molasses, salt, and hygroscopic materials) has been practiced since the early 1900s with varying degrees of success. The use of sludge made from black vlei soil was initiated in 1913 and used for many years, proving to be comparatively successful. The use of molasses is currently becoming popular again, having been approved by the authorities for application on tailings impoundments.

The flow behind the **barrier** is influenced strongly by the aerodynamic interaction between the barrier and the upstream wind field. The presence of the barrier results in a windward wind speed reduction zone, an overspeed zone above the barrier and a leeward wind speed-reduction zone. Observations have shown that maximum reductions in the windward wind speed occur within a downwind distance of 10H from the barrier (i.e. on the leeward side), with the flow becoming fairly normal at about 30H (where H represents the height of the barrier) (Wang and Takle, 1995).

Ridge ploughing is considered an effective temporary measure to control dust on fine-grained, flat surfaces such as the top of mine tailings impoundments. The low-level wind turbulence induced by the ridges causes dust to be lifted from the crests of the ridges and to be deposited immediately in the adjacent valleys.

9.3.4 Materials handling

Crushing and screening are the predominant materials handling sources and can result in significant impacts over long term averages. Enclosure of crushing and screening operations is very effective in reducing dust and will result in emission reductions. Enclosure of crushing operations is very effective in reducing dust, resulting in 75% control efficiency (CE) due to telescopic chutes with water sprays. Enclosure of storage piles where tipping occurs can achieve 99% CE. In addition, chemical suppressants or water sprays will assist in the reduction of the cumulative dust impacts. Water sprays can have up to 50% control efficiency and hoods with scrubbers up to 75%. In addition, enclosed scrubbers and screens could have a 100% control efficiency. It is recommended that control efficiencies of 60% should be achieved to ensure a significant reduction in off-site impacts. It is important that these control equipment be maintained and inspected on a regular basis to ensure that the expected control efficiencies are met.

The control efficiency of pure water suppression can be estimated based on the US.EPA emission factor which relates material moisture content to control efficiency. This relationship is illustrated in Figure 9-4. From the relationship between moisture content and dust control efficiency it is apparent that by doubling the moisture content of the material an emission reduction of 62% could be achieved. Thus chemicals mixed into the water will not just save on water consumption but also improve the control efficiency of the application even further.

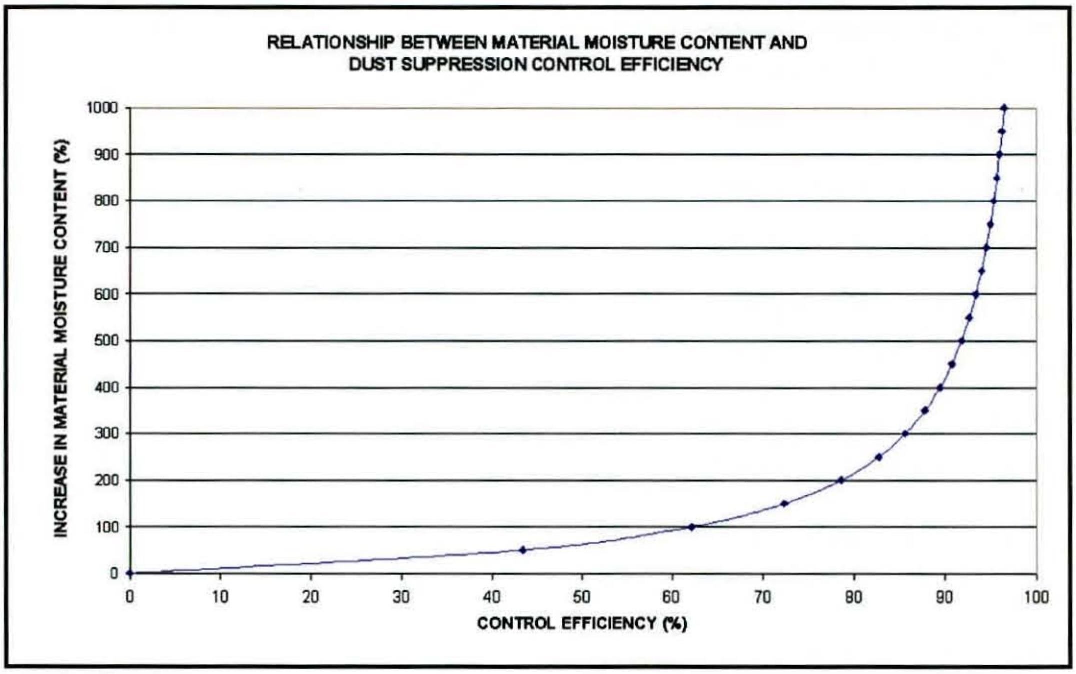

Figure 9-4: Relationship between the moisture content of the material handled and the dust control efficiency (calculated based on the US-EPA predictive emission factor equation for continuous and batch drop operations).

9.4 Performance Indicators

Key performance indicators against which progress may be assessed form the basis for all effective environmental management practices. 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 windblown dust exists represents an example of a source-based indicator, whereas maintaining off-site dust fall levels to below 600 $mg/m^2/day$ represents an impact- or receptor-based performance indicator. Source-based performance indicators have been included in regulations abroad.

- Source based performance indicators for the unpaved roads will be no visible dust when trucks/vehicles drive on the roads. It is recommended that dust fallout in the immediate vicinity of the road perimeter be less than 1 200 $mg/m^2/day$ and less than 600 $mg/m^2/day$ at the mine boundary.
- Blasting would always result in significant dust generation but the impacts need to be controlled by ensuring blasting only occurs during midday when there is no inversion layer and for as short durations as possible. In addition the dust fallout in the immediate vicinity of the open pit should be less than 1 200 $mg/m^2/day$.
- From all activities associated with the proposed Turquoise Moon Project, dust fallout levels should not exceed 600 $mg/m^2/day$ outside the mine boundary and at the sensitive receptor areas.
- PM_{10} GLCs should not exceed the NAAQS at the nearest sensitive receptor. That means that the PM_{10} concentrations should be below 40 $\mu g/m^3$ over an annual average and not exceed the daily limit of 75 $\mu g/m^3$ more than four times per calendar year.

No dust fallout network exist and it is recommended that a dust fallout network comprising of at least eight single dust fallout buckets be installed before construction commences. The buckets should follow the American Society for Testing and Materials standard method for collection and analysis of dust fall (ASTM D1739-98) as per the SANS requirements. This will provide management with an indication of what the reduction in fugitive dust levels are once mitigation measures are implemented. 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 proposed dust fallout network overlaid onto the proposed mine plan is provided in Figure 9-5 with a description of the locations as follow:

- TM01 – adjacent to the access road
- TM02 – upwind from the main mining operations
- TM03 – at the primary crusher and screen
- TM04 – adjacent to one of the haul roads
- TM05 – downwind from the main mining operations and WRD2
- TM06 – downwind from the main mining operations and WRD1
- TM07 – downwind from the TSF
- TM08 – upwind from the TSF

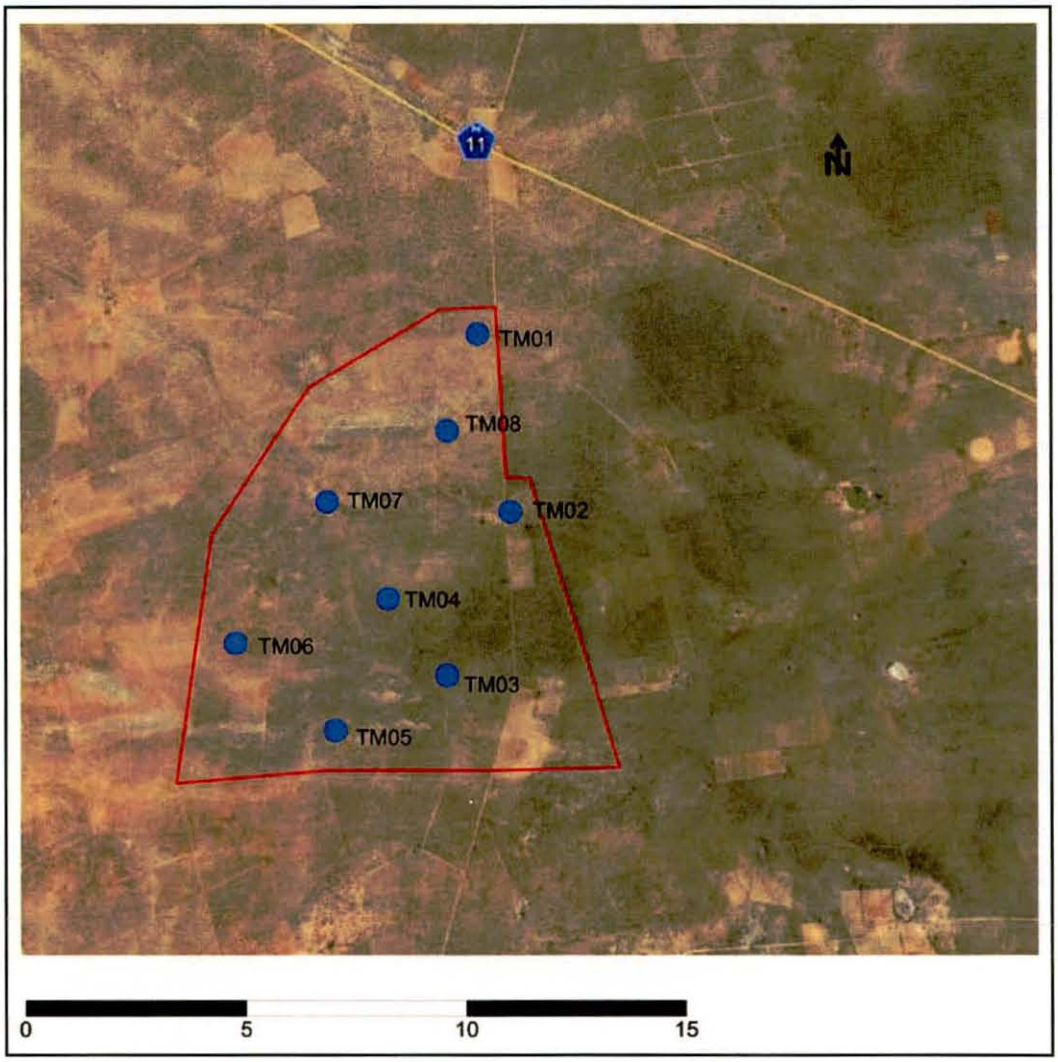

Figure 9-5: Proposed dust fallout network for Turquoise Moon Mine

It is recommended that a PM_{10} sampler be installed at the nearest sensitive receptor to the mine. The PM_{10} sampler can be either continuous or a manual operated device recording PM_{10} concentrations on a daily basis. Manual sampling can be done on a basis of 1 day out if every 6 days to ensure representative sampling of ambient PM_{10} concentrations in the region. In addition to the ambient PM_{10} concentrations, these samples (filter based) can be analyzed for metals and other compounds. A monitoring protocol will need to be established.

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11 Appendix A – Emissions Quantification Methodology

In the quantification of fugitive emissions such as fugitive dust releases from wind entrainment, vehicle entrainment, mining operations and materials handling it is recommended that use be made of emission factors. Given that no local emission factors are available it is proposed that reference be made to factors that are widely used internationally. The United States Environmental Protection Agency (US-EPA) AP42 Emission Factor Data Base is widely used for the quantification of fugitive and diffuse sources. Although this data base does not separately address gold processing operations it provides a comprehensive list of emission factors for use in mining and industrial processes. Separate emission factors are given for specific particle size ranges, viz. fine particulates in the inhalable range (PM_{10}, particulate matter less than 10 microns in aerodynamic diameter) and total suspended particulates (TSP). TSP is quantified for the purpose of assessing dust nuisance impact potentials, whereas PM_{10} is of concern due to the potential for human health risks associated with this Inhalable fraction.

11.1 Fugitive Dust Emission Estimation

In the quantification of fugitive dust emissions such as materials handling operations and wind entrainment from tailings storage facilities use was primarily made of US-EPA emission estimation factors and protocols.

11.1.1 Fugitive Dust Emissions from Materials Handling

The handling of lime and ore were identified as a potential source of dust generation at various of the gold plants. The quantity of dust that will be generated 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 predictive equation was used to estimate emissions from lime off-loading and ore handling operations:

$$E_{TSP} = 0.0016 \frac{(U/2.2)^{1.3}}{(M/2)^{1.4}} \qquad (1)$$

where,

$\boldsymbol{E_{TSP}}$ = Total Suspended Particulate emission factor (kg dust / t transferred)

$\boldsymbol{U}$ = mean wind speed (m/s)

M = material moisture content (%)

The PM10 fraction of the TSP was assumed to be 35%, and the PM2.5 fraction was taken as being 11% of TSP (EPA, 1996). Hourly emission rates, varying according to the prevailing wind speed, were used as input in the dispersion simulations.

11.1.2 Crushing and Screening

Fugitive dust emissions due to the crushing and screening operations for mine were quantified using US-EPA single valued emission factors for such operations (Table 11-1). These emission factors include emissions from the loading of crusher hoppers and screening.

Table 11-1: Emission factors for metallic minerals crushing and screening

Source	Emission Factor (kg/ton material processed)			
	Low Moisture Material[a]		High Moisture Material (b)	
	PM10	TSP	PM10	TSP
Primary crushing	0.02	0.2	0.004	0.01
Secondary crushing	0.04	0.6	0.012	0.03

Notes:

(a) Moisture content less than 4%
(b) Moisture content more than 4%

11.1.3 Drilling

Fugitive dust emissions due to the in-pit drilling operations at the mine were quantified using the Australian NPI single valued emission factors for mining given in Table 11-2.

Table 11-2: Australian NPI emission factors for drilling operations

Source	PM10 (kg PM10 / hole drilled)	TSP Emission (kg TSP / hole drilled)
Drilling	0.31	0.59

11.1.4 Blasting

Fugitive dust emissions due to blasting at the mine were quantified using the NPI predictive emission factor equation for mining:

$$EF = k \cdot 344 \cdot \frac{\left(A^{0.8}\right)}{\left(M^{1.9} \cdot D^{1.8}\right)} \qquad (2)$$

where;

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

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

A = *blast area (m²)*

M = *moisture (%)*

D = *hole depth (m)*

11.1.5 Wind Erosion of Open Areas and Stockpiles

Significant emissions arise due to the mechanical disturbance of granular material from tailings impoundments. 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 tailings, 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 tailings dam 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, 1994; Burger et al., 1995).

An hourly emissions file was created for the various tailings dams. The calculation of an emission rate for every hour of the simulation period was carried out using the ADDAS model. The emission rate model (ADDAS) is based on the dust emission model proposed by Marticorena and Bergametti (1995). This 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 ash dump emissions, the model incorporates the calculation of two important parameters, viz. the threshold friction velocity of each particle size, and the vertically integrated horizontal dust flux, in the quantification of the vertical dust flux (i.e. the emission rate). The equations used are as follows:

$$E_i = G_i 10^{(0.134C-6)} \qquad (3)$$

where,

$$G_i = 0.261\frac{\rho_a}{g}U_*^3(1+R_i)(1-R_i^2) \qquad (4)$$

$$R_i = \frac{U_{t*i}}{U_*} \qquad (5)$$

and,

E_i = Emission rate (size category i)

C = clay content (%)

ρ_a = air density

g = gravitational acceleration

U_* = frictional velocity

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

Dust mobilisation occurs only for wind velocities higher than a threshold value, and is not linearly dependent on the wind friction and velocity. The threshold friction velocity, defined as the minimum friction velocity required 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 proposed by Marticorena and Bergametti (1995), is illustrated in Figure 11-1.

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, 1995):

$$U^* = 0.053U_{10}^+ \qquad (6)$$

(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.)

Equivalent friction velocity can also be calculated using a re-arrangement of the logarithmic distribution of the wind speed profile in the surface boundary (EPA, 1995):

$$U^* = \frac{KU_{10}}{\ln\left(\frac{Z}{Z_0}\right)} \qquad (7)$$

where,

U^* = friction velocity (m/s)

K = von Karma's constant (0.41)

Z = wind speed height (in this case 10 m)

Z_0 = wind speed height (in this case 10 m)

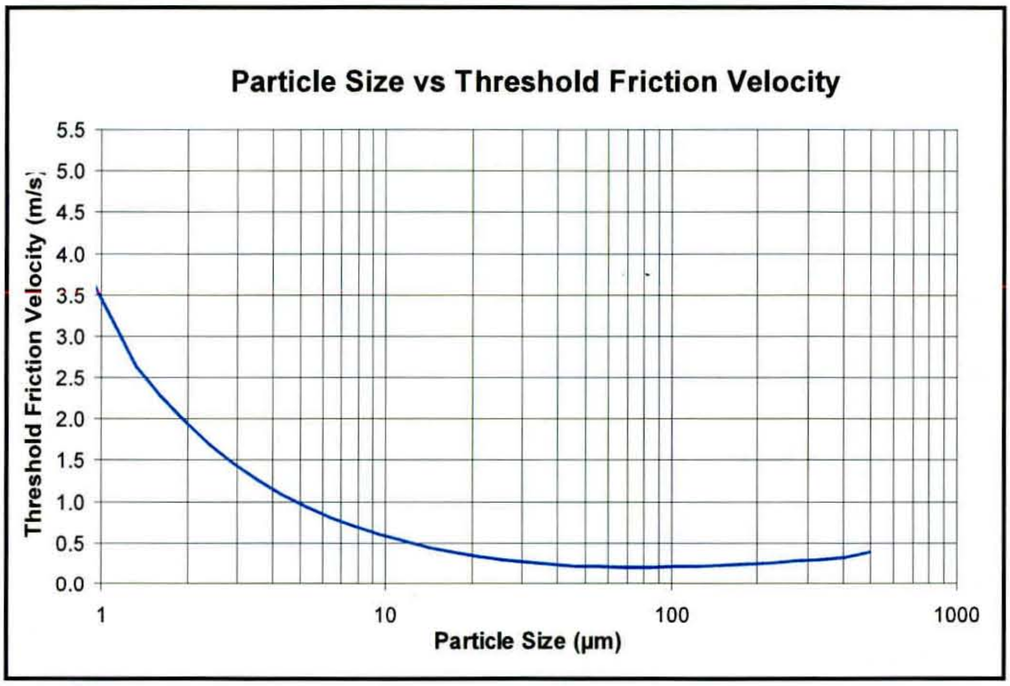

Figure 11-1: Relationship between particle sizes and threshold friction velocities using the calculation method proposed by Marticorena and Bergametti (1995).

The wind speed variation over the dump was 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 pile. The ratios of surface wind speed (u_s) to approach wind speed (u_r), derived from wind tunnel studies for two representative pile shapes, are indicated in Figure 11-2 (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.)

Particle size distribution data were obtained for the Turquoise Moon TSF. The PM_{10} component of the tailings material was estimated to represent, on average, 12% of the total tailings material sampled. The particle size distribution was taken into account both in the estimation of emissions and in the simulation of resultant dustfall and ambient PM_{10} concentrations.

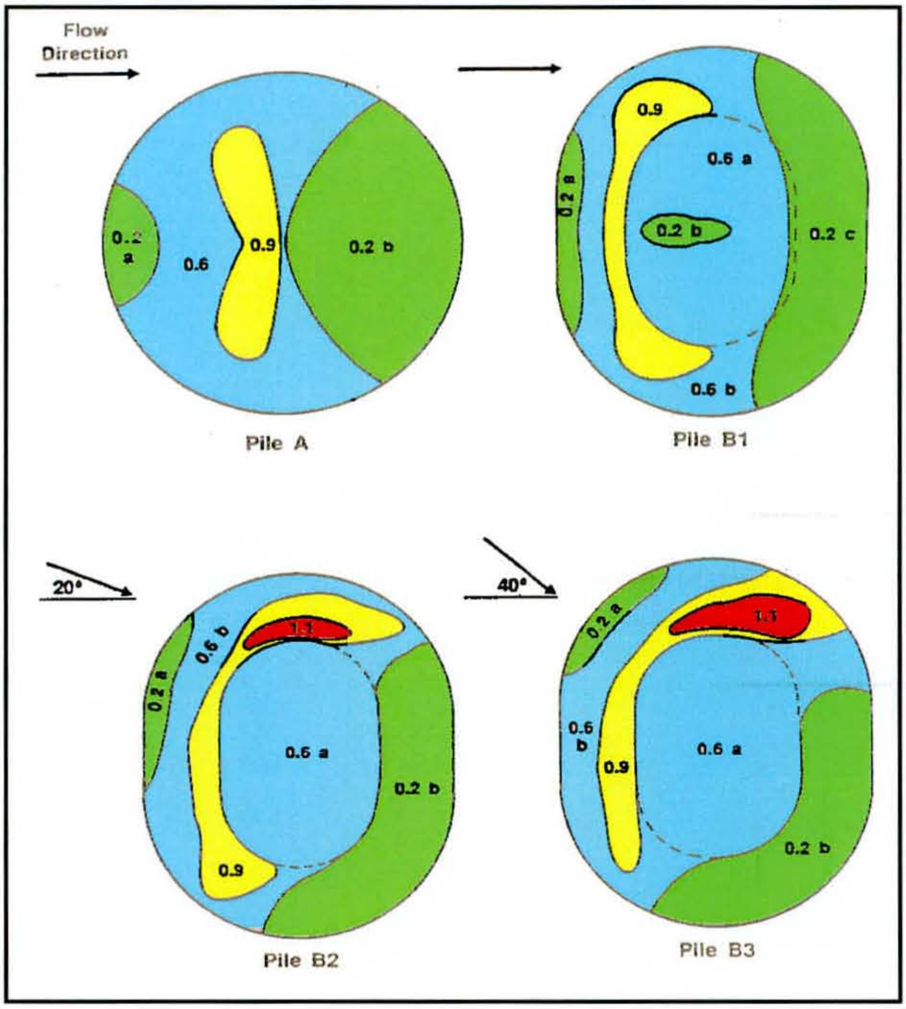

Figure 11-2: Contours of normalised surface wind speeds (i.e. surface wind speed/ approach wind speed) (after EPA, 1996).

11.1.6 Vehicle entrainment

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:

$$E = k\left(\frac{s}{12}\right)^{a} \cdot \left(\frac{W}{3}\right)^{b} \cdot 281.9 \qquad (8)$$

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.

12. Appendix B – Isopleth Plots

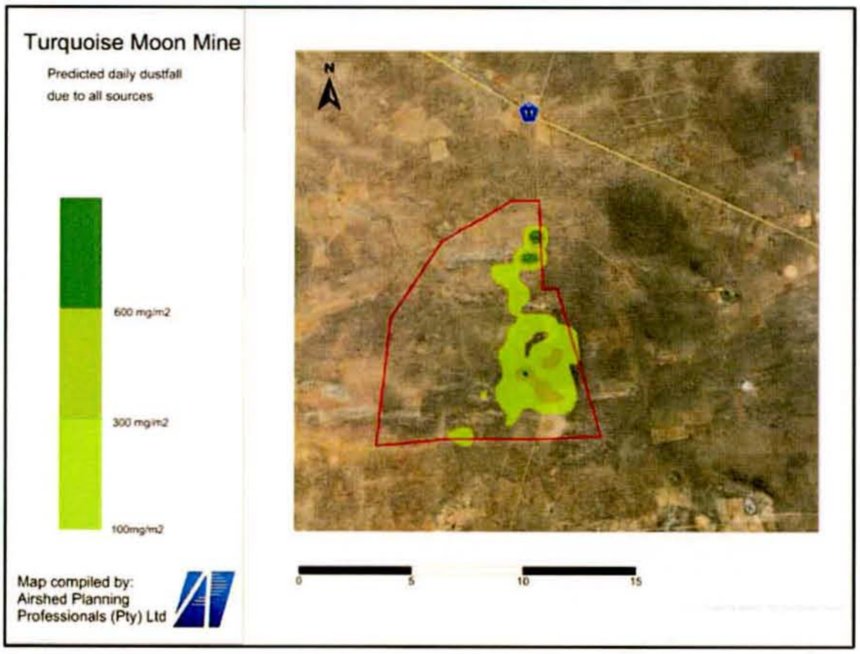

Figure 12-1: Predicted daily dustfall due to due to all sources

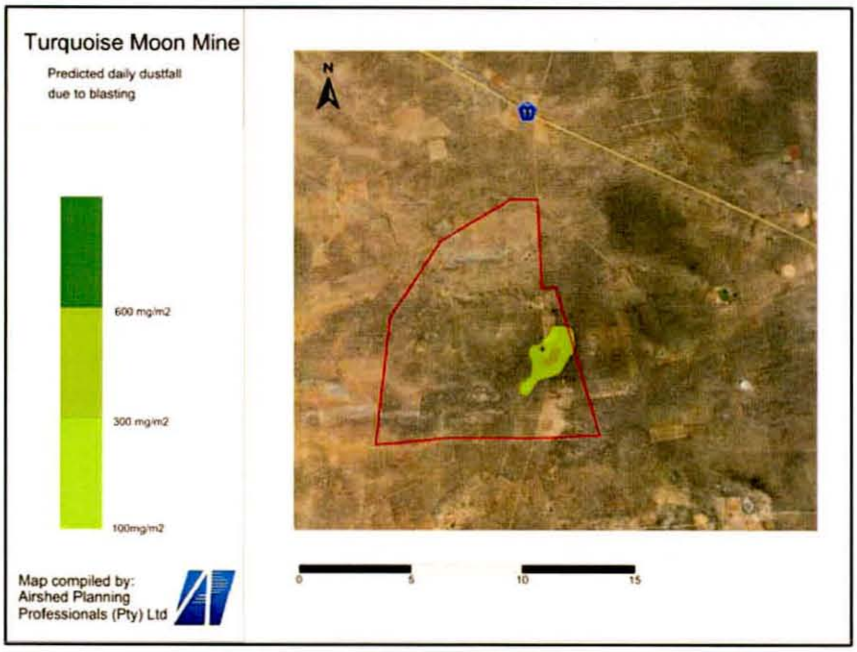

Figure 12-2: Predicted daily dustfall due to due to blasting

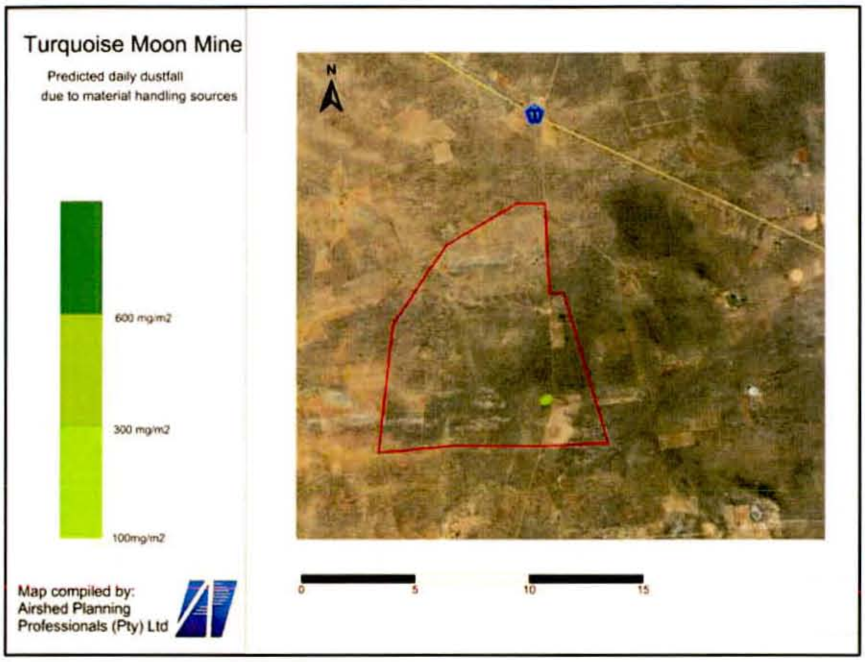

Figure 12-3: **Predicted daily dustfall due to due to material handling sources**

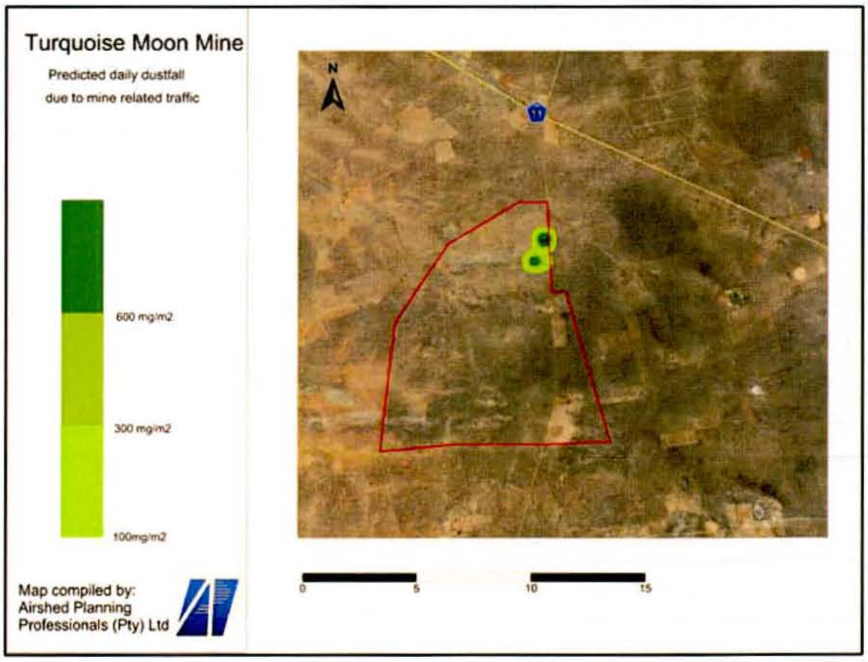

Figure 12-4: **Predicted daily dustfall due to due to public vehicle sources**

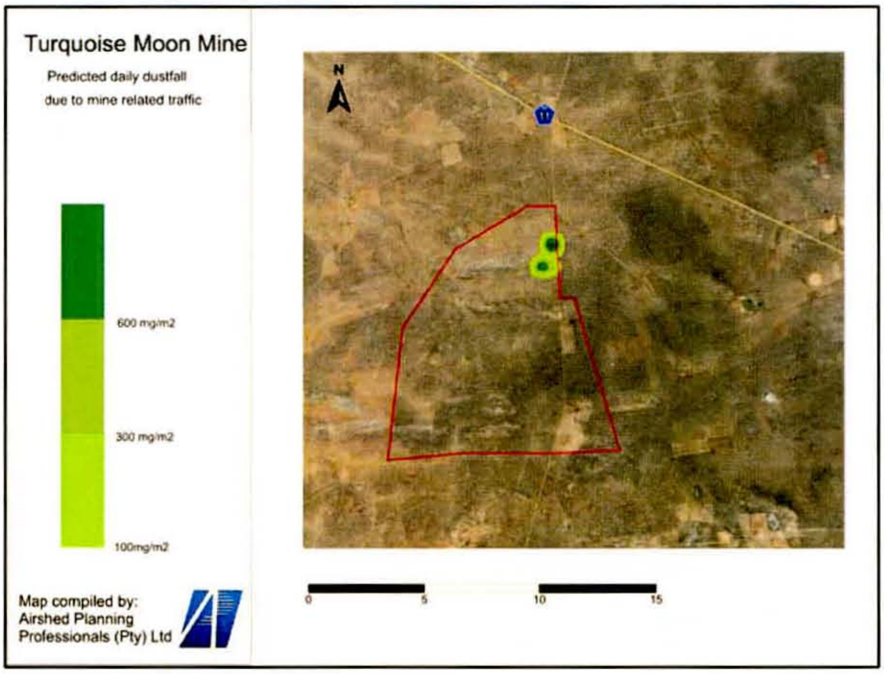

Figure 12-5: Predicted daily dustfall due to due to mine vehicle sources

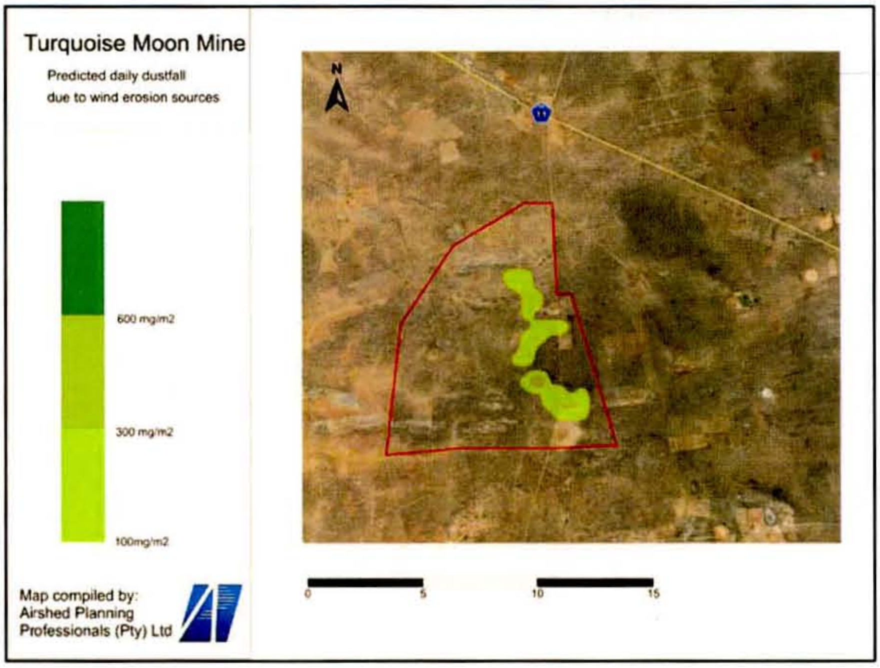

Figure 12-6: Predicted daily dustfall due to due to wind erosion sources

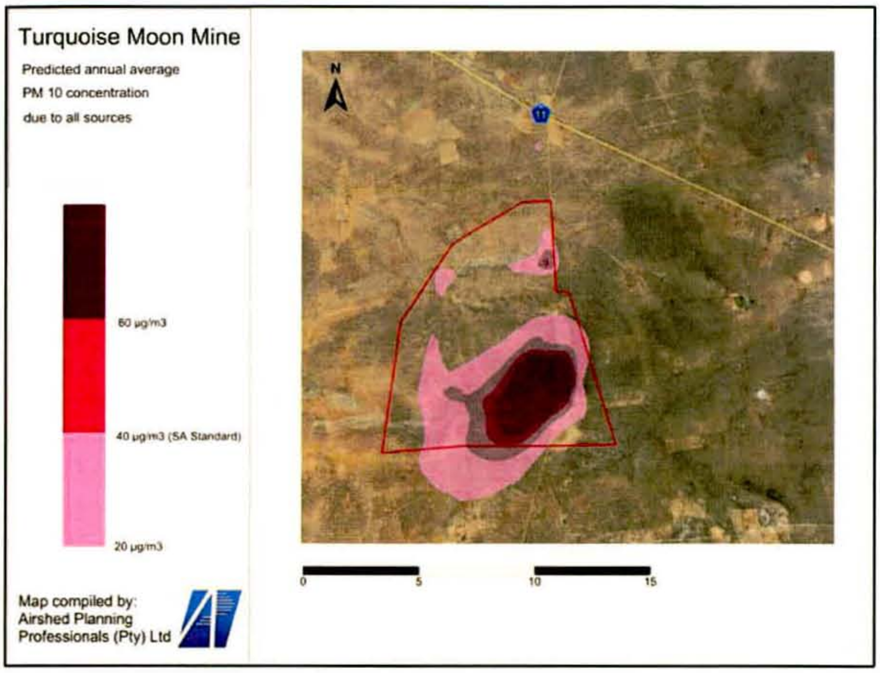

Figure 12-7: Predicted annual average PM_{10} concentration due to all sources (without mitigation)

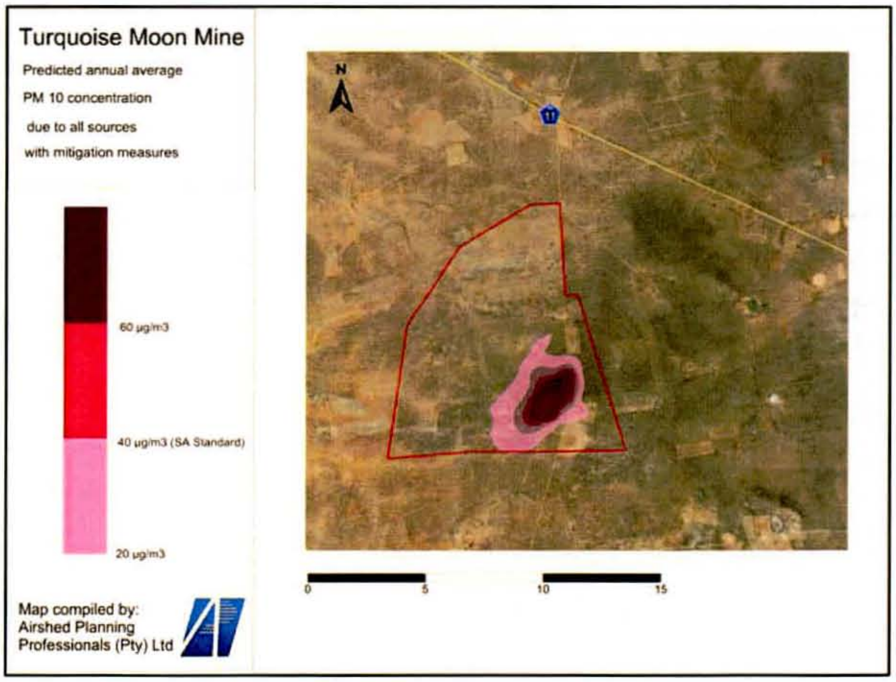

Figure 12-8: Predicted annual average PM_{10} concentration due to all sources (with mitigation)

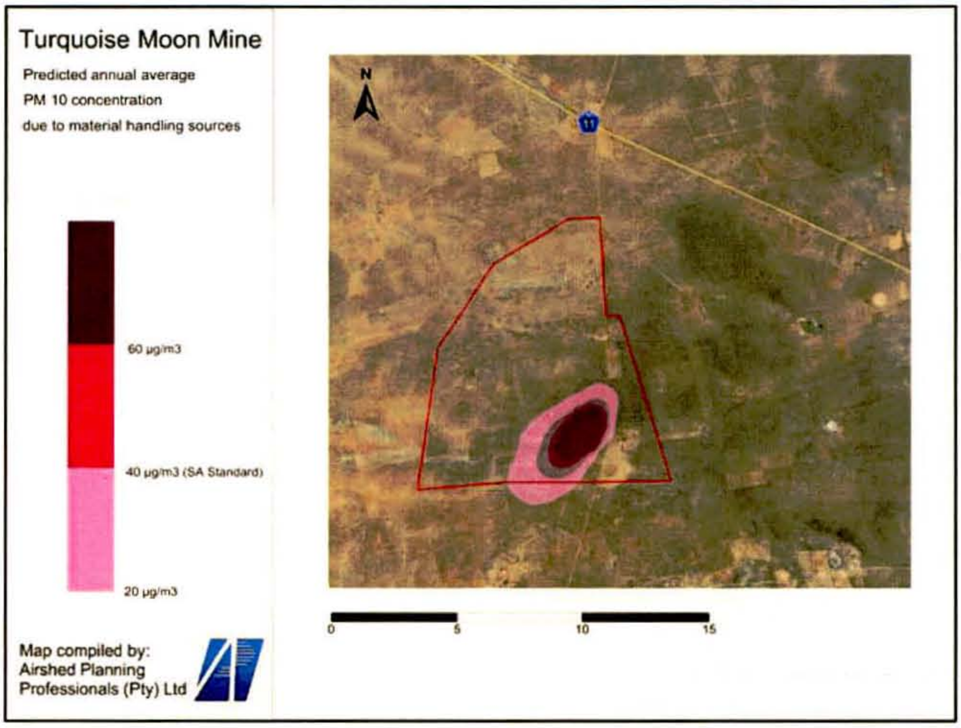

Figure 12-9: Predicted annual average PM_{10} concentration due to material handling sources (without mitigation)

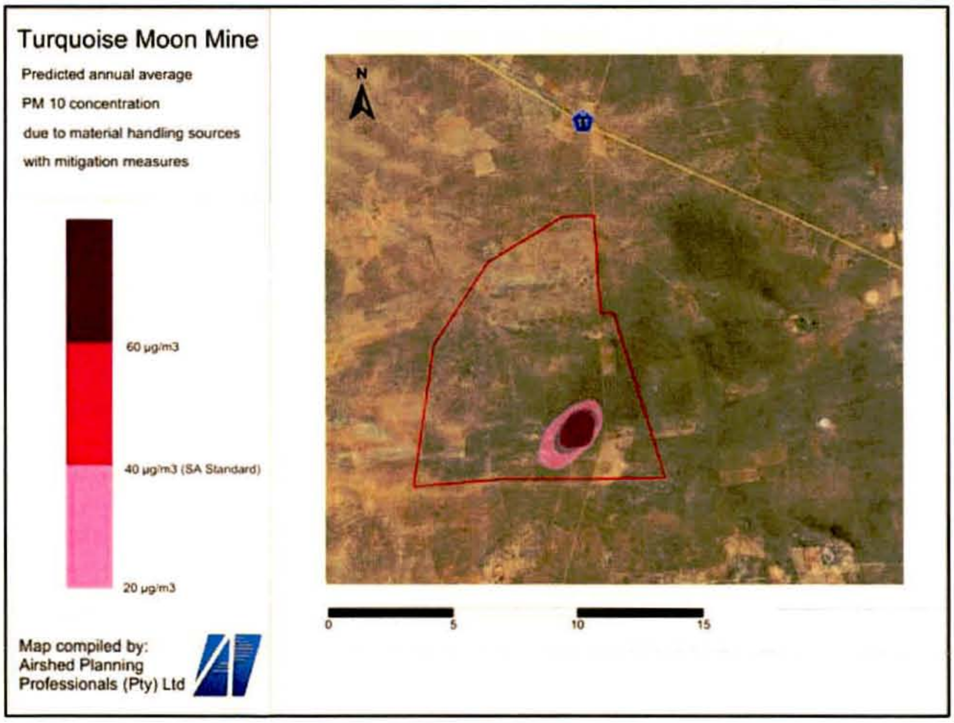

Figure 12-10: Predicted annual average PM_{10} concentration due to material handling sources (with mitigation)

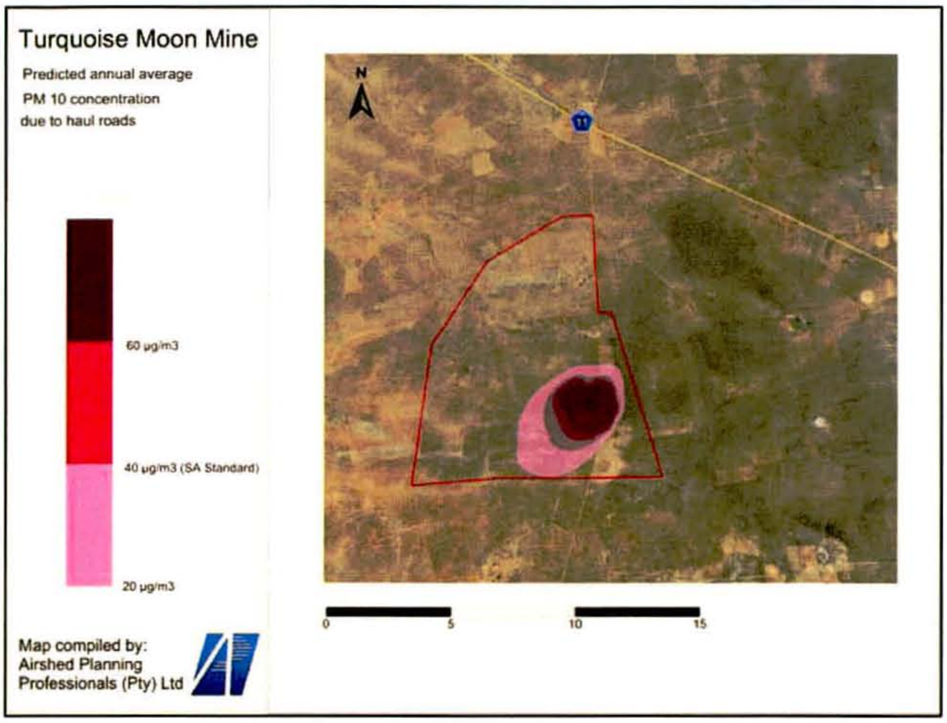

Figure 12-11: Predicted annual average PM_{10} concentration due to vehicle sources (without mitigation)

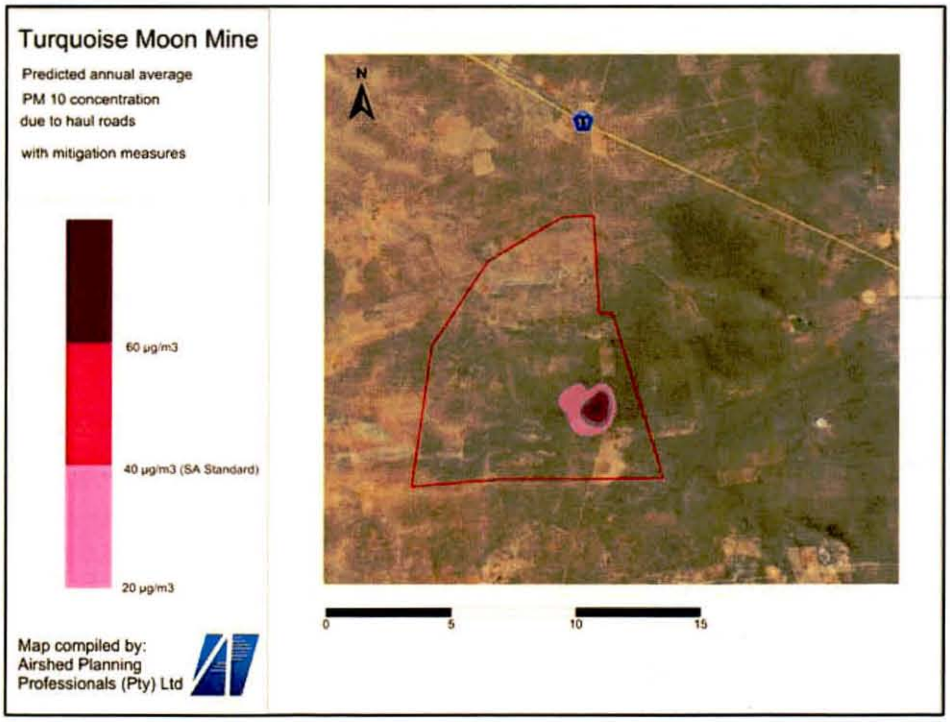

Figure 12-12: Predicted annual average PM_{10} concentration due to vehicle sources (with mitigation)

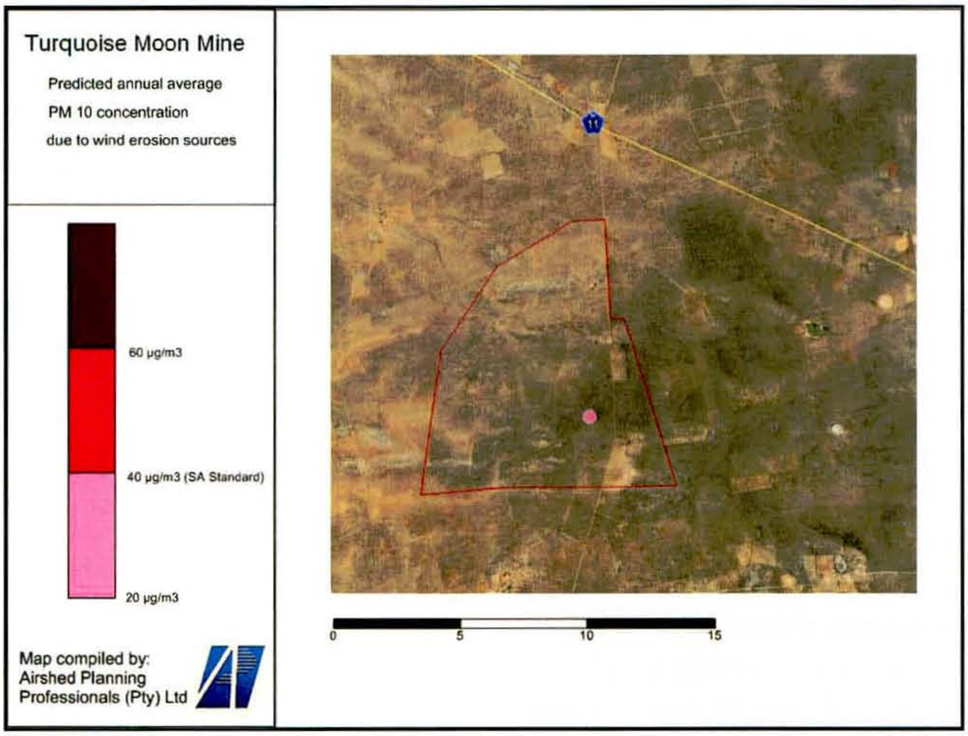

Figure 12-13: Predicted annual average PM_{10} concentration due to wind erosion sources

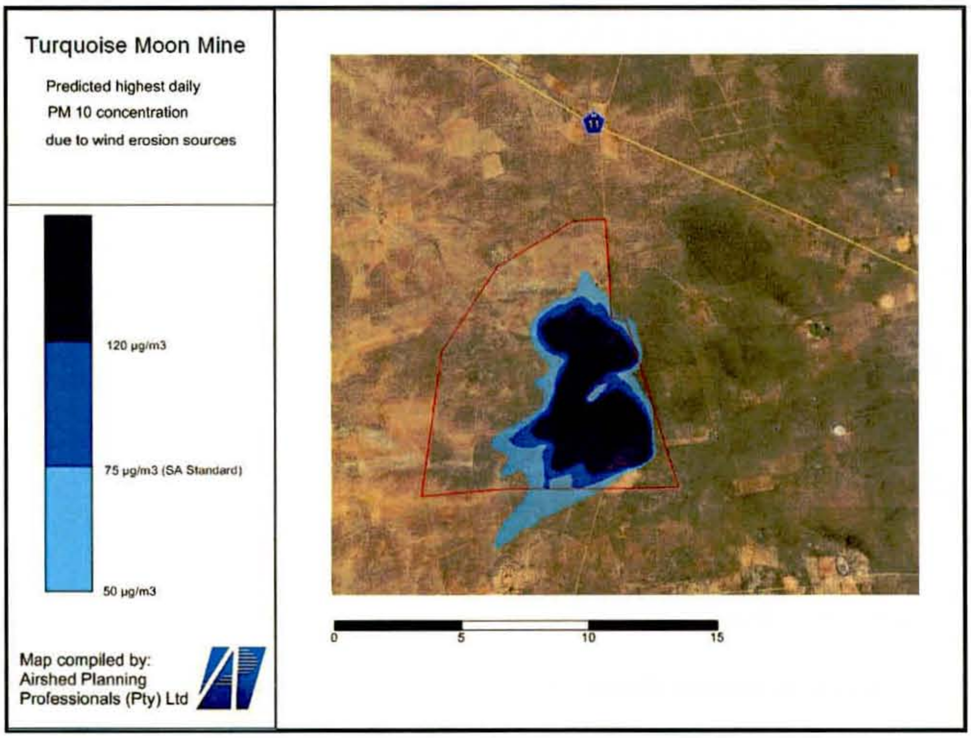

Figure 12-14: Predicted highest daily PM_{10} concentration due to wind erosion sources

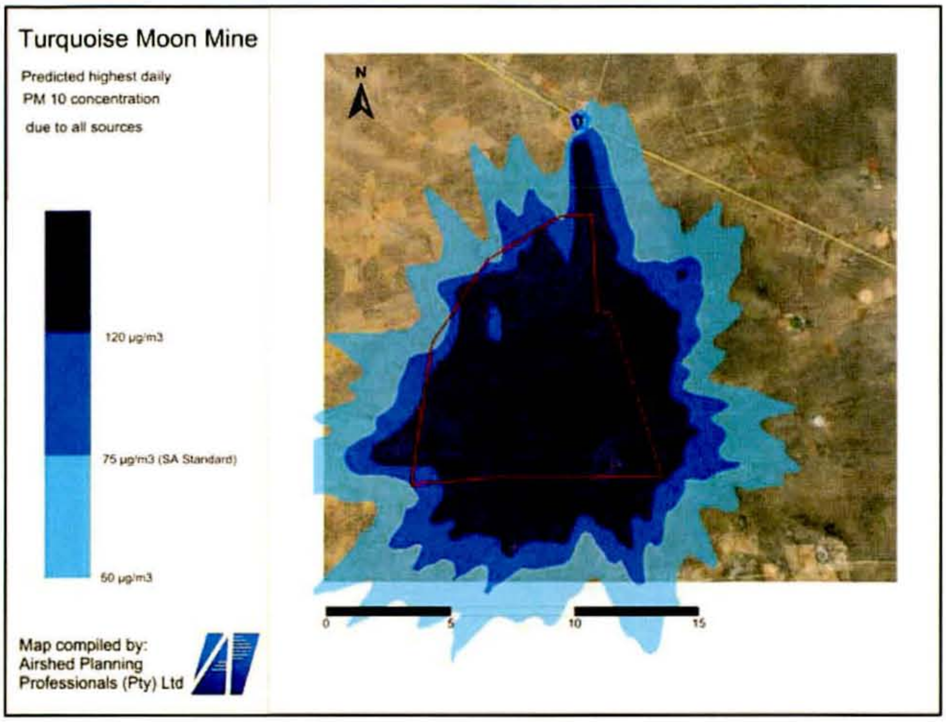

Figure 12-15: Predicted highest daily PM_{10} concentration due to all sources (without mitigation)

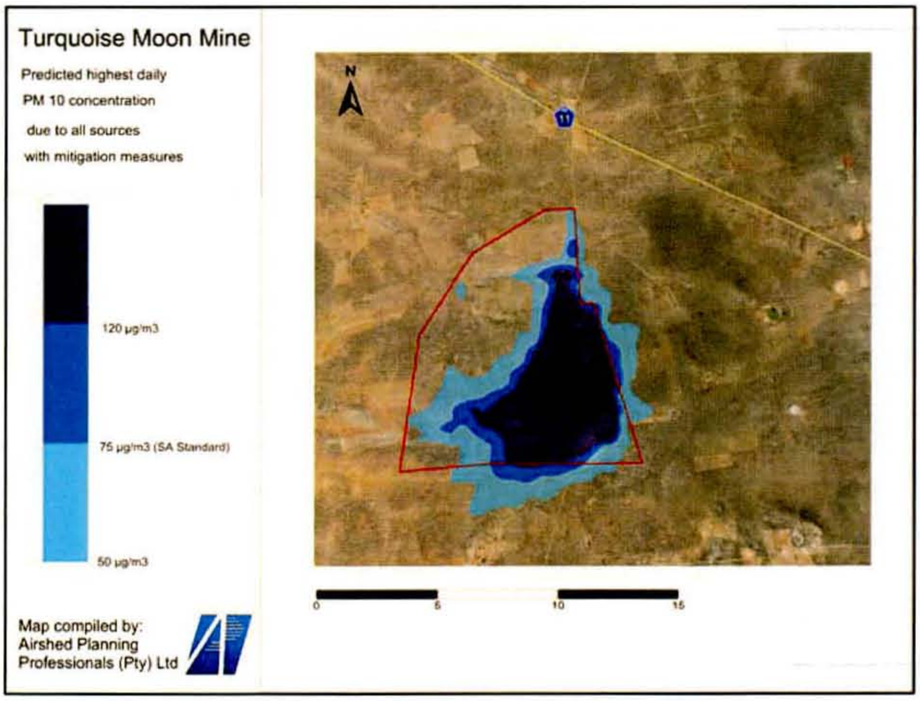

Figure 12-16: Predicted highest daily PM_{10} concentration due to all sources (with mitigation)

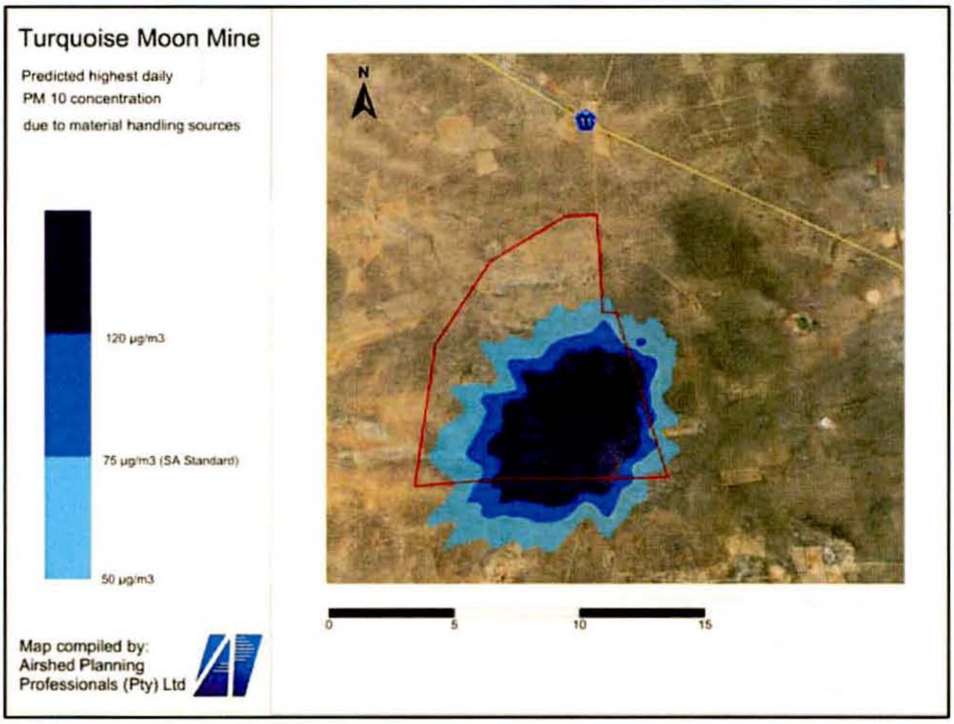

Figure 12-17: Predicted highest daily PM_{10} concentration due to material handling sources (without mitigation)

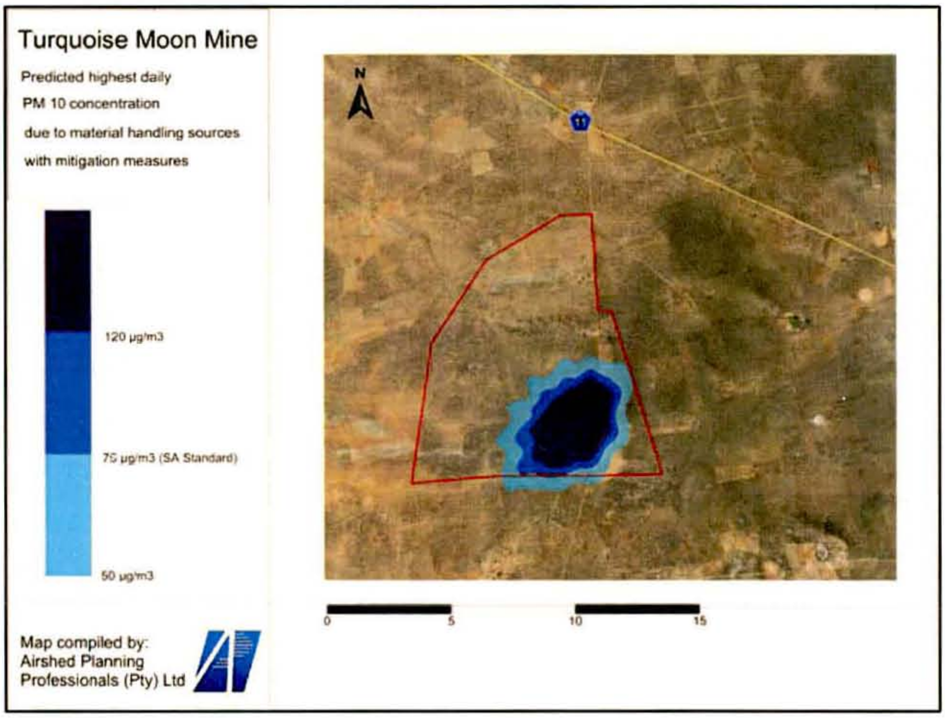

Figure 12-18: Predicted highest daily PM_{10} concentration due to material handling sources (with mitigation)

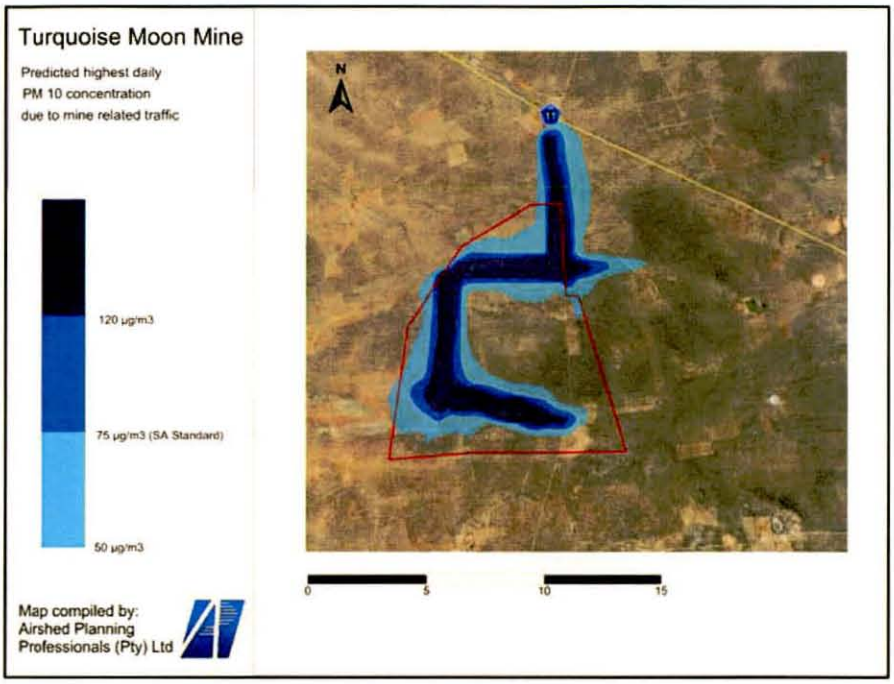

Figure 12-19: Predicted highest daily PM_{10} concentration due to the access road (without mitigation)

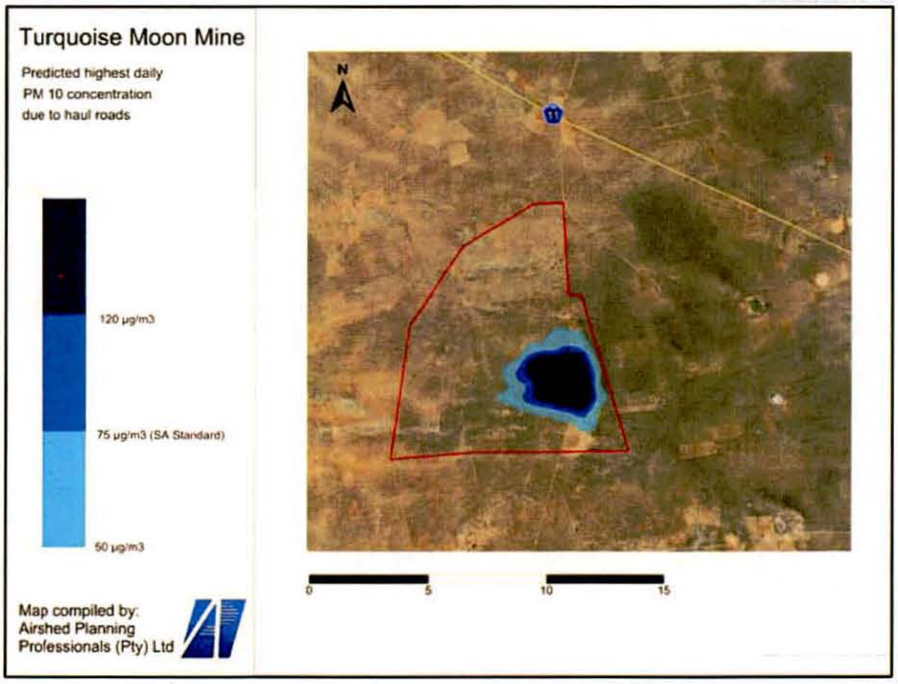

Figure 12-20: Predicted highest daily PM_{10} concentration due to the haul roads (without mitigation)

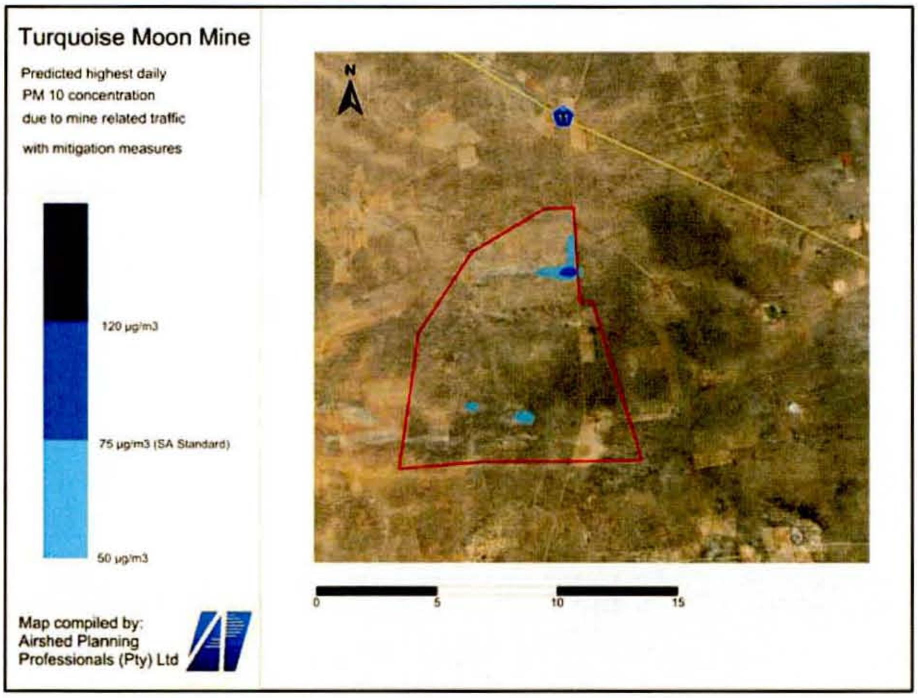

Figure 12-21: Predicted highest daily PM_{10} concentration due to the all roads (with mitigation)

13 Appendix C – Particulate Matter background Information

13.1 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).

13.2 Dust Effects on Vegetation

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

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

Regarding the first question, there is adequate evidence that dust does collect on all types of vegetation. Any type of vegetation causes a change in the local wind fields, with an increase in turbulence which enhances the collection efficiency. The characteristics of the vegetation influences the rate; the larger the "collecting elements" (branches and leaves), the lower the impaction efficiency per element. This would seem to indicate that, for the same volume of tree/shrub canopy, finer leaves will have a better collection efficiency. However, the roughness of the leaves themselves and particularly the presence of hairs on the leaves and stems 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 wasit 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.

13.3 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).