Project done on behalf of

Metago Environmental Engineers (Pty) Ltd

Air Quality Impact Assessment for the Proposed Swakop Uranium, Husab Project in Namibia

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REPORT DETAILS

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Executive Summary

Introduction

The Swakop Uranium Husab Project plans the development a new uranium mine to extract uranium from the deposit located approximately 5 km south of the existing Rössing Uranium Mine. The planned production rate will be between 4 000 and 7 000 tonnes of uranium oxide though conventional load and haul open pit mining and ore processing operations.

Airshed Planning Professionals (Pty) Ltd (Airshed) was appointed by Metago Environmental Engineers (Pty) Ltd (Metago) to undertake an air quality impact assessment for the proposed operation. The main objective of the study was to do an air dispersion impact assessment to determine potential impacts on the surrounding environment and human health.

Study Approach and Methodology

The air quality study included a baseline characterisation and impact assessment. Whereas the baseline study investigated the current state of ambient air in the vicinity of the Husab Project, the impact assessment looked at the potential impact from the proposed mining operations on the surrounding environment and human health.

In order to understand the baseline situation, meteorology was obtained from the on-site weather station and analysed. Meteorological characteristics of a site govern the dispersion, transformation and eventual removal of pollutants from the atmosphere. Pollution concentration levels fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth, and to shifts in the wind field. Spatial variations, and diurnal and seasonal changes, in the wind field and stability regime are functions of atmospheric processes operating at various temporal and spatial scales. Hourly average wind speed, wind direction, temperature and rainfall data measured over the period October 2008 to June 2010 were used to inform the local dispersion potential of the site.

For a comprehensive baseline assessment ambient monitoring data are required. Swakop uranium operates a dust fallout and PM_{10} monitoring network comprising of eight single dust fallout buckets and one PM_{10} minivol sampler. Data were available for the dust fallout from August 2009 up to July 2010. Due to technical problems the PM_{10} results were not useable and reference was made to ambient concentrations measured nearby and predicted baseline concentrations as obtained from the SEA report.

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.

The impact assessment was done through dispersion modelling. Dispersion models provide a useful tool in the assessing the potential impacts from “future” operations and require site specific meteorological data and source information as input.

The establishment of a comprehensive emission inventory formed the basis for the assessment of the impacts from of the proposed operation's 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. In the quantification of fugitive dust emissions use was made of emission factors which associate the quantity of a pollutant to the activity associated with the release of that pollutant. Particulate and gaseous emissions from fugitive sources as well as vehicle exhaust emissions were calculated using a comprehensive set of emission factors and equations as published by the US.EPA.

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

In the absence of local ambient air quality standards or guidelines, reference was made to international criteria. The guidelines as set out by the World Bank Group, World health Organisation and European Community were referenced. Given the similarities between Namibia and South Africa (environmentally, socially and economically) the newly published South African national standards were also referenced. The recommended evaluation criteria as set out in the SEA report for particulates was used.

PM_{10} and gaseous concentrations, and dustfall rates were simulated for the proposed operations and various operational scenarios. The simulation of ambient air pollutant concentrations and dust deposition due to the proposed operation was undertaken through the application of the Atmospheric Dispersion Modelling System (ADMS) developed by the Cambridge Environmental Research Consultants (CERC).

The following scenarios were included in the air quality impact assessment:

- **Construction Phase** – Including fugitive dust emissions from construction related activities.
- **Operational Phase (2017)** – Including fugitive dust emissions from mining related activities and gaseous emissions from the sulphuric acid plant and mining fleet vehicle exhaust emissions.

Mitigation measures considered for each of the scenarios included:

- Crushing and Screening – Wet ore and hooding with venture scrubbers, 83% control efficiency
- Drilling – Water sprays, 70% control efficiency
- Materials handling – Water sprays, 50% control efficiency
- Unpaved roads – Water sprays and(or) dust suppressants, 90% combined control efficiency

Limitations and Assumptions

Limitations and assumptions pertaining to the project were:

- Predicted air pollution impacts only include those air emissions associated with the proposed Husab Project. Cumulative impacts were extrapolated using the eleven months available dust deposition levels. Due to technical problems PM_{10} data were lost and use was made of the Erongo SEA predicted ambient concentrations to provide an indication of the cumulative impacts.
- It was assumed that all processing operations will have ceased by the closure phase of the project. 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.
- No information was available on the temporary on-site diesel generators at the time of the study. These are however considered less significant than the other mining sources provided the design complies with the International Finance Corporation (IFC) emission limits for diesel generators. The IFC emission limits allow between 1.5% to 3% sulphur content for SO_2 emissions, 1 460 to 1 850 mg/Nm³ for NOx and 50 mg/Nm³ for diesel particulates (DPM).
- The dispersion model cannot compute real-time processes, therefore average consumption and production rates were used. Operational locations and periods were selected to reflect the worst case scenarios.
- The assessment of dust entrainment from the access road to the Husab project did not fall within the scope of this study.
- The range of uncertainty of the model predictions could to be -50% to 200%. 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.
- Nitrogen oxide (NO) is rapidly converted in the atmosphere into nitrogen dioxide (NO_2). As a conservative measure, and in the absence of accurate O_3 data, all long- and short term NO_x impacts were assumed to be NO_2.

Conclusions

The main findings from the proposed Husab Project impact assessment were as follows:

Baseline Characterisation

- The prevailing wind field is from the north-northwest for most of the time, with more frequent slower northerly winds during the night. Seasonally the wind field varied significantly from predominant north-westerly airflow (summer and spring months), to north-easterly and west south-westerly airflow (autumn) and strong easterly and east north-easterly winds (winter). The highest wind speeds occur during the month of July and are associated with the so-called “easterly” winds.
- Temperature ranged from 11ºC in winter to 38 ºC in summer.
- The Husab Project falls within a summer rainfall area with the highest rainfall recorded in October (28 mm) and in February (32 mm).
- High frequency of very stable local atmospheric conditions occurred predominantly from the north to the north-western sector. Stable conditions is likely to result in high ground level concentrations for non-wind dependable low level emitters near the source such as fugitive dust sources associated with vehicle entrainment on roads and crushing and screening.
- Dust fallout in general was low and well within the limit of 350 mg/m^2/day and 600 mg/m^2/day for total daily deposition over a monthly average. Dust fallout levels ranged between 5 mg/m^2/day and 56 mg/m^2/day.
- Predicted background PM_{10} concentrations at the Husab Project indicated daily averages of 220 µg/m^3 and 60 µg/m^3 for annual averages, exceeding the Erongo Region selected evaluation criteria of 75 µg/m^3 and 30 µg/m^3, respectively.
- The main source of air pollution in the vicinity of the proposed Husab Project is windblown dust from the natural environment (57%) and secondly fugitive dust from Rössing Uranium Mine (39%) located ~ 5km to the north.

Impact Assessment

- **Construction phase:** Annual average ground level PM_{10} concentrations for unmitigated and mitigated construction activities were within 30 µg/m^3 at the mine boundary. For highest daily GLC the predicted impacts were high when no mitigation is applied, exceeding 75 µg/m^3 up to 10km from mining activities. With mitigation measures applied, the impact area shrunk to fall mainly within the mine boundary. The predicted impacts at the three receptor sites were within the required ambient air quality limits for both annual and daily averages. Unmitigated and mitigated PM_{10} impacts during the construction phase have LOW significance ratings.

Dust deposition predicted off-site for the unmitigated and mitigated construction phase was low and well within the screening criteria limit of 350 mg/m^2/day with a LOW significance.

- **Operational Phase (2017):** Unmitigated PM_{10} GLC for with no mitigation applied exceeded the annual limit of 30 µg/m^3 outside the mine boundary. Highest daily average PM_{10} GLC exceeded 75 µg/m^3 over the entire modelling domain. Predicted impacts at Arandis were within the annual and daily PM_{10} assessment criteria, but were exceeded at Rössing Uranium Mine and the Big Welwitschia. Predicted mitigated annual average concentrations only exceeded 30 µg/m³ on-site. Even though predicted highest daily PM_{10} concentrations exceeded the daily limit outside the mine boundary, it were within compliance at all three receptor sites. Unmitigated PM_{10} impacts during the operational phase have HIGH significance ratings whereas the mitigated scenario reduce to LOW significance. With background concentrations taken into consideration, already exceeding the evaluation criteria, the cumulative impacts will be in non-compliance at Arandis, Rössing Uranium Mine and the Big Welwitschia. The significance ranking therefore remains HIGH even with mitigation measures in place. This is however primarily due to windblown dust from natural background sources with the additional contribution from the Husab Project at about 3% (Liebenberg-Enslin et.al., 2010).

  Dust deposition predicted off-site for the unmitigated and mitigated operational phase was low and within the screening criteria limits of 350 mg/m^2/day with LOW significance ratings.

  Predicted annual average DPM concentrations did not exceed the US EPA RfC beyond the mine boundary. Very low concentrations were predicted at Arandis. The significance ranking was LOW. NO_2 concentrations exceeded the hourly limit outside the mine boundary (this was based on a very conservative approach assuming all NOx to be NO_2). Highest hourly and annual average NO_2 concentrations at Arandis were however well below the limits. The significance ranking was LOW. No exceedances of the limits for SO_2 were predicted to occur on or off- site with very low concentrations predicted at Arandis. The significance ranking was LOW. No exceedances of the limits for CO were predicted to occur on or off-site with very low concentrations predicted at Arandis. The significance ranking was LOW.

Recommendations and Air Quality Management Measures

Predicted incremental impacts (impacts associated only with the proposed Husab Project) were high for PM_{10}, and cumulative effects as a result of other sources of emission in the vicinity of the site will result in even higher impacts. Even though the off-site impacts from the Husab Project alone were predicted to be low at Arandis, high impacts were predicted at Rössing Uranium Mine and the Big Welwitschia. It is therefore recommended that mitigation measured be implemented to achieve set target control efficiencies to ensure the lowest possible cumulative contribution.

Main sources of impacts

The main pollutant of concern based on predicted impacts was PM_{10}. The main sources resulting in off-site impacts of PM10 included:

- **Unpaved roads** - Without mitigation in place, unpaved roads were the main source of PM_{10} GLC. With mitigation in place, unpaved roads remained the main contributor but to a lesser extent.
- **Materials handling**
- **Crushing and screening**

Target controls for the Main Sources

- Vehicle entrainment from the unpaved roads – 90% control efficiency through chemical surfactants on permanent haul roads. According to literature spraying of water on road surfaces can only achieve a maximum of 85% control. Water prays in combination with chemicals should however be applied to in-pit haul roads to achieve at least 85% control efficiency and an overall 90%.
- Crushing and Screening – 83% reduction through water sprays on ore and extraction hoods with venturi scrubbers.
- Materials handling (unloading of trucks) – at least 50% reduction through effective water sprays.

Suitable Mitigation Measures

Unpaved haul roads: It is recommended that chemical surfactants be used on the permanent haul roads at the Husab Project. It is however not practical to apply expensive chemicals to temporary roads such as in-pit roads and here it is recommended that water in combination with chemicals be used to achieve the required control efficiency of at least 80%. Watering alone will not suffice due to the high evaporation in the area and the low average rainfall (a watering rate of 4 $l/m^2/hour$ needs to be applied to achieve 90% control efficiency). One of the main benefits of chemical stabilisation in conjunction with wet suppression is the management of water resources. A cost-effective chemical control programme should be developed evaluating the costs and benefits arising from various chemical stabilization practices on site specific roads.

Crushing and materials handling operations: The crusher design for the Husab project will include water sprays at all transfer points in the crushing area (i.e. water sprays before the truck off-load, fog sprays with sensors at the ROM bin, etc). Ducted dust collection systems with extraction hoods will also be installed at all major dust generating points where the dust will be vented to venturi scrubber with a cyclonic separator, dry fan and stack. Enclosure of crushing operations is very effective in reducing dust. The combination of water sprays on the ore and extraction system with venturi scrubbers should ensure 83% control efficiency and more.

Monitoring Requirements

Key performance indicators against which progress may be assessed form the basis for all effective environmental management practices.

Source based performance indicators include the following:

- For unpaved roads it is recommended that dust fallout in the immediate vicinity of the road perimeter be less than 1 200 $mg/m^2/day$. This is based on the South African dust fallout limit for industrial areas and given the dry natural background of the Husab Project site and that there are no homesteads nearby this is regarded a feasible and reasonable limit.
- The absence of visible dust plume at all tipping points and at the primary crusher would be the best indicator of effective control equipment in place. In addition the dustfall in the immediate vicinity of various materials handling sources should be less than 1 200 $mg/m^2/day$.
- Similarly, the absence of a dust plume from the waste dump under strong wind conditions would be a good indicator. Again, dust fallout directly downwind of the waste dump should not exceed 1 200 $mg/m^2/day$.

Receptor based performance indicators include the following:

Due to the number of mines proposed to operate within the Erongo region, and the location of the proposed Husab Project close to the existing Rössing Uranium Mine, it is recommended that the mine continue with dust fallout monitoring and PM_{10} sampling. This will provide the mine management with measured data to inform management plans and focus the attention on the main areas of concern.

The current monitoring network at the Husab Project area comprises of 8 single dust fallout buckets and one PM_{10} minivol sampler (sampling every 6th day). Since the current dust fallout network was designed on limited knowledge as where the mining operations will be the network was redesigned for when the mine is in operation. This is reflected in Figure 1.

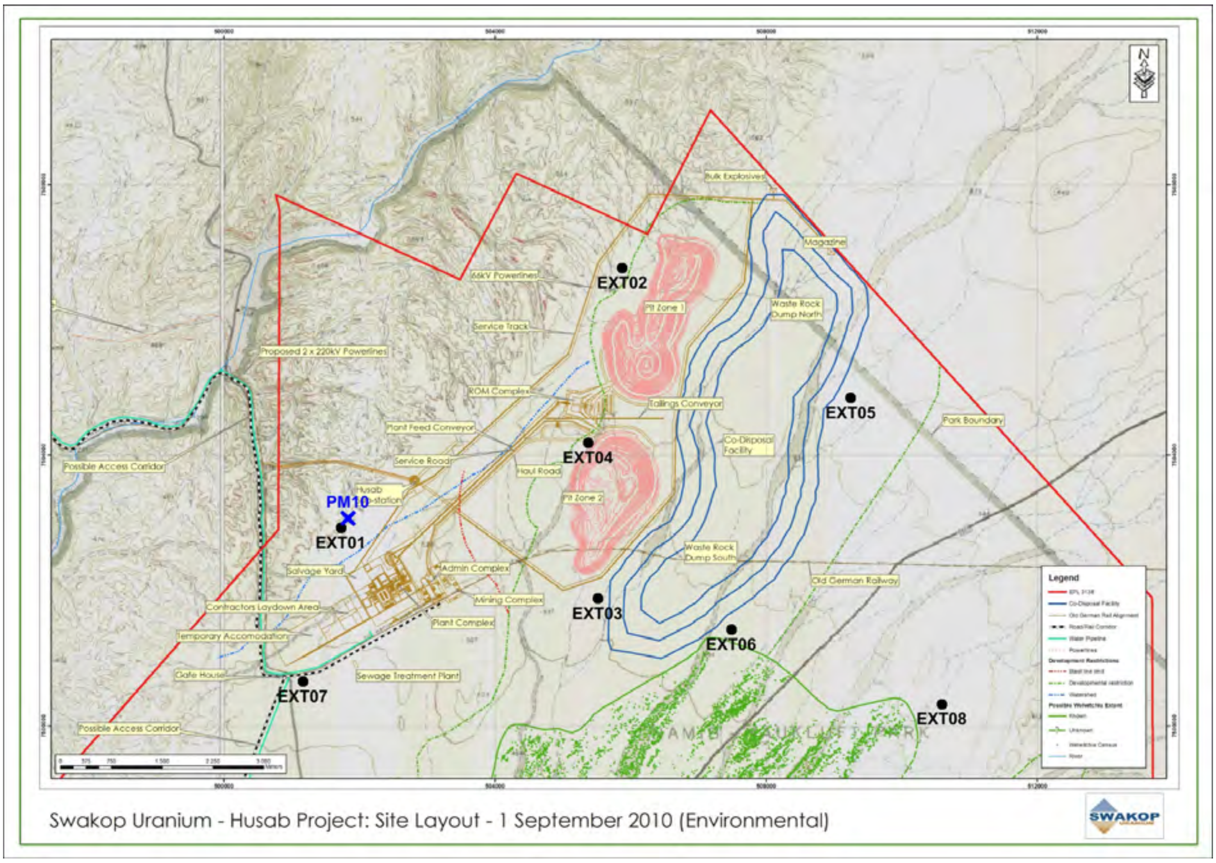
The proposed dust fallout network was designed based on the proposed mine layout and main areas of impact. These can be described as follows:

- EXT01 should remain at it s current location close to the weather station and PM10 site which will be directly west of the main mining operations;
- EXT02 to be paced to the west of the proposed Zone 1;
- EXT03 directly west of the waste dump and south of Zone 2;
- EXT04 to be located at the ROM complex;
- EXT05 downwind of the waste dump;

- EXT06 downwind of the waste dump;
- EXT07 located next to the main access road; and,
- EXT08 downwind (southeast) from all the mining operations.

The technical difficulties around the PM_{10} sampler is rectified and it is recommended that the mine continues with the PM_{10} sampling on a 6 day interval. The PM_{10} and dust fallout results should be kept in a central database with quarterly reports provide on the results.

It is recommended that site inspections and progress reporting be undertaken at regular intervals (at least quarterly) during operations, with annual environmental audits being conducted. Annual environmental audits will form part of the overall EMS for the Husab Project.



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Technical Terms and Abbreviations

ADMS	Atmospheric Dispersion Modelling System
Airshed	Airshed Planning Professionals (Pty) Ltd
amsl	above mean sea level
APCS	Air Pollution Control System
APIA	Air Pollution Impact Assessment
APPO	The Atmospheric Pollution Prevention Ordinance (No.11 of 1976)
AQG	Air quality guidelines
BAT	Best Available Technology
CERC	Cambridge Environmental Research Consultants
CO	Carbon monoxide
DEA	South African Department of Environmental Affairs
DPM	Diesel particulate matter
EMP	Environmental Management Programme
EHS	Environmental, Health, and Safety Guidelines
EU	European Union
g	gram
GDP	Gross Domestic Product
GIIP	Good International Industry Practice
GLC	Ground Level Concentration
h	Hour
HSE	UK Health and Safety Executives
IFC	International Finance Corporation
l	Litre
m	metre
m^3	Cubic metre
NAAQS	South Africa National Air Quality Standards
NO	Nitrogen Monoxide
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
NEMAQA	South Africa National Environment Management Air Quality Act (No. 39 of 2004)
PM_{10}	Particulate Matter with an aerodynamic diameter of less than 10µ
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter of less than 2.5µ
ROM	Run Of Mine
SA	South Africa

SANS	South African National Standards
SEPA	Scottish Environmental Protection Agency
SO_2	Sulphur Dioxide
tpd	Tons per day
TSP	Total Suspended Particles
μ	Microns
μg	Micrograms
US-EPA	United States Environmental Protection Agency
WBG	The World Bank Group
WHO	The World Health Organisation

Glossary

"**air pollution**" means any change in the composition of the air caused by smoke, soot, dust (including fly ash), cinders, solid particles of any kind, gases, fumes, aerosols and odorous substances.

"**ambient air**" is defined as any area not regulated by Occupational Health and Safety regulations.

"atmospheric emission" or **"emission"** means any emission or entrainment process emanating from a point, non-point or mobile source that results in air pollution.

"averaging period" means a period of time over which an average value is determined.

"frequency of exceedance" means a frequency (number/time) related to a limit value representing the tolerated exceedence of that limit value, i.e. if exceedences of limit value are within the tolerances, then there is still compliance with the standard.

"greenhouse gas" means gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation and includes carbon dioxide, methane and nitrous oxide.

"standard" means a measure which have components that define it as a "standard", which components may include some or all of the following; limit values, averaging periods, frequency of exceedences and compliance dates.

"vehicle entrainment" means the lifting and dropping of particles by the rolling wheels leaving the road surface exposed to strong air current in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

Air Quality Impact Assessment for the Proposed Swakop Uranium, Husab Project in Namibia

1 Introduction

Swakop Uranium plans the development of a new uranium mine approximately 5 km south of the existing Rössing Mine. The mine will produce around 8 000 tonnes of uranium oxide though conventional load and haul open pit mining and ore processing operations. Operations will also include a sulphur plant for the production of sulphuric acid (H_2SO_4).

Airshed Planning Professionals (Pty) Ltd (Airshed) was appointed by Metago Environmental Engineers (Pty) Ltd (Metago) to undertake an air quality impact assessment for the proposed operation. The main objective of the study was to do air dispersion modelling to determine potential impacts on the surrounding environment and human health.

1.1 Terms of Reference

The air quality impact assessment for the proposed project will form part of the Environmental Impact Assessment (EIA) undertaken by Metago. In order to determine the possible impacts from the proposed operations on the surrounding environment and human health, a baseline study, impact assessment and mitigation recommendation study was undertaken.

The **baseline air quality characterisation** included:

- Identification of the potential sensitive receptors within the vicinity of the proposed site;
- Characterisation of the regional climate and site-specific atmospheric dispersion potential; and
- Identification of existing sources of emission and determine the ambient air quality and dustfall levels in the region based on observational data recorded to date.

The **impact prediction study** included the following:

- Compilation of an emissions inventory, comprising the identification and quantification of potential routine and upset sources of atmospheric emission due to the new mining operations;
- Dispersion simulations of respirable particulate and gaseous emissions and dust-fall levels;
- Analysis of the dispersion modelling results;
- The evaluation of the potential for human health and environmental impacts based on the simulated results screened against ambient air quality guidelines and standards; and,
- Recommendations on mitigation and management measures.

1.2 Study Approach and Methods

Typically required from an EIA is both a baseline characterisation and impact assessment. The baseline assessment is to establish an understanding of the current status of air quality in the region with the impact assessment determining the additional contribution to the current state of air.

As part of the baseline, the way in which pollutants will disperse in the atmosphere needs to be understood. The analysis of meteorological data observed for a site provides the basis for the parameterisation of the meso-scale ventilation potential of the site. Parameters that need to be taken into account in the characterisation of meso-scale ventilation potentials include wind speed, wind direction, extent of atmospheric turbulence, ambient air temperature and mixing depth. Swakop Uranium installed and has been managing an on-site weather station since October 2008. In characterising the dispersion potential of the site reference was made to hourly average on-site meteorological data for the period October 2008 to June 2010.

Ambient monitored data for at least one year is required for a comprehensive baseline. Swakop Uranium installed eight single dust fallout buckets and a PM_{10} minivol sampler in August 2009. This serves to measure background dust deposition and PM_{10} ambient concentrations, respectively. Eleven months data were included in this study to provide an indication of the background dust fallout levels and PM_{10} concentrations prior to the commencement of mining operations.

The establishment of a comprehensive emission inventory formed the basis for the assessment of the impacts from of the proposed operation's emissions on the receiving environment. This comprises the identification of all sources of emission associated with the proposed mining operations, and the quantification of each source's contribution to ambient air pollution concentrations. In the quantification of fugitive dust emissions use was made of emission factors which associate the quantity of a pollutant to the activity associated with the release of that pollutant. Due to the absence of locally generated emission factors, use was made of the comprehensive set of emission factors and equations published by the US Environmental Protection Agency (US-EPA) in its AP-42 document Compilation of Air Pollution Emission Factors and the Australian National Pollutant Inventory (NPI). These emission factors are of the most widely used in the field of air pollution.

Particulate matter is the main pollutant of concern when assessing mining operations. In the estimation of emissions and the simulation of patterns of dispersion, a distinction was made between Total Suspended Particulates (TSP) and PM_{10} (particulate matter with an aerodynamic diameter of less than 10 µm). Whereas TSP is of interest due to its implications in terms of nuisance dust impacts, the PM_{10} fraction is taken into account to determine the potential for human health risks. Gaseous emissions will derive from combustions sources such as mining equipment, vehicles, and power generation.

PM_{10} concentrations and dustfall rates were simulated for the proposed operations and various operational scenarios. The simulation of ambient air pollutant concentrations and dust deposition due to the proposed operation was undertaken through the application of the Atmospheric Dispersion Modelling System (ADMS Version 4.2) developed by the Cambridge Environmental Research Consultants (CERC). ADMS 4 is a new generation air dispersion model which differs from the regulatory models traditionally used in a number of aspects, the most important of which are the description of atmospheric stability as a continuum rather than discrete classes (the atmospheric boundary layer properties are described by two parameters; the boundary layer depth and the Monin-Obukhov length, rather than in terms of the single parameter Pasquill Class) and in allowing more realistic asymmetric plume behaviour under unstable atmospheric conditions. Dispersion under convective meteorological conditions uses a skewed Gaussian concentration distribution (shown by validation studies to be a better representation than a symmetric Gaussian expression). ADMS 4 is currently used in many countries worldwide and users of the model include Environmental Agencies in the UK and Wales, the Scottish Environmental Protection Agency (SEPA) and regulatory authorities including the UK Health and Safety Executive (HSE).

1.3 Limitations and Assumptions

Human health risk assessment is an intricate process based on high level data. Dispersion modelling results are directly related to the input data with any error introduced in the input data carried through to the results. Thus, it is important to list and evaluate all data limitations and assumptions to ensure these are considered during interpretation of the results.

Limitations and assumptions pertaining to the project were:

- Predicted air pollution impacts only include those air emissions associated with the proposed Husab Project. Cumulative impacts were extrapolated using the eleven months available dust deposition levels. Due to technical problems PM_{10} data were lost and use was made of the Erongo SEA predicted ambient concentrations to provide an indication of the cumulative impacts.
- It was assumed that all processing operations will have ceased by the closure phase of the project. 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.
- No information was available on the temporary on-site diesel generators at the time of the study. These are however considered less significant than the other mining sources provided the design complies with the International Finance Corporation (IFC) emission limits for diesel generators. The IFC emission limits allow between 1.5% to 3% sulphur content for SO_2 emissions, 1 460 to 1 850 mg/Nm³ for NOx and 50 mg/Nm³ for diesel particulates (DPM).
- The dispersion model cannot compute real-time processes, therefore average consumption and production rates were used. Operational locations and periods were selected to reflect the worst case scenarios.
- The assessment of dust entrainment from the access road to the Husab project did not fall within the scope of this study.

- The range of uncertainty of the model predictions could to be -50% to 200%. 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.
- Nitrogen oxide (NO) is rapidly converted in the atmosphere into nitrogen dioxide (NO_2). As a conservative measure, and in the absence of accurate O_3 data, all long- and short term NO_x impacts were assumed to be NO_2.

1.4 Report Outline

Section 2:	Assessment Criteria and Regulatory Context
Section 3:	Baseline Characterisation
Section 4:	Impact Assessment
Section 5:	Conclusions
Section 6:	Recommendations and Air Quality Management Measures
Section 7:	References

2 Legal Requirements and Human Health Criteria

In addressing the impact of air pollution emanating from proposed operations, some background on the health effects of the various pollutants relevant to the study need to be provided. Since the terms of reference exclude a detailed toxicological study, this discussion is limited to the most important health impact aspects.

Air quality guidelines and standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site. The ambient air quality guideline values and standards indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Air quality guidelines and standards are normally given for specific averaging periods. These averaging periods refer to the time-span over which the air concentration of the pollutant was monitored at a location. Generally, five averaging periods are applicable, namely an instantaneous peak, 1-hour average, 24-hour average, 1-month average, and annual average. The application of these standards varies, with some countries allowing a certain number of exceedances of each of the standards per year.

Reference is made to the ambient air quality guidelines as stipulated locally and internationally for criteria pollutants. This is discussed in more detail in the sections below.

2.1 Namibian Legislation

As far as could be ascertained, Namibia has adopted the South African air pollution legislation for air quality control in the form of the Atmospheric Pollution Prevention Act (Act No 45 of 1965) (APPA). Based on the stipulations of this act, the following parts are applicable:

Part II : Controls of noxious or offensive gases;

Part III : Atmospheric pollution by smoke;

Part IV : Dust control; and

Part V : Air pollution by fumes emitted by vehicles.

The Namibian Atmospheric Pollution Prevention Ordinance (No. 11 of 1976) does not include any ambient air standards to comply with, but the Chief Air Pollution Officer (CAPCO) provides air quality guidelines for consideration during the issuing of Air Pollution Certificates (APC). Air Pollution Certificates are only issued for so called “Scheduled Processes” which are processes resulting in noxious or offensive gasses and typically pertain to point source emissions. The air pollution guidelines included in the APC are primarily for criteria pollutants namely, sulphur dioxide, oxides of nitrogen, carbon monoxide, ozone, lead and particulate matter. Mining operations do not fall under “Scheduled Processes” and hence do not require an APC resulting in no specified ambient air quality guidelines.

2.2 International Requirements

Typically when no local ambient air quality criteria exists, or are in the process of being developed, reference is made to international health screening criteria. This serves to provide an indication of the severity of the potential impacts from the proposed activities. The most widely referenced international air quality criteria are those published by the World Bank Group, the World Health Organisation and the European Community. The newly promulgated South African ambient air quality standards are also referenced since it is regarded more representative indicators for Namibia due to the similar environmental, social and economic characteristics between the two countries.

2.2.1 World Bank Requirements

As of April 30, 2007, new versions of the World Bank Group Environmental, Health, and Safety Guidelines (known as the 'EHS Guidelines') are now in use. They replace those documents previously published in Part III of the Pollution Prevention and Abatement Handbook and on the International Finance Corporation (IFC) website.

The new EHS Guidelines were developed as part of a two and a half year review process. The EHS Guidelines are intended to be 'living documents', and will be updated on a regular basis going forward.

When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures are appropriate in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

2.2.2 World Health Organisation

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 PM10 and PM2.5 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).

2.2.3 European Community

The European Community (EC) air quality criteria represent objectives/standards to be achieved by the year 2004/2005 and were designed primarily to protect human health. The EC standards have superseded the European Union (EU) standards. The current EU standards were determined through consultation with due regard to environmental conditions, the economic and social development of various regions, and the importance of a phased approach to attaining compliance.

2.2.4 South Africa

It is not clear how the legal developments in South Africa will affect the Namibian legislation. It is however regarded more representative of the environmental, social and economic situation than the European criteria.

The South African Bureau of Standards (SABS) was engaged to assist the Department of Environmental Affairs (DEA) in the facilitation of the development of ambient air quality standards. This included the establishment of a technical committee to oversee the development of standards. Standards were determined based on international best practice for particulate matter less than 10 µm in aerodynamic diameter (PM_{10}), dustfall, sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide, lead and benzene (SANS 69, 2006). These standards were published for comment in the Government gazette on 9 June 2007. The final standards were published on the 24th of December 2009 and include a margin of tolerance (i.e. frequency of exceedances) and implementation timelines linked to it.

2.3 Ambient Air Quality Standards and Guidelines

In this section, the guidelines and standards as stipulated by the World Bank Group (WBG) and the Namibian Government are discussed. The newly updated EHS guidelines published by the IFC in April 2007 reference the WHO guidelines or other internationally recognised sources (US and EC) in the absence of national legislated standards. The new South African ambient air quality standards are also referenced.

2.3.1 *Suspended Particulate Matter*

The impact of particles on human health is largely dependent 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. The deposition of particles in different regions of the respiratory system depends on their size.

Air quality guidelines for particulates are given for various particle size fractions, including total suspended particulates (TSP), thoracic dust 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 previously, such fine particles are able to be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung. PM_{10} limits and standards for the World Bank Group, EC and South Africa are documented in Table 2-1. The air quality guidelines and interim targets issued by the WHO in 2005 for particulate matter are given in Table 2-2 and 2-3.

Table 2-1: Air quality guidelines and standards for inhalable particulates (PM10).

Authority	Maximum 24-hour concentration (µg/m³)	Annual Average concentration (µg/m³)
World Bank Group	(a)	(a)
European Community (EC)	50 (b)	40 (c)
SA Standards (d)	120 (e)(g) 75 (f)(g)	50 (e) 40 (f)

Notes:

(a) WBG, 2007. EHS Guidelines (http://www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines). Guidelines state that pollutant concentrations do not reach or exceed relevant ambient quality guidelines and standards by applying national legislated standards, or in their absence, the current WHO Air Quality Guidelines, or other internationally recognized sources.
(b) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). In force since 1 January 2005. Not to be exceeded more than 35 times per calendar year.
(c) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). In force since 1 January 2005.
(d) Promulgated on the 24 December 2009 (Gazette No. 32816).
(e) Applicable immediately to 31 December 2014.
(f) Applicable from 1 January 2015.
(g) Not to be exceeded more than 4 times per year.

Table 2-2: Annual average WHO AQG and IT for particulate matter (WHO, 2005)

Annual Mean Level	PM10 (µg/m³)	PM2.5 (µg/m³)	Basis for the selected level
WHO interim target-1 (IT-1)	70	35	These levels were estimated to be associated with about 15% higher long-term mortality than at AQG
WHO interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower risk of premature mortality by approximately 6% (2-11%) compared to WHO-IT1
WHO interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce mortality risks by another approximately 6% (2-11%) compared to WHO-IT2 levels.
WHO Air Quality Guideline (AQG)	20	10	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to PM2.5 in the American Cancer Society (ACS) study (Pope *et al.*, 2002 as cited in WHO 2005). The use of the PM2.5 guideline is preferred.

Table 2-3: Daily average WHO AQG and IT for particulate matter (daily mean) (WHO, 2005)

Daily Mean Level	PM10 (µg/m³)	PM2.5 (µg/m³)	Basis for the selected level
WHO interim target-1 (IT-1)	150	75	Based on published risk coefficients from multi-centre studies and meta-analyses (about 5% increase of short-term mortality over AQG)
WHO interim target-2 (IT-2)[(a)]	100	50	Based on published risk coefficients from multi-centre studies and meta-analyses (about 2.5% increase of short-term mortality over AQG)
WHO interim target-3 (IT-3) [(b)]	75	37.5	Based on published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase of short-term mortality over AQG)
WHO Air Quality Guideline (AQG)	50	25	Based on relation between 24-hour and annual levels

<u>**Notes:**</u>

(a) 99th percentile (3 days per year).

(b) For management purposes, based on annual average guideline values; precise number to be determined on basis of local frequency distribution of daily means.

2.3.2 Sulphur Dioxide

Sulphur dioxide is damaging to the human respiratory function. Exposure to sulphur dioxide concentrations above certain threshold levels increases the prevalence of chronic respiratory disease and the risk of acute respiratory illness. Due to it being highly soluble, sulphur dioxide is more likely to be adsorbed in the upper airways rather than penetrate to the pulmonary region.

Ambient air quality guidelines and standards issued for various countries and organisations for sulphur dioxide (SO_2) are given in Table 2-5. It is important to note that the WHO AQGs published in 2000 for SO_2 have been revised (WHO, 2005). Although the 10-minute AQG of 500 µg/m³ has remained unchanged, the previously published daily guideline has been significantly reduced from 125 µg/m³ to 20 µg/m³. The previous daily guideline was based on epidemiological studies. WHO (2005) makes reference to more recent evidence which suggests the occurrence of health risks at lower concentrations. Although WHO (2005) acknowledges the considerable uncertainty as to whether SO_2 is the pollutant responsible for the observed adverse effects (may be due to ultra-fine particles or other correlated substances), it took the decision to publish a stringent daily guideline in line with the precautionary principle. The WHO (2005) stipulates an annual guideline is not needed for the protection of human health, since compliance with the 24-hour level will assure sufficiently lower levels for the annual average. Given that the 24-hour WHO AQG of 20 µg/m³ is anticipated to be difficult for some countries to achieve in the short term, the WHO (2005) recommends a stepped approach using interim goals as shown in Table 2-4.

Table 2-4: WHO air quality guidelines and interim guidelines for SO_2 (WHO, 2005)

Guideline	24-hour Average Sulphur Dioxide (µg/m³)	10-minute Average Sulphur Dioxide (µg/m³)
WHO interim target-1 (IT-1) (2000 AQF level)	125	-
WHO interim target-2 (IT-2)	50[(a)]	-
WHO Air Quality Guideline (AQG)	20	500

Notes:

(a) Intermediate goal based on controlling either (i) motor vehicle (ii) industrial emissions and/or (iii) power production; this would be a reasonable and feasible goal to be achieved within a few years for some developing countries and lead to significant health improvements that would justify further improvements (such as aiming for the guideline).

Table 2-5: International ambient air quality guidelines and standards for SO_2

Authority	Maximum 10-minute average (µg/m³)	Maximum 1-hourly average (µg/m³)	Maximum 24-hour average (µg/m³)	Annual Average concentration (µg/m³)
World Bank (General Environmental Guidelines)	(a)	(a)	(a)	(a)
European Community (EC)	-	350 (b)	125 (c)	20 (d)
SA standards (e)	500 (f)	350 (g)	125 (h)	50

Notes:

(a) IFC EHS Guidelines, 2007. Adopted the WHO 2005 air quality guidelines.
(b) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Already in force since 1 January 2005. Limit to protect health (not to be exceeded more than 24 times per calendar year).
(c) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Already in force since 1 January 2005. Limit to protect health (not to be exceeded more than 3 times per calendar year).
(d) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Limited value to protect ecosystems.
(e) Promulgated on the 24 December 2009 (Gazette No. 32816). Applicable immediately.
(f) Not to be exceeded more than 526 times per year.
(g) Not to be exceeded more than 88 times per year.
(h) Not to be exceeded more than 4 times per year.

2.3.3 Nitrogen Dioxide

Nitrogen oxides (NO_x), primarily in the form of nitrogen oxide (NO), are one of the primary pollutants emitted during combustion. Nitrogen dioxide (NO_2) is formed through oxidation of these oxides once released in the air. NO_2 is an irritating gas that is absorbed into the mucous membrane of the respiratory tract. The most adverse health effect occurs at the junction of the conducting airway and the gas exchange region of the lungs. The upper airways are less affected because NO_2 is not very soluble in aqueous surfaces. Exposure to NO_2 is linked with increased susceptibility to respiratory infection, increased airway resistance in asthmatics and decreased pulmonary function.

The standards and guidelines of most countries and organisations are given exclusively for NO_2 concentrations in Table 2-6.

Table 2-6: Ambient air quality guidelines and standards for NO_2

Authority	Instantaneous peak (µg/m³)	Maximum 1-hourly average (µg/m³)	Maximum 24-hour average (µg/m³)	Maximum 1-month average (µg/m³)	Annual average concentration (µg/m³)
World Bank (General Environmental Guidelines)	-	(a)	-	-	(a)
World Health Organisation	-	200(b)	-	-	40(b)
European Community (EC)	-	200(c)	-	-	40(d)
SA standards (e)	-	200(f)	-	-	40

Notes:

(a) IFC EHS Guidelines, 2007. Adopted the WHO 2005 air quality guidelines.
(b) WHO guidelines. World Health Organisation air quality guidelines global update 2005.
(c) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Not to be exceeded more than 18 times per year. This limit is to be complied with by 1 January 2010.
(d) EC Directive, 2008/50/EC (http://ec.europa.eu/environment/air/quality/legislation/directive.htm). Already in force since 1 January 2005. Annual limit value for the protection of human health, to be complied with by 1 January 2010.
(e) Promulgated on the 24 December 2009 (Gazette No. 32816). Applicable immediately.
(f) Not to be exceeded more than 88 times per year.

2.3.4 Carbon Monoxide

Carbon monoxide (CO) absorbed through the lungs reduces the blood's capacity to transport available oxygen to the tissues. Approximately 80-90% of the absorbed CO binds with haemoglobin to form carboxyhaemoglobin (COHb), which lowers the oxygen level in blood. Since more blood is needed to supply the same amount of oxygen, the heart needs to work harder. These are the main causes of tissue hypoxia produced by CO at low exposure levels. At higher concentrations, the rest of the absorbed CO binds with other heme proteins such as myoglobin and with cytochrome oxidase and cytochrome P-450. CO uptake impairs perception and thinking, slows reflexes and may cause drowsiness, angina, unconsciousness or death.

The ambient air quality guidelines and other standards issued for various countries and organisations for CO are given in Table 2-7.

Table 2-7: Ambient air quality guidelines and standards for carbon monoxide

Authority	Maximum 1-hourly Average ($\mu g/m^3$)	Maximum 8-hour Average ($\mu g/m^3$)
World Bank	[a]	[a]
World Health Organisation	30 000[b]	10 000[b]
European Community (EC)	-	10 000[c]
SA standards [d]	30 000[e]	10 000[f]

Notes:

(a) IFC EHS Guidelines, 2007. Adopted the WHO 2005 air quality guidelines.
(b) WHO Guidelines for the protection of human health (WHO, 2000).
(c) EC Second Daughter Directive, 2000/69/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Annual limit value to be complied with by 1 January 2005.
(d) Promulgated on the 24 December 2009 (Gazette No. 32816). Applicable immediately.
(e) Not to be exceeded more than 88 times per year.
(f) Not to be exceeded more than 11 times per year.

2.3.5 Diesel Particulate Matter

Diesel engine exhaust (DE) is an intricate mixture of airborne particles and gases. Diesel particulate matter (DPM) is composed of elemental carbon particles and adsorbed organic compounds and is the most frequently determined measure of DE and the measure reported in toxicological studies of diesel engine exhaust (US EPA IRIS, 2003). Chronic respiratory effects are the main non-cancer hazard to humans from long-term environmental exposure to diesel engine exhaust, or emissions (DE).

Diesel particulate has been classified by the US EPA as a compound with non-cancer chronic inhalation risk for which a reference concentration (RfC) is given. Reference concentrations are derived from clinical studies. An uncertainty factor is applied to the No Observed Adverse Effect Level (NOAEL) from these studies, allowing (for instance) for application of results of animal studies to human health risks. Concentration values below the RfC imply that no risk has been identified; above the RfC does not necessarily imply risk, but further investigation might be warranted. The USA EPA IRIS database gives an RfC value of 5 $\mu g/m^3$ for annual exposure, and this value will be used for the preliminary health screening.

In addition, diesel engines emit benzene and 1,3-butadiene which have both been classified as carcinogens. Standards for carcinogens are not set using the same methodology as for non-carcinogens, as they have no lower threshold for adverse effects. However, using an appropriate acceptable risk level, annual average concentration standards may be derived. In South Africa, the proposed SANS standard for benzene is 5 $\mu g/m^3$ (annual average). Using the relative toxicity of 1,3 butadiene to benzene (as indicated by the relative US EPA unit risk factors) the standard for 1,3 butadiene on the same basis would be 1,3 $\mu g/m^3$. However, the rate of emissions of the benzene and 1,3 butadiene is approximately 1% of the emission rate of particulates (California ARB 2002). Screening for diesel particulate as an indicator of transport-related emissions therefore provides a conservative screening value for the carcinogens mentioned above.

2.3.6 *Sulphur Trioxide*

When SO_3 is exposed to air, it rapidly takes up water and gives off white fumes. The Texas Commission on Environmental Quality (TSEQ) provides short-term (10 µg/m³) and chronic (1 µg/m³) Effect Screening Levels (ESLs) for SO_3 ground level concentrations. It should be noted that ESLs are based on data concerning health effects, odour nuisance potential, vegetation effects, or corrosion effects. ESLs are not ambient air quality standards. If predicted or measured airborne levels of a constituent do not exceed the screening level, it is not expected that any adverse health or welfare effects would results. If ambient levels of constituents in air exceed the screening levels it does not, however, necessarily indicate a problem, but should be viewed as a trigger for a more in-depth review.

2.3.7 *Dust Deposition*

Foreign dust deposition standards issued by various countries are given in Table 2-8. It is important to note that the limits given by Argentina, Australia, Canada, Spain and the USA are based on annual average dustfall. The standards given for Germany are given for maximum monthly dustfall and therefore comparable to the dustfall categories issued in South Africa. Based on a comparison of the annual average dustfall standards it is evident that in many cases a threshold of ~200 mg/m^2-day to ~300 mg/m^2-day is given for residential areas.

Table 2-8: Dust deposition standards issued by various countries

Country	Annual Average Dust Deposition Standards (based on monthly monitoring) (mg/m^2-day)	Maximum Monthly Dust Deposition Standards (based on 30 day average) (mg/m^2-day)
Argentina	133	
Australia	133 (onset of loss of amenity) 333 (unacceptable in New South Wales)	
Canada Alberta: Manitoba	179 (acceptable) 226 (maximum acceptable) 200 (maximum desirable)	
Germany		350 (maximum permissible in general areas) 650 (maximum permissible in industrial areas)
Spain	200 (acceptable)	
USA:		

Country	Annual Average Dust Deposition Standards (based on monthly monitoring) (mg/m^2-day)	Maximum Monthly Dust Deposition Standards (based on 30 day average) (mg/m^2-day)
Hawaii	200	
Kentucky	175	
New York:	200 (urban, 50 percentile of monthly value)	
	300 (urban, 84 percentile of monthly value)	
Pennsylvania	267	
Washington:	183 (residential areas)	
	366 (industrial areas)	
Wyoming:	167 (residential areas)	
	333 (industrial areas)	

Air quality standards are not defined by all countries for dust deposition, although some countries may make reference to annual average dustfall thresholds above which a 'loss of amenity' may occur. 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 dustfall. The South African Department of Minerals and Energy (DME) uses the uses the 1200 mg/m^2/day threshold level as an action level. In the event that on-site dustfall exceeds this threshold, the specific causes of high dustfall should be investigated and remedial steps taken.

According to the proposed SA dustfall limits an enterprise may submit a request to the authorities to operate within the Band 3 ACTION band for a limited period, providing that this is essential in terms of the practical operation of the enterprise (for example the final removal of a tailings deposit) and provided that the best available control technology is applied for the duration. No margin of tolerance will be granted for operations that result in dustfall rates in the Band 4 ALERT. The SANS four-band scale is presented in Table 2-9. Proposed target, action and alert thresholds for ambient dust deposition are given in Table 2-10.

Table 2-9: 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 2-10: 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.

2.4 Adopted Evaluation Criteria for the Husab Project

For the purpose of this study the evaluation criteria used are provided in Table 2-11. The WHO Air Quality Guidelines (AQG) provides the initial screening criteria for the Husab Project impact assessment. The WHO does however state that these AQG and interim targets should be used to guide standard-setting processes and should aim to achieve the lowest concentrations possible in the context of local constraints, capabilities, and public health priorities. These guidelines were also aimed at urban environments within developed countries (WHO, 2005). It is in this light that the WHO IT3 and South African Standards were selected as representative screening criteria. The South African Standards agree with the WHO IT3 guidelines and were developed for example with the knowledge that the background PM_{10} concentrations are higher than in Europe and should be achievable within a semi-arid environment. These also correlate with the evaluation criteria recommended for the Erongo Region (Liebenberg-Enslin et.al., 2010).

Also, due to the limited international guidelines for dust fallout, both the German and South African guidelines are referenced.

Table 2-11: Proposed evaluation criteria for the Husab Project

Pollutant	Averaging Period	Selected Criteria	Country of Origin
PM_{10}	24-hour Mean (µg/m³)	$75_{(a)}$	WHO IT3 & SA Standard
	Annual Mean (µg/m³)	30	WHO IT3
SO_2	1-hour Mean (µg/m³)	$350_{(b)}$	EC limit & SA Standard
	24-hour Mean (µg/m³)	$125_{(a)}$	WHO IT1 & SA Standard
	Annual Mean (µg/m³)	50	SA Standard
NO_2	1-hour Mean (µg/m³)	$200_{(b)}$	WHO AQG & SA Standard
	Annual Mean (µg/m³)	40	WHO AQG & SA Standard
CO	1-hour Mean (µg/m³)	$30\ 000_{(a)}$	WHO AQG & SA Standard
	8-hour Mean (µg/m³)	$10\ 000_{(c)}$	WHO AQG & SA Standard
Dust fallout	30-day average (mg/m²/day)	350	German limit in general areas
		$600_{(d)}$	SA SANS residential action limit

Notes:
(a) Not to be exceeded more than 4 times per year (SA).
(b) Not to be exceeded more than 88 time per year (SA).
(c) Not to be exceeded more than 11 times per year (SA).
(d) Not to be exceeded more than 3 time per year or 2 consecutive months.

3 Baseline Characterisation

In characterising the baseline air quality, reference is made to details concerning the study area, atmospheric dispersion potential and other potential sources of atmospheric emissions in the area. The consideration of the existing air quality is important so as to facilitate the assessment of the potential for cumulative air pollutant concentrations arising due to the proposed development.

3.1 Study Area

The local study area for the air quality impact assessment was selected based on the expected extent of air quality impacts and possible sensitive receptors such as individual homes and communities. A study area of 35 km east-west and 35 km north-west was identified, with the site considered for the location of the proposed operation approximately in the centre. The closest residential area, Arandis, is situated approximately 16 km to the northwest of the proposed mine (Figure 3-1). The proposed mine will be located about 5 km south of the exiting Rössing Uranium Mine. The Big Welwitschia (Welwitschia Miräbilis), located ~2.5 km south of the Husab Project is a major tourism attraction. The terrain of study area is shown in Figure 3-2.

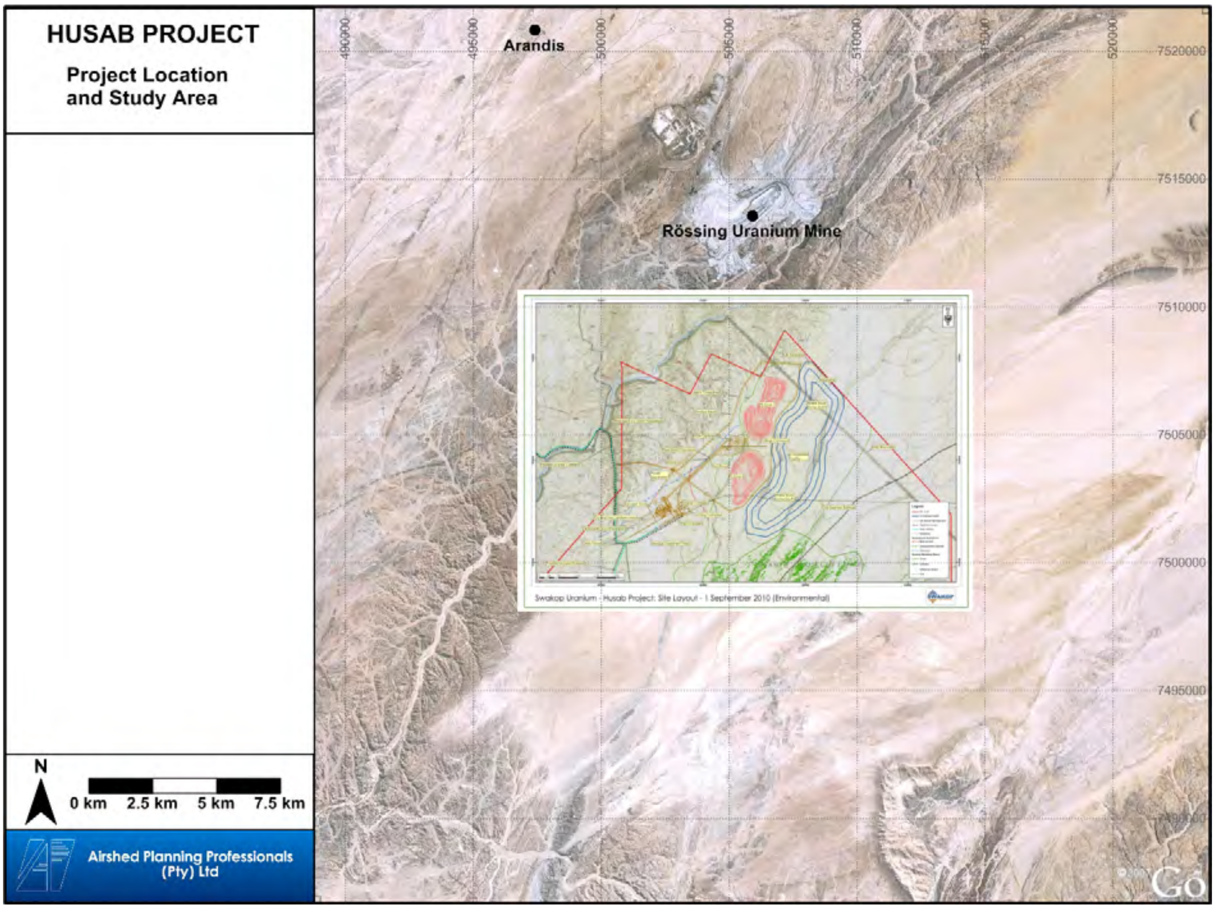

Figure 3-1: Study area (35 x 35 km)

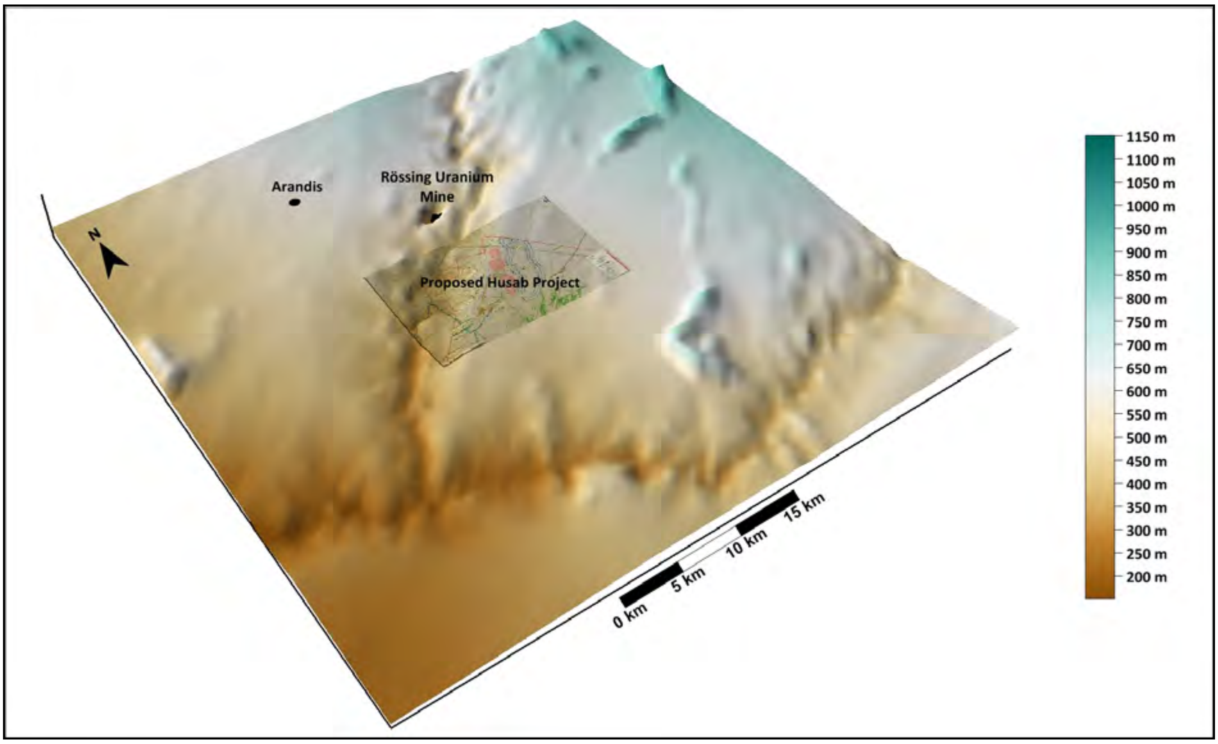

Figure 3-2: Terrain elevation of study area

3.2 Regional Climate

The Husab Project falls within the west coast arid zone of Southern Africa. Historical meteorological data are limited, with the Gobabeb Research Station (located ~100 km to the south of the site on the border with the Namib Desert) being in operation since 1962. Information on the climatic conditions of the region is therefore primarily focussed on the Central Namib.

The main focus of this section on the local meteorology with a summary of the main regional climatic features influencing the local meteorology is provided within this section. Additional information on the regional climate is provided in Appendix B.

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. The average rainfall in the west coast region is slight with an annual average of 23 mm measured over the period 1962 - 1967 at Gobabeb. Historical records for Swakopmund, dating as far back as 1899, indicate an annual average of 14 mm. As is typical of arid areas, rainfall can vary considerably and can be of great intensity. The highest daily total rainfall measured in 1972 was 16.5 mm at Gobabeb and 22 mm at Goanikontes with Swakopmund receiving 153 mm in 1934 (Goudie, 1972). More recent statistics for Swakopmund indicate the total annual rainfall for 2008 to be 30 mm (http://weather.namsearch.com). According to the Directorate of Environmental Affairs, Ministry of Environment and Tourism Digital Atlas of Namibia, rainfall within the Erongo Region ranges between 0-50 mm at the coast to 400 mm in the northeast of the region. The Husab Project falls within the 50-100 mm/year rainfall belt and in the 3000-3200 mm per year evaporation rate region. Evaporation rates are between 2400-3400 mm per year increasing from the coast inland reaching a maximum in the central part of the Erongo Region (http://209.88.21.36/Atlas/Atlas_web.htm).

Fog, a form of precipitation, is characteristic of this region. Swakopmund, for instance, has high incidences of fog days of more than 125 days per year (http://209.88.21.36/Atlas/Atlas_web.htm). Within the Erongo Region, fog can extend up to 110 km inland with an average number of days per annum recorded at Gobabeb of 102 between 1964 and 1967 (Goudie, 1972). The annual fog precipitation at Swakopmund was estimated to be 35-45 mm in relation to 20 mm 40 km inland (Goudie, 1972).

Air temperature is an important parameter for the development of the mixing and inversion layers with relative humidity being the inverse function of ambient air temperature, increasing as ambient air temperature decreases. Historical data for the region indicate similar average monthly and annual temperatures along the Namib Coast. The range between the coldest and warmest months is also small being 9°C at both Swakopmund and Walvis Bay. Frost is not associated with the region but extreme temperatures of over 40°C have been linked to strong easterly “berg” winds (Goudie, 1972). The number of sunshine hours in the Erongo Region also increases rapidly from the coast towards the east, ranging from less than 5 hours at Swakopmund to more than 10 hours just a few kilometres inland. Relative humidity for the Erongo Region varies between <10% to 70% during both the least humid month and the most humid month. The relative humidity is the highest along the coast and lowest inland (http://209.88.21.36/Atlas/Atlas_web.htm). The average humidity recorded at Swakopmund for the year 2008 ranged between 22% and 96% (http://weather.namsearch.com).

Incoming solar radiation increases from sunrise (06:00) to reach a maximum at midday (12:00 – 13:00) and then decreases till sunset (19:00). Within the Erongo Region solar radiation is on average <5.4 kWhr per m^2 per day at the coast and up to 5.8 kWhr per m^2 per day further east. The Husab Project falls within the 5.6-5.8 kWhr per m^2 per day category (http://209.88.21.36/Atlas/Atlas_web.htm).

The wind field of the region represents a combination of the synoptic-scale circulation and the local land-sea breeze circulation. Wind data recorded during 2008 at Swakopmund indicate on average wind speeds below 4 m/s. Periods of high wind incidents (above 10 m/s) did however occur with the highest wind speeds measured during 2008 of 36 m/s (http://weather.namsearch.com). The wind field varies significantly within the Erongo Region with wind direction in the central northern part predominantly easterly and north-easterly and south-westerly. The easterly and north-easterly winds are also associated with high wind speeds. The wind field changes slightly around the project area with a shift towards northerly and north-westerly winds but keeping the strong presence of south-easterly winds. Wind speed for the region also varies but most of the stations records wind speeds between 0-10 m/s.

3.3 Local Atmospheric Dispersion Potential

In the assessment of the possible impacts from air pollutants on the surrounding environment and human health, a good understanding of the regional climate and local air dispersion potential of a site is essential.

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

Pollution 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 (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.

Parameters that need to be taken into account in the characterisation of meso-scale ventilation potentials include wind speed, wind direction, extent of atmospheric turbulence, ambient air temperature and mixing depth. In the description of the atmospheric dispersion potential of the study area, reference was made to on-site meteorological data for the period October 2008 to June 2010.

3.3.1 Mixing Height and Atmospheric Stability

The vertical component of dispersion is a function of the extent of thermal turbulence and the depth of the surface mixing layer. Unfortunately, the mixing layer is not easily measured, and must therefore often be estimated using prognostic models that derive the depth from some of the other parameters that are routinely measured, e.g. solar radiation and temperature. During the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface and the extension of the *mixing layer* to the lowest elevated inversion. Radiative flux divergence during the night usually results in the establishment of ground based inversions and the erosion of the mixing layer. The mixing layer ranges in depth from ground level (i.e. only a stable or neutral layer exists) during night-times to the base of the lowest-level elevated inversion during unstable, day-time conditions. Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table 3-1.

Table 3-1: 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 is likely to occur during unstable, daytime conditions. The wind speed resulting in the highest ground level concentration depends on the plume buoyancy. If the plume is considerably buoyant (high emission velocity and temperature) together with a low wind, the plume will reach the ground relatively far downwind. With stronger wind speeds, on the other hand, the plume may reach the ground closer, but due to the increased ventilation, it would be more diluted. A wind speed between these extremes would therefore be responsible for the highest ground level concentrations. The highest concentrations for low level releases would occur during weak wind speeds and stable (night-time) atmospheric conditions, with the exception of wind dependent sources where high wind speeds are needed to generate emissions.

The occurrence of the various stability classes associated with the 16 main wind directions are presented in Figure 3-3. Stable atmospheric conditions tend to result in high ground level concentrations for ground level emitters such as fugitive dust from unpaved roads and crushers. High frequency of very stable (F – stability) conditions occurred predominantly from the north to the north-western sector.

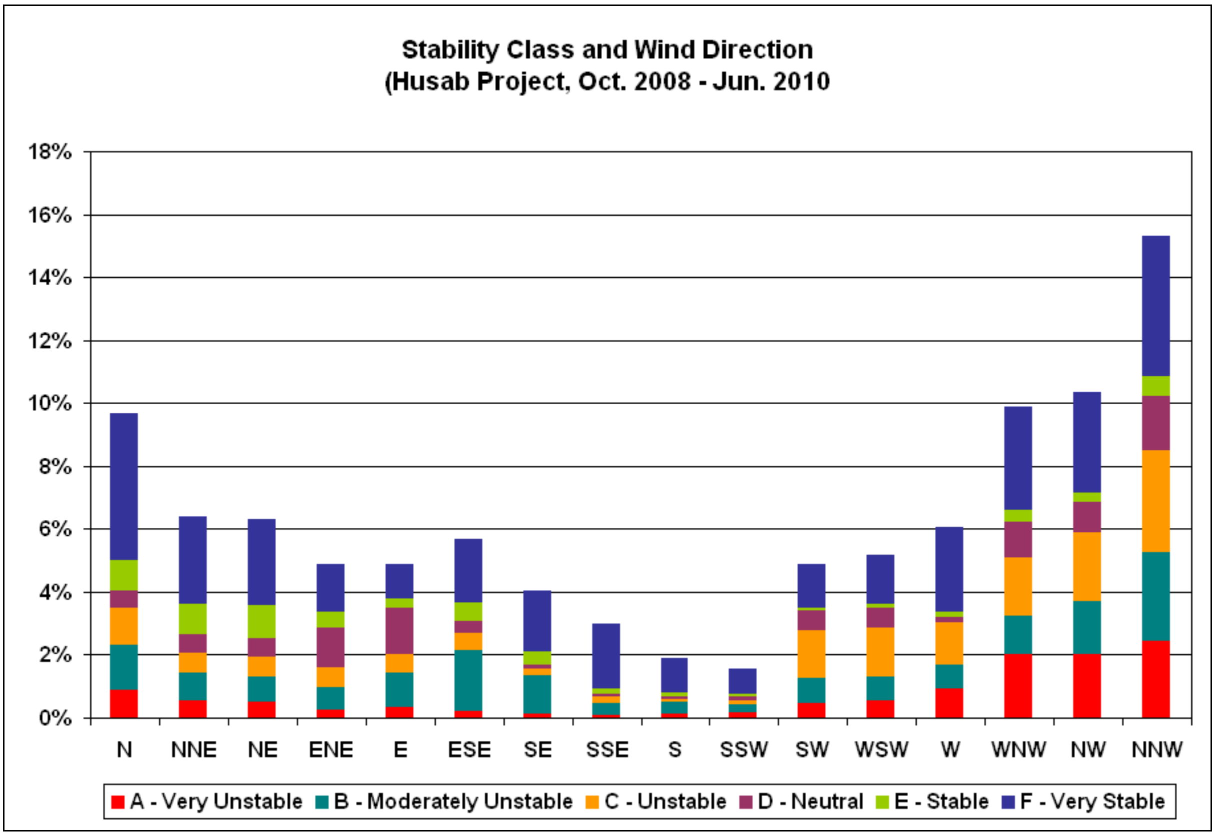

Figure 3-3: Wind direction and stability class

3.3.2 Local Wind Field

Wind roses comprise 16 spokes, which represent the directions from which winds blew during a specific period. The colours used in the wind roses below, reflect the different categories of wind speeds; the red area, for example, representing winds of 6 to 10 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. The frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s are also indicted.

The period wind field and diurnal variability in the wind field are shown in Figure 3-4. Seasonal and monthly variations in the wind field recorded on site are provided in Figure 3-5 and Figure 3-6 respectively.

The wind field is characterised by dominant north-westerly winds. Wind from the north-northwest occurred 12% of the time with calm conditions occurring 27% of the time. There is not much variation between night-time and day-time wind flow, with a slight increase in frequency of winds from the north and north-east during the night. The night-time conditions are also characterised by lower wind speeds and a higher percentage of calm conditions.

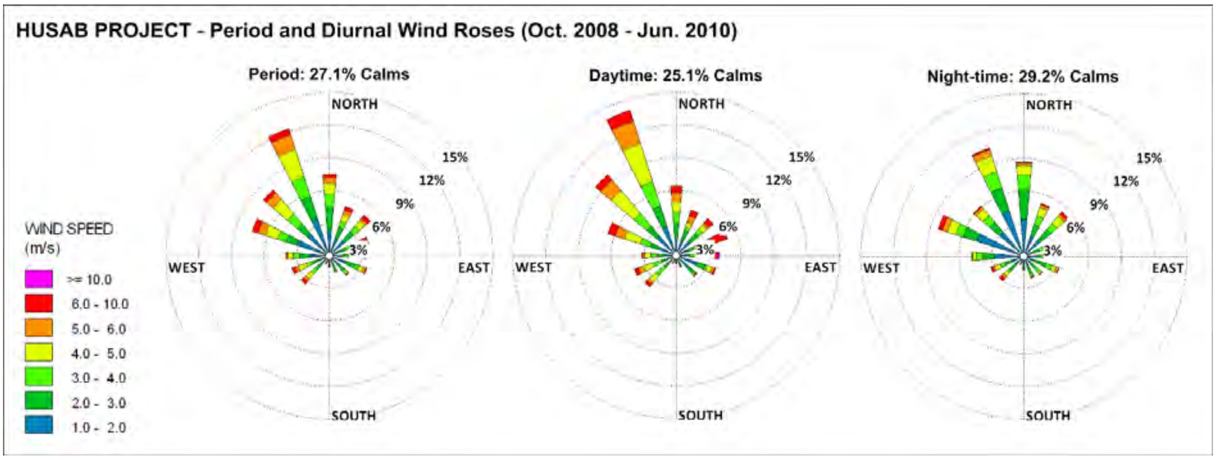

Figure 3-4: Period average and diurnal wind roses (Husab Project, Oct. 2008 – Jun. 2010)

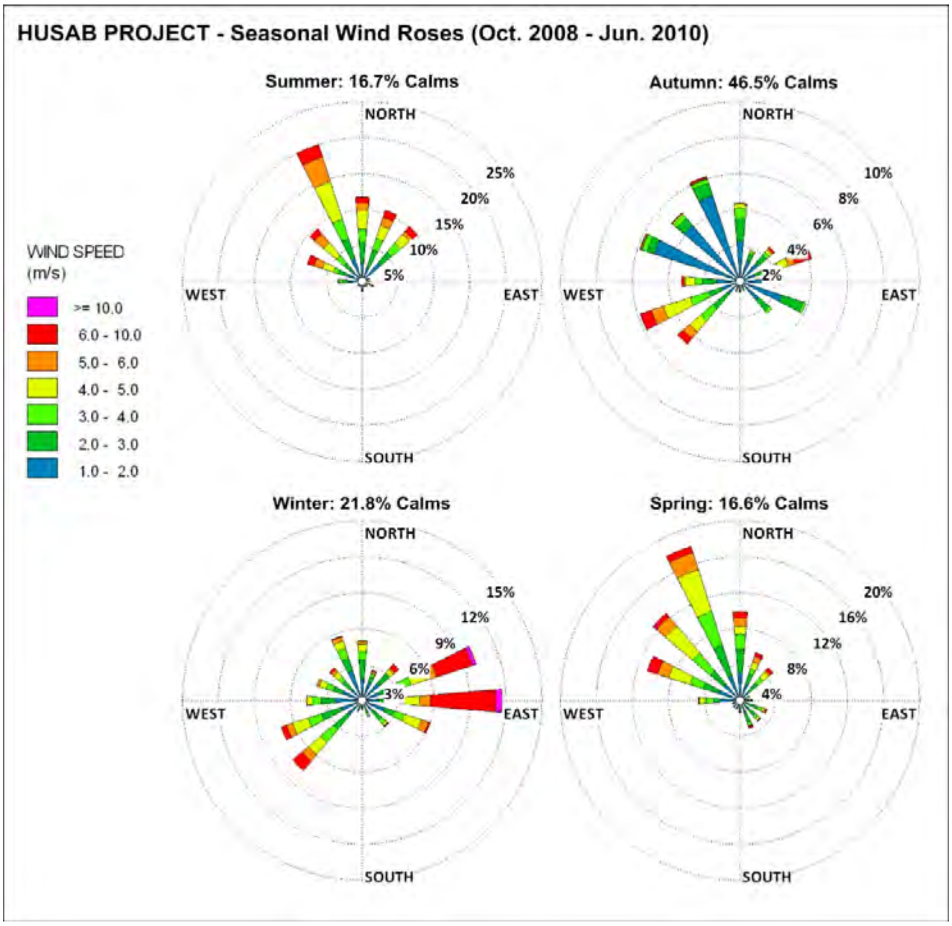

Figure 3-5: Seasonal wind roses (Husab Project, Oct. 2008 – Jun. 2010)

Significant variation in seasonal wind field was observed. During the summer and spring months north-north-westerly winds dominate with an increase in easterly, east-north-easterly and west-south-westerly airflow during the autumn and winter months. The so-called "easterly winds" associated with high wind speeds occurred most frequently during the month of July (Figure 3-6).

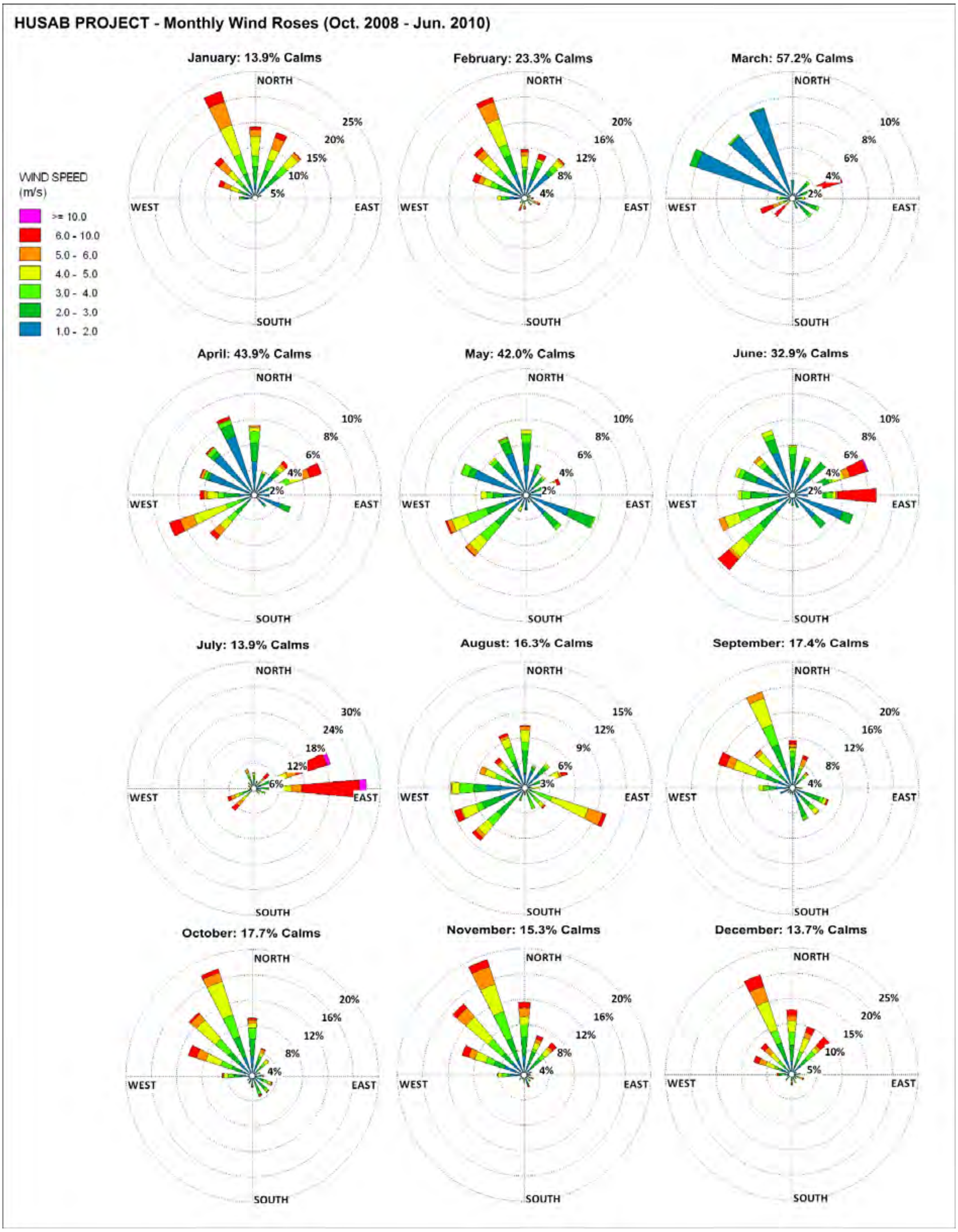

Figure 3-6: Monthly wind roses (Husab Project, Oct. 2008 – Jun. 2010)

3.3.3 Temperature

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume is able to rise), and determining the development of the mixing and inversion layers. The diurnal temperature trend is presented in Figure 3-7.

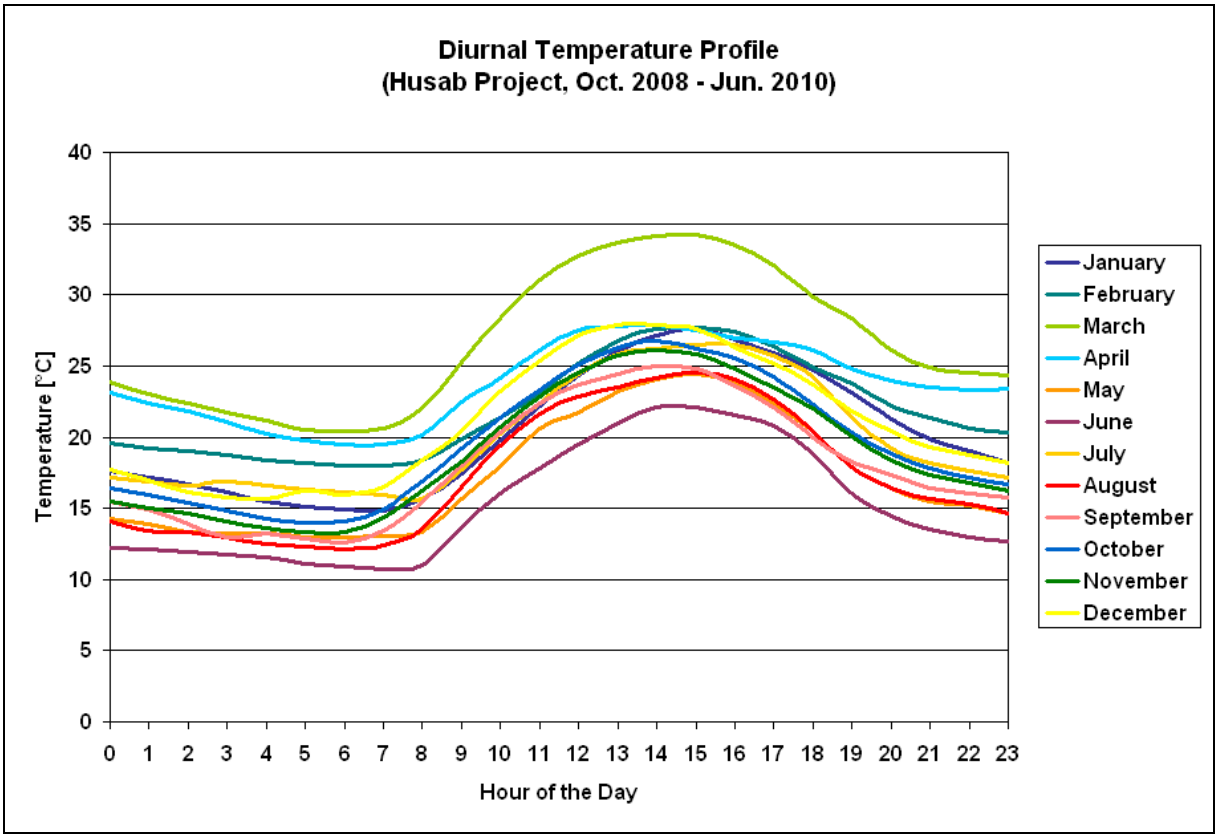

Figure 3-7: Diurnal temperature profile (Husab Project, Oct. 2008 – Jun. 2010)

3.3.4 Rainfall

Precipitation is important to air pollution studies since it represents an effective removal mechanism of atmospheric pollutants. Monthly rainfall recorded at the project area is presented in Figure 3-8.

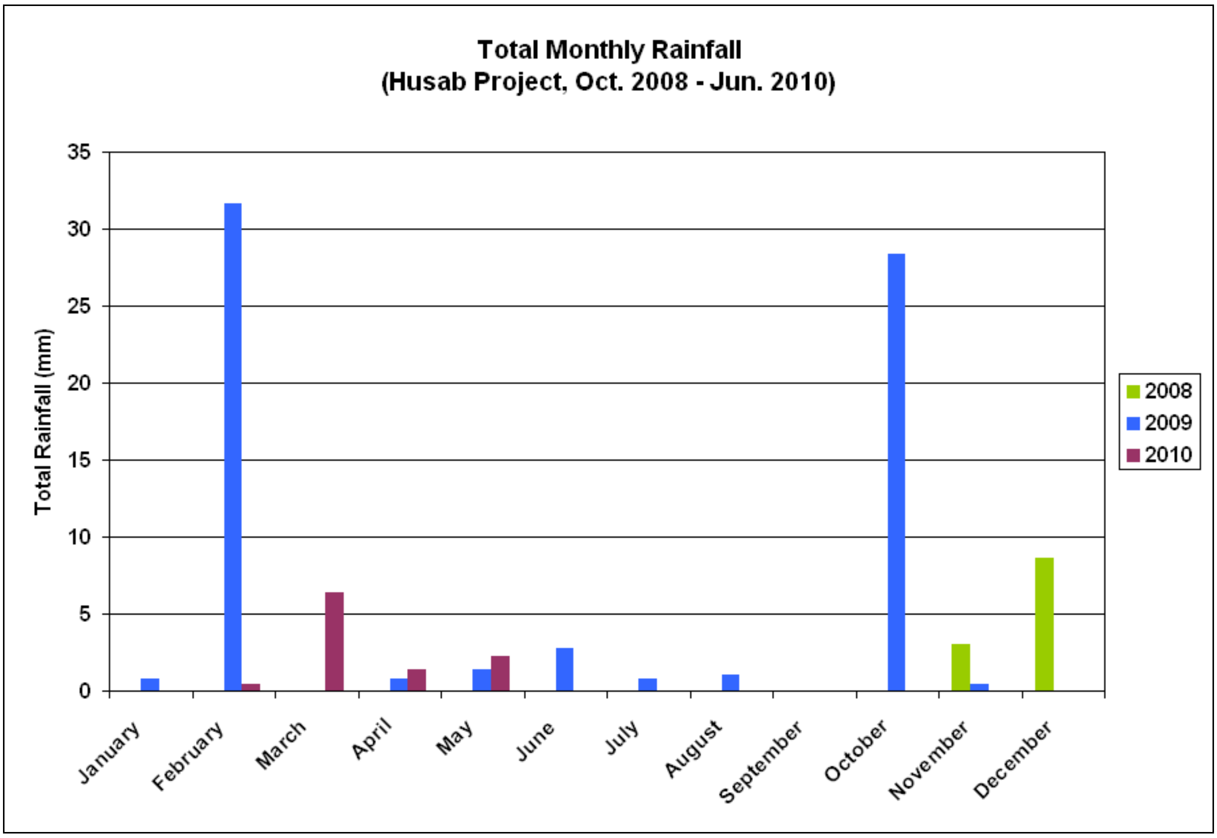

Figure 3-8: **Monthly rainfall (Husab Project, Oct. 2008 – Jun. 2010)**

3.4 Existing Sources of Atmospheric Emissions

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

A comprehensive emissions inventory was developed in the Radiation and Air Quality Study as part of the Strategic Environmental Assessment (SEA) "Central Namib Uranium Rush", Namibia (Liebenberg-Enslin et.al., 2010). This study identified and quantified all existing sources of atmospheric dust emissions in the region including windblown dust from natural mineral sources, dust generation from roads and existing mining activities. Gaseous pollutants may derive from mining operations, vehicle tailpipe emissions and stack releases.

3.4.1 Existing Mining Operations

Current operating mines in the Erongo region include Rössing Uranium Mine, located approximately 5 km to the north (Figure 3-1). Rössing Mine comprises of open-pit mining and is one of the largest uranium mines in the world. The only other operational uranium mine in the region, Langer Heinrich Uranium Mine, is situated ~70 km to the southeast. Valencia Uranium and Trekkopje mines are approved proposed uranium mines in the region and will also utilise opencast mining methods. Trekkopje is located approximately 55 km to the north of the proposed Husab Project, with Valencia located ~40 km to the northeast. The existing Langer Heinrich Uranium Mine is regarded too far away to have a significant influence on the ambient air quality in the vicinity of the proposed Husab Project. However, the close proximity of the Rössing mining operations will add to the cumulative impacts from the Husab Project. The proposed mining operations at the Etango Project ~25 km to the southwest could also add to the cumulative load in future. In addition there are a number of small scale stone operations throughout the region with two large salt works located north of Swakopmund and south of Henties Bay. These sources are however located too far away to have a significant influence on the air quality at the Husab Project site.

Fugitive dust sources associated with mining activities include drilling and blasting operations, materials handling activities, vehicle-entrainment by haul vehicles and wind-blown dust from tailings impoundments and stockpiles. Mining operations represent potentially the most significant sources of fugitive dust emissions (PM_{10} and TSP) with small amounts of respirable dust ($PM_{2.5}$), oxides of nitrogen (NO_x), carbon monoxide (CO), sulphur dioxide (SO_2), methane, and carbon dioxide (CO_2) being released during blasting operations and from mine trucks.

All existing mining sources in the Erongo Region are listed in Table 3-2 (as taken from the Uranium Rush Strategic Environmental Assessment).

Table 3-2: Current large-scale mining operations within the Erongo region (SEA, 2010)

Name of Mine	Owner	Type of mineral Mined	Start Date	Approx. Closure date	Production rate 2010
Rössing Uranium Mine	Rössing Uranium Ltd	Uranium	1976	2020	4,067 t of U_3O_8
Langer Heinrich Uranium	Langer Heinrich Uranium Ltd	Uranium	2006	2024	1,680 t of U_3O_8
Navachab Gold Mine	Anglogold Namibia (Pty) Ltd	Gold	1989	2016	2,126 kg of gold

3.4.2 Vehicle Tailpipe Emissions

There are a number of main roads within the region. The B2 between Swakopmuund and Usakos, and Swakopmund and Henties Bay is most likely the busiest road in the area. Roads within the immediate vicinity of the Husab Project include the unpaved C28 through the Namib Naukluft Park (linking Swakopmund and Windhoek) and the D1991. The road towards the Husab Project turn from the D1991 and is primarily used by the mining contractors and tourists visiting the Big Welwitschia plant near the Husab Project.

Air pollution from vehicle emissions may be grouped into primary and secondary pollutants. Primary pollutants are those emitted directly into the atmosphere, and secondary, those pollutants formed in the atmosphere as a result of chemical reactions, such as hydrolysis, oxidation, or photochemical reactions. The significant primary pollutants emitted by vehicles include CO_2, CO, hydrocarbons (HCs), SO_2, NO_x, particulates and lead. Secondary pollutants include: nitrogen dioxide (NO_2), photochemical oxidants (e.g. ozone), HCs, sulphur acid, sulphates, nitric acid, nitric acid and nitrate aerosols. Toxic hydrocarbons emitted include benzene, 1.2-butadiene, aldehydes and polycyclic aromatic hydrocarbons (PAH). Benzene represents an aromatic HC present in petrol, with 85% to 90% of benzene emissions emanating from the exhaust and the remainder from evaporative losses.

3.4.3 Fugitive Dust Sources

Fugitive dust emissions may occur as a result of vehicle entrained dust from local paved and unpaved roads, and wind erosion from open areas. The extent of particulate emissions from the main roads will depend on the number of vehicles using the roads and on the silt loading on the roadways. The areas prone to wind erosion within the region of the Husab Project are significant. The quantification of these sources is however not a trivial task. The extent, nature and duration of windblown dust is a function of the moisture and silt content of soils, the wind speed, and the extent of exposed areas. A distinct thin crust on the surface binds the material reducing the potential for wind erosion when undisturbed. When disturbed however, very fine loose material is exposed to wind erosion.

The Air Quality study (Liebenberg-Enslin et.al., 2010) as part of the Erongo Region Uranium Rush Strategic Environmental Assessment (SEA, 2010) quantified emissions from both the unpaved and paved public roads in the region and windblown dust from the natural environment. The baseline assessment indicated that the main contributing source to background PM_{10} concentrations and dust fallout rates is windblown dust from natural sources (82% on average). Dust generated by traffic on unpaved roads is the second largest source contributing 13% to the total dust load.

3.5 Ambient Air Quality

Ambient air quality data for the Husab Project are limited to dust concentrations and fallout rates with no information available on gaseous concentrations.

Swakop Uranium Husab Project implemented a dust fallout and PM_{10} monitoring network in the second week of August 2009. The monitoring contract is currently for 1 year but likely to be continued by the mine throughout the life of mine. Data from the monitoring campaign are provided in the sections below for the period August 2009 to July 2010. Figure 3-9 shows the locations of the dust fallout buckets and PM_{10} minivol sampler at the Husab Project.

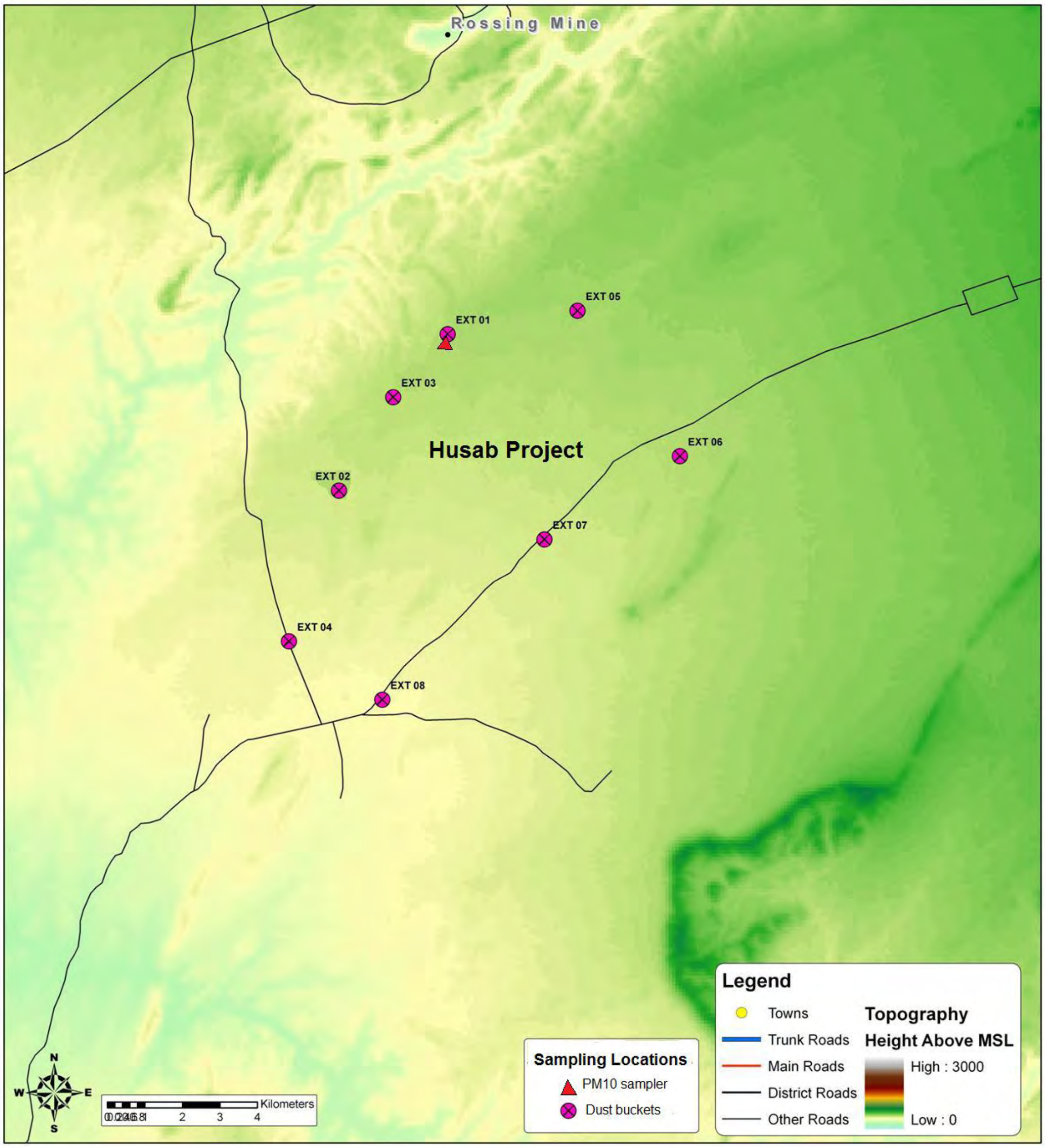

Figure 3-9: Dust fallout and PM_{10} monitoring network at the Husab Project.

3.5.1 Dust Deposition Levels at the Husab Project

The dust fallout network comprises of a total of 8 single dust fallout buckets following the American Society for Testing and Materials standard method for collection and analysis of dustfall (ASTM D1739-98). The buckets were installed on the 11th and 14th of August 2009.

The ASTM method employs a simple device consisting of a cylindrical container (not less than 150 mm in diameter) exposed for one calendar month (30 ±2 days). The method provides for a dry bucket exposure but de-ionised water can be added to ensure the dust remains trapped in the bucket. In areas such as the Erongo region, adding water is not practical due to the high evaporation rate.

The bucket stand should comprise a wind shield at the level of the rim of the bucket to provide an aerodynamic shield. The bucket holder is connected to a 2 m galvanized steel pole, which is either directly attached to a fence post or can be attached to a galvanized steel base plate. This allows for a variety of placement options for the fallout samplers. Exposed buckets, when returned to the laboratories, are rinsed with deionised water to remove residue from the sides of the bucket, and the bucket contents filtered through a coarse (>1 mm) filter to remove insects and other course organic detritus. The sample is then filtered through a pre-weighed paper filter to remove the insoluble fraction, or dust fallout. This residue and filter are dried, and gravimetrically analysed to determine the insoluble fraction (dust fallout).

During the installation of the dust fallout network, one of the Swakop Uranium employees was trained to change the dust fallout buckets every month. Two buckets are provided for each stand and each are clearly marked. Thus, after the first month, the buckets get exchange with the second set. The buckets are taken to the SGS Laboratory in Swakopmund for analysis.

Dust fallout results were available for eleven months (August 2009 to July 2010) and are depicted in Table 3-3 and Figure 3-10. The dust fallout levels are evaluated against the selected criteria for the Husab Project (Section 2.4). On average, dust deposition levels recorded over the eleven months are low and well within the German dust fallout category of 350 mg/m²/day and the SANS limit for residential areas of 600 mg/m²/day. The highest levels were generally recorded at site EXT08 located close to the access road and near the public road to the Big Welwitschia. The single highest level recorded was 256 mg/m²/day during Dec/Jan period at site EXT02 located downwind (southwest) from the exploration activities. The lowest dust fallout levels were recorded at EXT06, located near the north-eastern boundary where there is not much activity at the moment. A significant increase in dust fallout is noted for the period June – July 2010 at all the sites (even though it is still below the dust-fall criteria). The regional dust fallout (Liebenberg-Enslin et.al., 2010) does not reflect a similar trend for the same period and can be a result of the increased drilling operations at the Husab Project during this period.

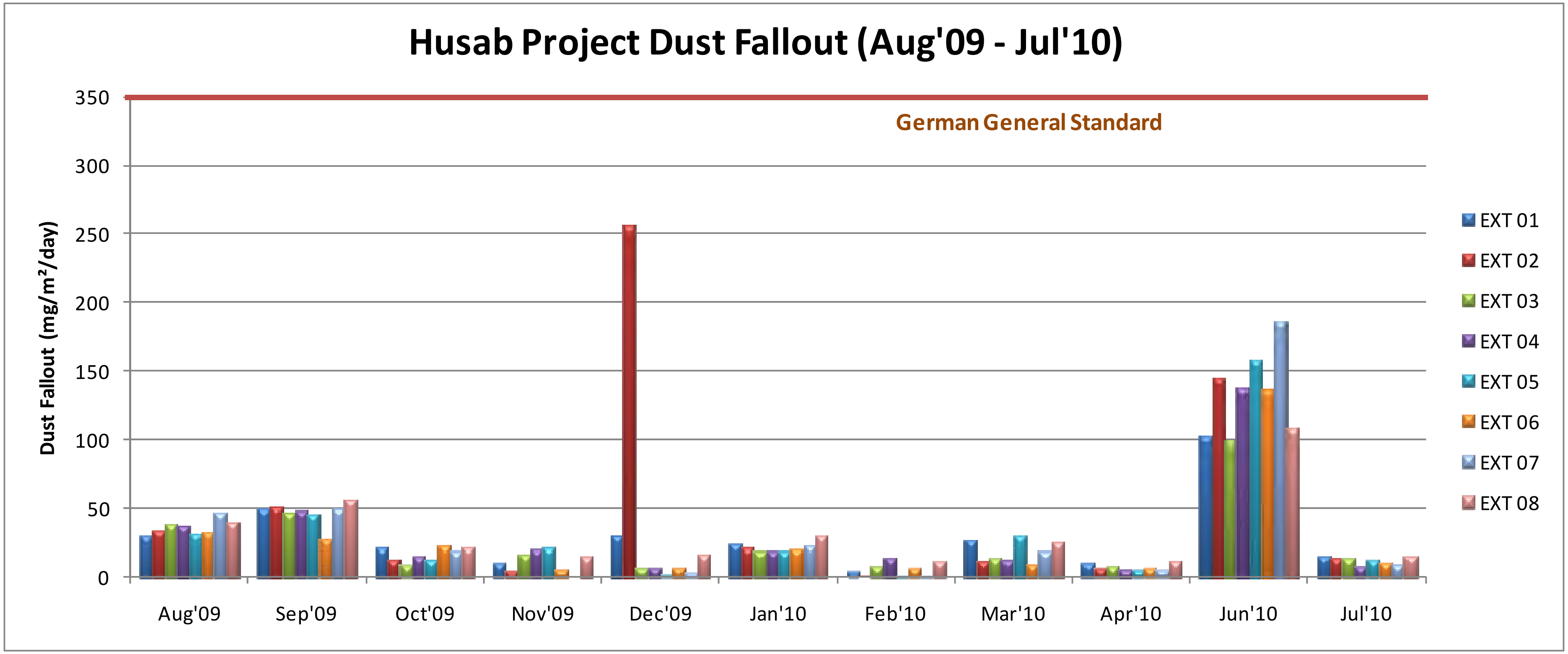

Figure 3-10: Dust deposition levels at the eight locations measured during the months of August 2009 to July 2010

Table 3-3: Dust deposition levels for the months of August 2009 to June 2010

Bucket ID	Dust Deposition levels (mg/m^2-day)										
	Aug'09	Sep'09	Oct'09	Nov'09	Dec'09	Jan'10	Feb'10	Mar'10	Apr'10(a)	Jun'10	Jul'10
EXT01	30	49	22	11	31	24	4	27	10	104	16
EXT02	34	51	13	5	256	21	2	12	6	145	14
EXT03	39	47	9	17	7	19	8	14	8	100	14
EXT04	38	48	16	21	7	20	15	13	6	138	8
EXT05	31	45	13	21	2	19	1	30	5	159	13
EXT06	33	28	22	6	7	21	7	10	7	136	11
EXT07	47	50	19	0	3	23	1	19	5	187	10
EXT08	40	56	22	15	17	30	11	25	12	108	16

Notes: (a) April represents two months (April and May) of dust fallout recorded. Exposed for 60 days.

3.5.2 Ambient PM_{10} concentrations at the Husab Project

The PM_{10} sampler was installed on the 11th of August at the weather station at the Husab Project with sampling done every 6th day. During the first two quarters, all the results were either negative or very low due to damaged fibres. Airshed conducted a site visit beginning of June 2010 to assess the monitoring network and procedures. The Swakop Uranium personnel conducting the exchanges follow the correct procedures but it was found that the filter cassette, when closed too tightly, cause damage to the filters. Airshed agreed to investigate this further. In the interim, causing were to be taken in not to close the filter cassette too tightly.

The Erongo SEA Air Quality report provided background PM_{10} concentrations for the Etango site located ~30 km southwest of the Husab project. The results over the period March to November 2009 resulted in a period average PM_{10} concentration of 40 µg/m³ for the nine-months. The highest daily concentration recorded is 329 µg/m³ and the WHO IT-3 of 75 µg/m³ was exceeded 11% of the time.

The simulated PM_{10} concentrations from the SEA project correlated well with the measurements at the Etango sampler location. Thus, the predicted PM_{10} concentrations at the Husab Project are regarded representative of the background air quality. The daily predicted concentration at the Husab project due to background sources (i.e. wind erosion from natural environment, unpaved roads and mining operations of Rössing and Langer Heinrich) is 220 µg/m³ with the annual average at 60 µg/m³. The predicted GLC at Arandis, Rössing Uranium and the Big Welwitschia are listed in Table 3-4, with the plots provided in Figures 3-11 and 3-12 for highest daily and annual averages, respectively. Thus, the predicted background is already in exceedance of the evaluation criteria of 75 µg/m³ and 30 µg/m³, for highest daily and annual averages respectively.

Table 3-4: Predicted baseline(a) PM10 ground level concentrations and dustfall levels (SEA, 2010)

Receptor	Annual Average PM10 GLC (µg/m³)(b)	Daily Average PM10 GLC (µg/m³)(c) (days of exceedence indicated in brackets)
Arandis	65	242 (81)
Rössing Uranium Mine (Southwest boundary)	160	610 (275)
Big Welwitschia	90	550 (125)

Notes:

(a) Includes the following sources of emission: background wind erosion, fugitive dust from paved and unpaved public roads, Rössing Uranium Mine and Langer Heinrich Uranium Mine.

(b) WHO IT-3 guideline for annual averages of 30 µg/m³

(c) WHO IT-3 guideline for daily averages of 75 µg/m³

(d) German standard of 350 mg/m²/day and SANS limit of 600 mg/m²/day

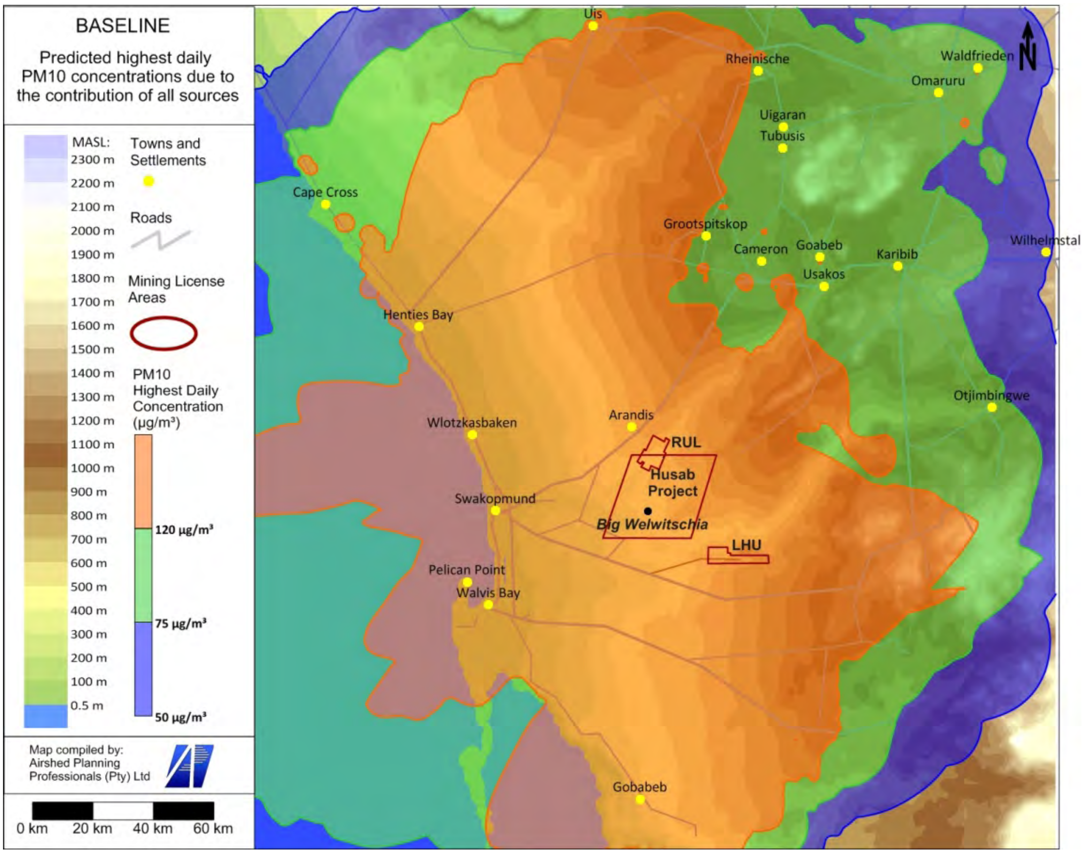

Figure 3-11: Predicted Baseline PM10 daily average concentrations

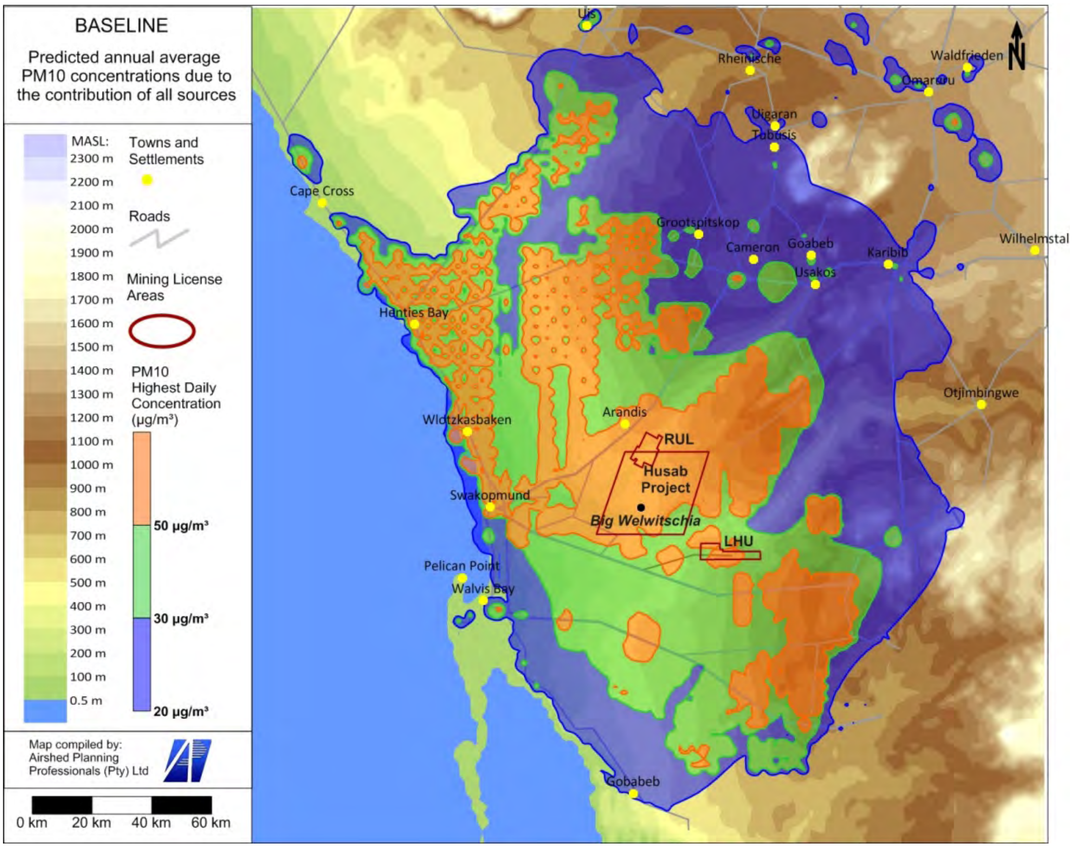

Figure 3-12: Predicted Baseline PM10 annual average concentrations

4 Impact Assessment

The Swakop Uranium Husab Project will produce around 8 000 tonnes of uranium oxide through conventional load and haul open pit mining and ore processing operations. Operations will also include a sulphur plant for the production of sulphuric acid (H_2SO_4). Potential sources of atmospheric emission were identified from process description provided by the client.

Emissions and air quality impacts were assessed for the construction phase and the operational phase. Year 2017, being the year with the highest mining and production rates, was selected to be representative of the worst-case operational phase. Emissions and impacts were also assessed without and with fugitive dust mitigation measures in place.

The proposed site layout as used in the air quality assessment is provided in Figure 4-1.

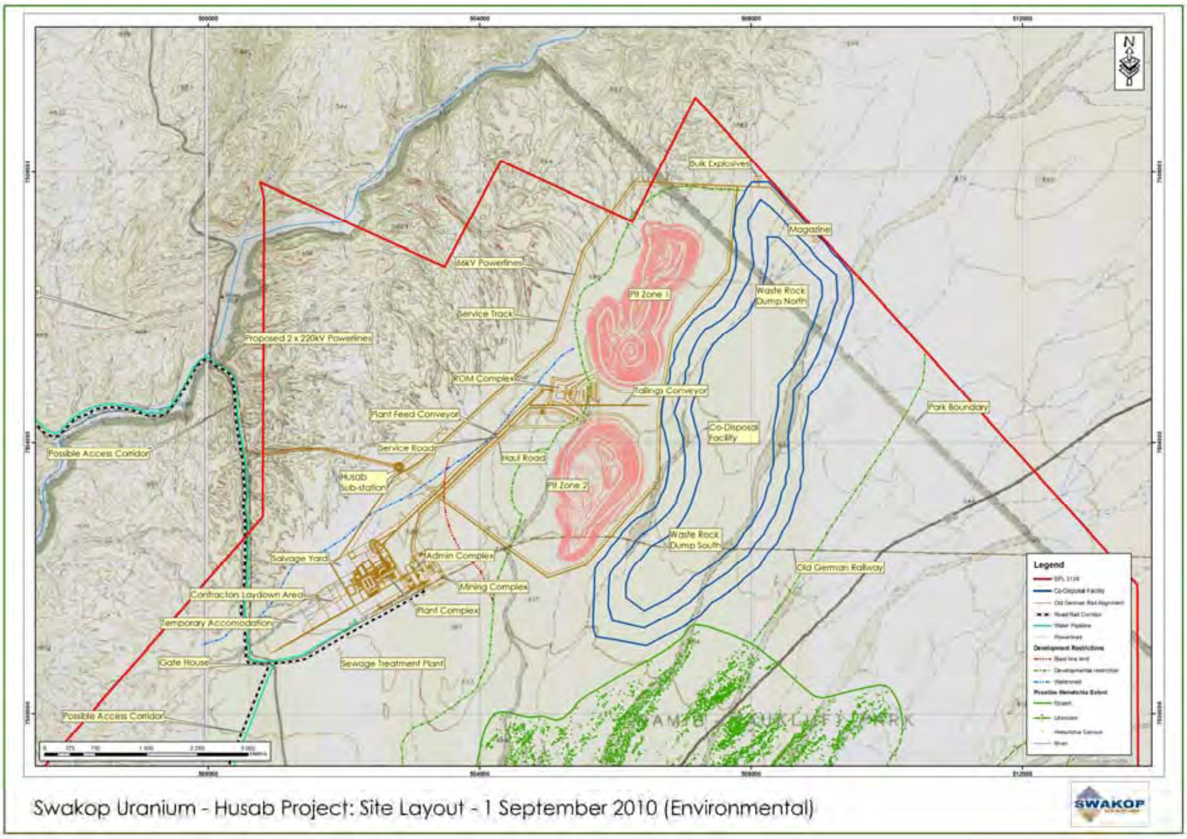

Figure 4-1: Proposed site layout (Metago, 2010)

4.1 Emissions Inventory

Based on the process description for the proposed Husab Project operations, as provided by Metago, the following potential sources of atmospheric emission were identified:

- fugitive dust emissions from construction related emissions;
- fugitive dust emissions as a result of drilling and blasting;

- fugitive dust emissions as a result of handling of ore and waste;
- fugitive dust entrained by vehicles travelling unpaved roads;
- fugitive dust emissions from the crushing and screening of ore;
- windblown fugitive dust from tailings storage facilities;
- mine fleet particulate and gaseous exhaust emissions;
- gaseous emissions from the sulphuric acid plant.

4.1.1 Fugitive Dust Emissions

Fugitive dust emissions as a result of vehicle-entrained dust from unpaved roads, material handling operations, crushing and screening operations, drilling and blasting were quantified through the application of emission factors which associate the quantity of a pollutant to the activity associated with the release of that pollutant. Due to the absence of locally generated emission factors, use was made of emission factors including those published by the US Environmental Protection Agency (US-EPA) in its AP-42 document Compilation of Air Pollution Emission Factors and the Australian NPI Emission Estimation Technique Manual for Mining. A detailed discussion of these emission factors and equations are provided in Appendix A. Mining rates used in the calculation of fugitive dust emissions for the representative operational phase are presented in Table 4-1.

Fugitive dust emissions were estimated assuming both unmitigated and mitigated operations. Assumptions pertaining to the control of fugitive dust emissions were based on mitigation and efficiency data provided in the Australian NPI Emission Estimation Technique Manual for Mining (NPI, 2008). An additional 5% and 50% control efficiency was applied to in-pit PM10 and TSP emissions respectively to account for pit retention (NPI, 2001).

Table 4-1: Mining rates applied in the estimation of fugitive dust emissions

	Year 2017	
Material	**Ore**	**Waste**
Zone 1	14.1 Mtpa	85.4 Mtpa
Zone 2	1 Mtpa	26.3 Mtpa
Total	**15.1 Mtpa**	**112 7Mtpa**

4.1.1.1 Construction

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. A list of all the potential dust generation activities expected during the construction phase is provided in Table 4-2.

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 4-2, for emissions quantification and dispersion simulations. Due to the lack of detailed information, emissions from the construction of infrastructure were instead estimated on an area wide basis. The quantity of dust emissions was assumed to be proportional to the area of land being worked and the level of construction activity.

Table 4-2: Typical fugitive dust impacts and associated activities during construction

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

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 **2.69 Mg/hectare-month of activity**.

The PM_{10} fraction was assumed at 35% of the US-EPA total suspended particulate factor. It is applicable to construction operations with active large scale earth moving operations. These emission factors are most applicable to construction operations with (i) medium activity levels, (ii) moderate silt contents, and (iii) semi-arid climates. It was assumed that construction activities will take place 9 hours per day, 5 days per week over a 12 month period. A control efficiency of 50% for dust suppression using water sprays (NPI, 2001) was applied to mitigated emissions. Table 4-3 summarises expected emissions estimated for construction activities that included the following areas:

- Zone 1 pit area;
- Zone 2 pit area;
- unpaved haul roads to the waste dump and ROM complex;
- conveyor from ROM complex to processing plant;
- processing plant; and
- buildings and infrastructure.

Table 4-3: Estimated construction related emissions

Scenario	Particulate Emissions (tons per annum)			
	Unmitigated		Mitigated[a]	
	PM_{10}	TSP	PM_{10}	TSP
Construction	2 080	5 950	1 040	2 980

Notes:
(e) Water sprays, mitigation efficiency 50%

4.1.1.2 Dust from 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 (Appendix A). It was indicated that a maximum of 200 holes will be drilled per blast area of 8000 m². The drill rigs will be equipped with water sprays and it was assumed to result in 70% control of dust emissions (NPI, 2001). Emissions calculated to result from drilling activities are summarised in Table 4-4.

Table 4-4: Estimated emissions from drilling operations

Scenario	Particulate Emissions (tons per annum)			
	Unmitigated		Mitigated[a]	
	PM_{10}[b]	TSP[b]	PM_{10}	TSP
Drilling (2017)	43.0	43.1	12.9	12.9

Notes:

(a) Water sprays, mitigation efficiency 70%
(b) Pit retention: PM10 – 5%, TSP – 50%

4.1.1.3 Dust from Blasting Operations

It was assumed that blasting will take twice a day, once in Zone 1 and once in Zone 2.

Fugitive dust emissions as a result of in-pit blasting operations were quantified using the Australian NPI emission factor equation for blasting (Appendix A). It was indicated that a maximum area of 8000 m^2 will be blasted per event and that the hole depth will be 12 m. Except for the effects of pit retention, no mitigation was applied to blasting emissions. Emissions calculated to result from blasting activities are summarised in Table 4-5.

Table 4-5: Estimated emissions from blasting operations

Scenario	Particulate Emissions (tons per annum)	
	Unmitigated	
	PM_{10}[a]	TSP[a]
Blasting (2017)	1 880	1 900

Notes:
(a) Pit retention: PM10 – 5%, TSP – 50%

4.1.1.4 Vehicle Entrained Dust from Unpaved Roads

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

- In pit haulage of ore and waste;
- Transport of ore from open pits to the ROM complex;
- Transport of waste from open pits to the waste dump; and
- Transport of product from site

Fugitive dust emissions from unpaved roads were calculated using the US EPA predictive emission factor equation (Equation 1, Appendix A) assuming haulage of the material volumes as given in Table

4-1. In pit and surface haul road locations for 2017 provided. An on-site haul road network of a total of approximately 30 km in length was used in the calculations and all roads were assumed to be 40 m wide. Vehicles used for the delivery of raw materials and transport of product from site will have a capacity of approximately 250 tons and an average vehicle weight of 560 tons. Trucks used for the transport of final product were assumed have a capacity of 28 tons. The percentage road surface material less than 75 µm in diameter (silt content, 20%) was used as determined from site specific particle size analysis of roads at similar uranium mining operations in the area. It was assumed that water trucks will be used on site to suppress dust from unpaved roads. Water used in combination with chemical suppressant has a reported efficiency of 90%. Estimated fugitive dust emissions rates due to vehicle-entrained dust from the unpaved roads are given in Table 4-6.

Table 4-6: Estimated emissions from unpaved roads

Scenario	Particulate Emissions (tons per annum)			
	Unmitigated		Mitigated[(a)]	
	PM_{10}[(b)]	TSP[(b)]	PM_{10}	TSP
Unpaved roads (2017)	19 700	43 100	1 970	4 310

Notes:
(a) Water and chemical dust suppression, mitigation efficiency 90%
(b) In pit haul road emissions subject to pit retention: PM10 – 5%, TSP – 50%

4.1.1.5 Dust from Materials Handling Activities

Materials handling points at the proposed operation include front end loader (FEL) material handling activities, 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 2, Appendix A) was used to estimate emissions from material transfer operations.

The material volumes used in the calculation of materials handling emissions are presented in Table 4-1. The moisture content of ore and waste of 1% and 2% respectively, was provided by the client. Water sprays with a general control efficiency of 50% (NPI, 2001) were applied in the estimation of mitigated emissions. Emissions from materials handling points were calculated using the hourly average wind speed of 2.8 m/s measured on site. Expected materials handling emissions are summarised in Table 4-7.

Table 4-7: Estimated emissions from materials handling activities

Scenario	Particulate Emissions (tons per annum)			
	Unmitigated		Mitigated	
	PM_{10} [(b)]	TSP [(b)]	PM_{10}	TSP
Materials Handling (2017)	426	663	213	331

Notes:
(a) Water sprays, mitigation efficiency 50%
(b) In pit materials handling emissions subject to pit retention: PM10 – 5%, TSP – 50%

4.1.1.6 Dust from 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 the re-entrained of dust emitted by vehicles or by the wind at a later date. The large percentage of fines in this deposited material enhances the potential for it to become airborne. Fugitive dust emissions due to the crushing and screening operations for mine were quantified using US-EPA single valued emission factors for such operations (Table 8-1, Appendix A).

Primary crushing and screening emissions were quantified. Emissions were estimated for low moisture ore volumes provided in Table 4-1. Mitigated emissions were calculated assuming a control efficiency of 83% (wet ore and hooding with venture scrubbers) (NPI, 2001). Estimated emissions from crushing and screening operations are provided in Table 4-8.

Table 4-8: Estimated emissions from crushing and screening

Scenario	Particulate Emissions (tons per annum)			
	Unmitigated		Mitigated [(a)]	
	PM_{10}	TSP	PM_{10}	TSP
Crushing and Screening (2017)	302	3 020	51.3	513

Notes:
(a) Dust extraction with venture scrubbers, control efficiency 75%. Water sprays to keep ore wet, control efficiency 50%. Assumed 83% control efficiency due to wet ore with scrubbers.

4.1.1.7 Windblown Dust

A discussion about the estimation of wind erosion emissions from areas with fine material (diameter less than 2mm) using the ADDAS model is provided in Appendix A. The waste to tailings ratio of the waste disposal dump was given as 7:1. Waste rock and tailings was assumed to be uniformly distributed through the dump. Particle size analyses were provided by the client. From the particle data, wind erosion potential from waste rock was considered negligible. Source parameters used in the emissions estimation and simulations for wind erosion of the waste dump is given in Table 4-9. Wind erosion emission estimates from the waste dump are provided in Table 4-10.

Table 4-9: Parameters pertaining to windblown dust emissions from the waste dump

Parameter	Waste Dump
Waste dump area	12.7 km²
% of surface area available for wind erosion	13%[(a)]
Surface material moisture	less than 5%
Material bulk density	2 100 kg/m³
Material particle density	2.65 g/cm³

Notes:
(a) 7:1 waste rock to tailings disposal ratio.

Table 4-10: Estimated windblown dust emissions

Scenario	Particulate Emissions (tons per annum)	
	Unmitigated	
	PM_{10}	TSP
Wind Erosion (2017)	349	508

4.1.2 Mine Fleet Gaseous Exhaust Emissions

Exhaust emissions from the mining fleet were calculated based on the maximum annual projected fuel consumption rate of 78.7 million litres and emission factors as published in the NPI Emission Estimation Technique Manual for Combustion Engines (NPI, 2008) (Table 4-11).

Table 4-11: Emission factors for diesel industrial vehicle exhaust emissions (NPI, 2008)

Pollutant	Emission Factor (kg/L)
CO	1.41 E -02
DPM	1.38 E -03
NO_x	3.27 E -02
SO_2[(a)]	1.20 E -03
VOC	1.55 E -03

Notes:
(a) SO_2 emission factor was based on 500 ppm sulphur content in diesel fuel.

Table 4-12: Estimated maximum diesel industrial vehicle exhaust emissions

Pollutant	Emission (tons per annum)
CO	1 150
DPM	151
NO_x	2 660
SO_2	94.3
VOC	122

4.1.3 Gaseous Emissions from Sulphuric Acid Production

The acid plant will produce approximately 420 000 tons of H_2SO_4 per year. The amount of SO_2 released from the sulphur plant stack is an inverse function of the sulphur conversion efficiency (the amount of SO_2 oxidised to SO_3). The plant will be designed as a double contact absorption process and will include a scrubber to minimise SO_2 emissions. The controlled SO_2 emission factor of 2 kg/ton H_2SO_4 produced was therefore applied in the current study. An SO_3 emission factor of 0.065 kg/ton H_2SO_4 produced was applied in the calculations. Stack parameters pertaining to sulphur plant are provided in Table 4-13. NO_x emissions were calculated based on the best available technology (BAT) emission limit of 30 mg/Nm³.

Table 4-13: Sulphur plant stack parameters and emission factors

	Pollutant	Parameters & Emissions Factors
Stack Parameters	Stack Height	50 m
	Stack Diameter	3.5 m
	Gas Exit Velocity	3.24 m/s
	Gas Exit Temperature	75 °C
Emission Factors	NO_x	30 mg/Nm³
	SO_2	2 kg/ton H_2SO_4
	SO_3	0.065 kg/ton H_2SO_4

4.1.4 Other Emissions

The potential exists for the generation of other gaseous emissions from the processing of uranium ore. These may include emissions from the leaching process and emissions from mixer-settlers. Information pertaining to emissions from these processes is limited and could not be included in the emissions inventory. Impacts from these sources are however expected to be limited.

4.1.5 Summary of Emissions

4.1.5.1 Construction Phase

Unmitigated PM_{10} and TSP emissions from construction activities amounted to 2 080 and 5 950 tpa respectively. With mitigation measures (50% control efficiency) in place, estimated PM_{10} and TSP emissions reduced to 1 040 and 2 980 tpa respectively.

4.1.5.2 Operational Phase (2017)

A summary of estimated particulate emissions for the operational phase is provided in Table 4-14.

TSP emissions without any mitigation applied to fugitive dust sources amounted to 44 000 tpa. Unpaved road emissions were estimated to contribute most significantly (97%) to unmitigated TSP emissions. Mitigation of fugitive dust emissions reduced total TSP emissions to 5 140 tpa (88% reduction) with emissions from unpaved haul roads contributing most significantly (84%) to the total.

PM_{10} emissions without and with mitigation amounted to 20 500 and 2 530 tpa respectively. Mitigation measures resulted in an 88% reduction in fugitive PM_{10} emissions. Emissions from unpaved haul roads were estimated to be the main contributing source to both unmitigated and mitigated PM_{10} emissions (96% and 78% respectively).

Table 4-14: Summary of estimated particulate emissions – Year 2017 of operation

Summary of estimated particulate emissions – Year 2017 of operation								
Source Group	Unmitigated				Mitigated(a)			
	PM_{10}(b)		TSP(b)		PM_{10}		TSP	
	Estimated Emission (tpa)	Contribution (%)	Estimated Emission (tpa)	Contribution (%)	Estimated Emission (tpa)	Contribution (%)	Estimated Emission (tpa)	Contribution (%)
Blasting	1 880	9.16%	1 900	4.29%	1 880	74.2%	1 900	36.9%
Crushing	302	1.47%	3 020	6.82%	51.3	2.03%	513	9.98%
Drilling	43.0	0.21%	43.1	0.10%	12.9	0.51%	12.9	0.25%
Materials Handling	399	1.94%	622	1.40%	199	7.88%	311	6.04%
Unpaved Roads	19 700	96.2%	43 100	97.4%	1 970	77.9%	4 310	83.9%
Wind Erosion	347	1.69%	506	1.14%	347	13.71%	506	9.84%
Total	**20 500**	**100%**	**44 300**	**100%**	**2 530**	**100%**	**5 140**	**100%**

Notes:

(a) Mitigation measures applied:

i. Crushing and Screening – Water sprays on ore and hooding with venture scrubbers, 83% control efficiency
ii. Drilling – Water sprays, 70% control efficiency
iii. Materials handling – Water sprays, 50% control efficiency
iv. Unpaved roads – Water sprays and(or) dust suppressants, 90% control efficiency

(b) In pit sources subject to pit retention factors: PM10 – 5%, TSP – 50%

4.1.5.3 Gaseous Emissions

A summary of estimated gaseous emissions as a result of mining fleet exhaust and sulphuric acid production are provided in Table 4-15.

Table 4-15: Summary of estimated gaseous emissions

Source Group	Estimated Maximum Gaseous Emissions (tpa)					
	CO	DPM	NO_x	SO_2	SO_3	VOC
Sulphur Plant	-	-	21.7	805	26.2	-
Mine Fleet Exhaust	1 150	151	2 660	94.3	-	122
Total	**1 150**	**151**	**2 680**	**900**	**26.2**	**122**

4.2 Dispersion Model Selection and Data Requirements

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

For the purpose of the current study, it was decided to use the Atmospheric Dispersion Modelling System (ADMS) developed by the Cambridge Environmental Research Consultants (CERC). CERC was established in 1986, with the aim of making use of new developments in environmental research from Cambridge University and elsewhere for practical purposes. CERC's leading position in environment software development and associated consultancy has been achieved by encapsulating advanced scientific research into a number of computer models which include ADMS 4. This model simulates a wide range of buoyant and passive releases to the atmosphere either individually or in combination. It has been the subject of a number of inter-model comparisons (CERC, 2000), one conclusion of which is that it tends provide conservative values under unstable atmospheric conditions in that it predicts higher concentrations than the older models close to the source.

ADMS 4 is a new generation air dispersion model which differs from the regulatory models traditionally used in a number of aspects, the most important of which are the description of atmospheric stability as a continuum rather than discrete classes (the atmospheric boundary layer properties are described by two parameters; the boundary layer depth and the Monin-Obukhov length, rather than in terms of the single parameter Pasquill Class) and in allowing more realistic asymmetric plume behaviour under unstable atmospheric conditions. Dispersion under convective meteorological conditions uses a skewed Gaussian concentration distribution (shown by validation studies to be a better representation than a symmetric Gaussian expression).

ADMS 4 is currently used in many countries worldwide and users of the model include Environmental Agencies in the UK and Wales, the Scottish Environmental Protection Agency (SEPA) and regulatory authorities including the UK Health and Safety Executive (HSE). Concentration and deposition distributions for various averaging periods may be calculated. 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. For the purposes of this report, the shortest time period modelled is one hour.

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. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model description of atmospheric physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere. Nevertheless, dispersion modelling is generally accepted as a valid tool to quantify and analyse the atmospheric impact of existing installations and for determination of the impact of future installations. Input data types required for the ADMS model include: source data, meteorological data, terrain data and information on the nature of the receptor grid.

4.2.1 Meteorological Requirements

For the purpose of the current study use was made of data recorded the on-site meteorological station for the period October 2008 to June 2010 (Section 3.2).

4.2.2 Source Data Requirements

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

- Stacks – modelled as point sources;
- Construction – modelled as area sources;
- Unpaved roads – modelled as area sources;
- Wind erosion – modelled as area sources;
- Materials handling and crushing – modelled as volume sources;
- Drilling – modelled as area sources; and
- Blasting – modelled as point sources.

4.2.3 Modelling Domain

The dispersion of pollutants expected to arise from proposed operations was modelled for an area covering approximately 35 km (east-west) by 35 km (north-south). The area was divided into a grid matrix with a resolution of 500 m by 500 m, with the proposed operation located approximately in the centre of the receptor area. Arandis, the closest residential area to the site (Figure 3-1) was specified as a receptor point. With the potential impacts on the neighbouring Rössing Uranium Mine and the Big Welwitschia as a tourist location, these were also added as receptors. ADMS simulates ground-level concentrations for each of the grid receptor points.

4.3 Dispersion Model Results and Assessment

Dispersion modelling was undertaken to determine highest hourly, highest daily and annual average ground level concentrations for each pollutant. These averaging periods were selected to facilitate the comparison of predicted pollutant concentrations with relevant air quality guidelines and health effect screening levels.

The dispersion modelling scenarios included in the study were:

- **Construction Phase** – Including fugitive dust emissions from construction related activities.
- **Operational Phase (2017)** – Including fugitive dust emissions from mining related activities, gaseous emissions from sulphuric acid production and mining fleet vehicle exhaust emissions.

Both unmitigated and mitigated options were simulated. Mitigation accounted for include:

- Crushing and Screening – Wet ore and hooding with venture scrubbers, 83% control efficiency
- Drilling – Water sprays, 70% control efficiency
- Materials handling – Water sprays, 50% control efficiency
- Unpaved roads – Water sprays and dust suppressants, combined 90% control efficiency

Ground level concentration (GLC) isopleths plots presented in this section depict interpolated values from the concentrations predicted by ADMS for each of the receptor grid points specified. Plots reflecting hourly (daily) and averaging periods contain only the 99.99^{th} (99.73^{th}) percentile of predicted ground level concentrations, for those averaging periods, over the entire period for which simulations were undertaken. It is therefore possible that even though a high hourly (daily) average concentration is predicted to occur at certain locations, that this may only be true for one hour (day) during the year.

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 guidelines and standards are therefore not occupation heath indicators but applicable to areas where the general public has access.

Arandis was identified as the closest residential area to the Husab Project and predicted GLC are reported. Predicted GLC were screened against the selected health and environmental criteria as depicted in Table 2-11 (Section 2.4). The significance of the impacts are reflected as the number of allowable exceedances of the selected limits as described in Table 2-11.

4.3.1 Predicted PM_{10} Concentrations and Impacts

The cumulative impacts were derived based on the methodology as proposed by the UK Environment Agency (MFE, 2001). Whereas annual average concentrations can be added together for cumulative representation, daily averages cannot. This is because the location of highest daily concentrations may not be the same for the baseline and incremental simulations. The methodology therefore proposes adding double the annual baseline concentration to the incremental daily concentration. Thus, the cumulative daily concentrations should be viewed as an average daily GLC, and not the highest daily GLC as with incremental.

4.3.1.1 Construction Phase

Predicted PM_{10} GLCs for the construction phase are provided in Table 4-16, reflecting both incremental (Husab Project alone) and cumulative (predicted baseline as discussed under Section 3.5). Isopleth plots indicating PM_{10} impact areas are presented in Figure 4-2 to Figure 4-11 for the Husab Project only.

Incremental: Annual average ground level PM_{10} concentrations for unmitigated construction activities were within the limit of 40 µg/m^3 in the mining boundary (Figure 4-2). With mitigation applied, the area of impact reduces significantly (Figure 4-3). For highest daily GLCs the predicted impacts are high when no mitigation is applied, exceeding 75 µg/m^3 up to 10km from mining activities (Figure 4-4). When mitigation measures are applied, the impact area shrinks to fall mainly within the mine boundary (Figure 4-5).

Cumulative: The predicted incremental impacts at Arandis were within the required ambient air quality limits for both annual and daily averages as depicted in Table 4-16. Cumulatively, the predicted GLCs exceeded both the annual and daily WHO IT-3 guidelines at all three receptors (i.e. Arandis, Rössing Uranium Mine and the Big Welwitschia). With mitigation in place, a slight reduction at all three receptors are shown, but still remaining in non-compliance.

Table 4-16: Predicted PM_{10} concentrations at Arandis, Rössing Uranium Mine and the Big Welwitschia from Construction activities

Sensitive / Discrete Receptor	Predicted Incremental GLC (µg/m³)[a]			Predicted Cumulative GLC (µg/m³)[b]	
	Annual Average	Highest Daily Average	FOE (days)	Annual Average	Highest Daily Average
	Unmitigated Construction Phase				
Arandis	1	8	0	66	138
Rössing Uranium Mine (SW Boundary)	1	21	0	161	341
Big Welwitschia	2	40	0	92	220
	Mitigated Construction Phase				
Arandis	0.6	4	0	66	134
Rössing Uranium Mine (SW Boundary)	0.4	10	0	160	330
Big Welwitschia	1	20	0	91	200

Notes:

(a) Impact assessment criteria:

i. Annual PM_{10} Concentrations – WHO IT3 guideline, 30 µg/m³

ii. Daily PM_{10} Concentrations – WHO IT3 guideline, 75 µg/m ³ with permitted frequency of exceedence of 4 days per year (as per SA Standard)

(b) Predicted annual average baseline GLCs from Table 3-5 were added to predicted incremental annual average and twice the predicted annual average baseline GLCs were added to highest daily PM10 GLCs as per New Zeeland Ministry for the Environment methodology (MFE, 2001).

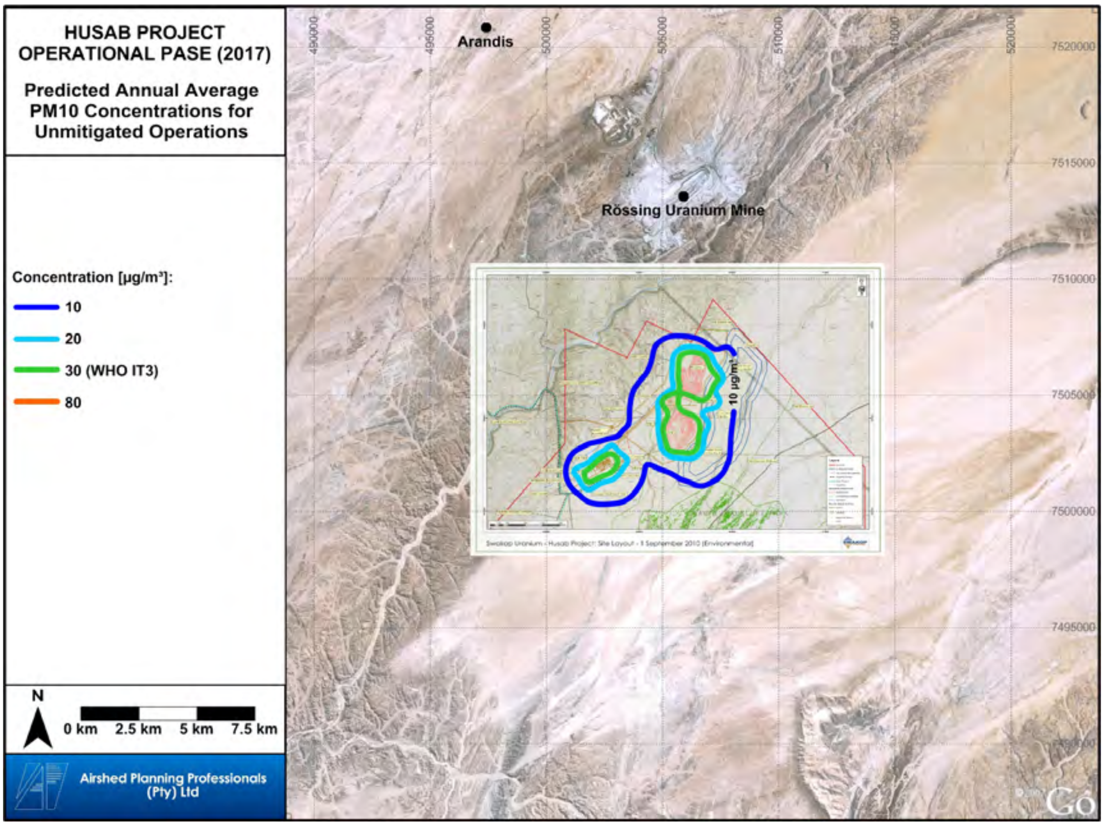

Figure 4-2: Construction Phase – Unmitigated annual average PM_{10} concentrations

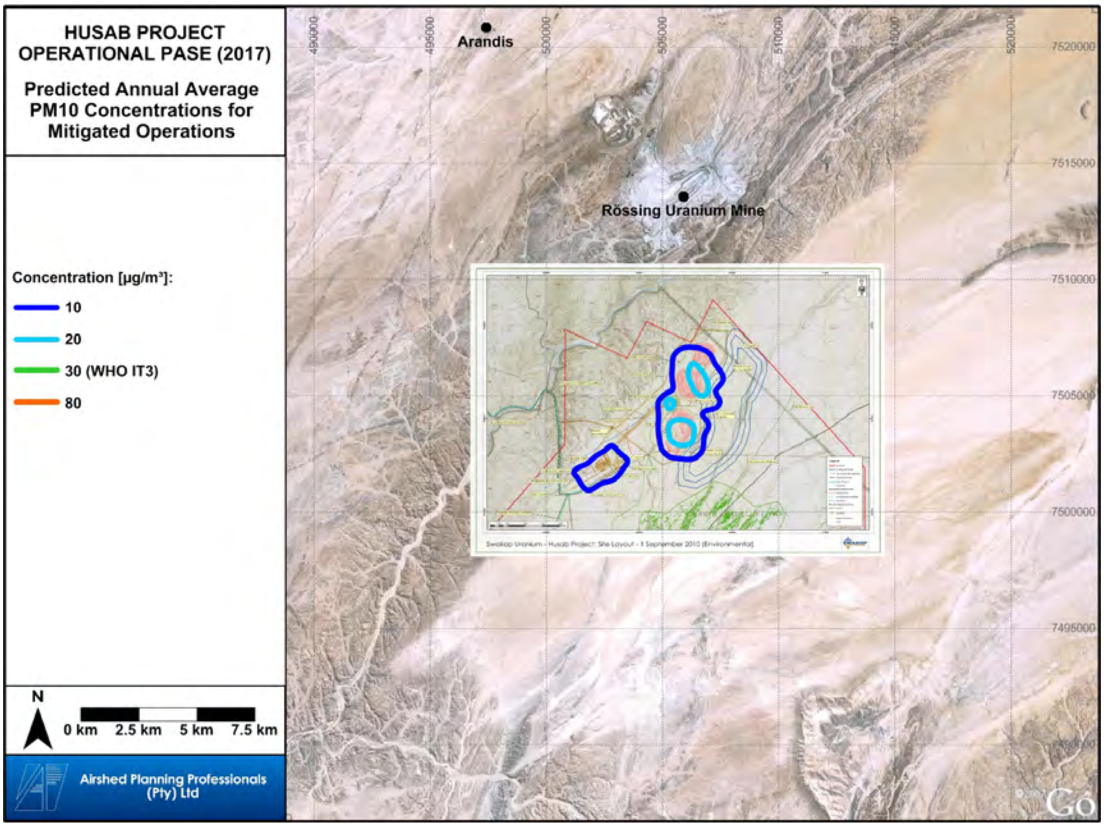

Figure 4-3: **Construction Phase – Mitigated annual average PM_{10} concentrations**

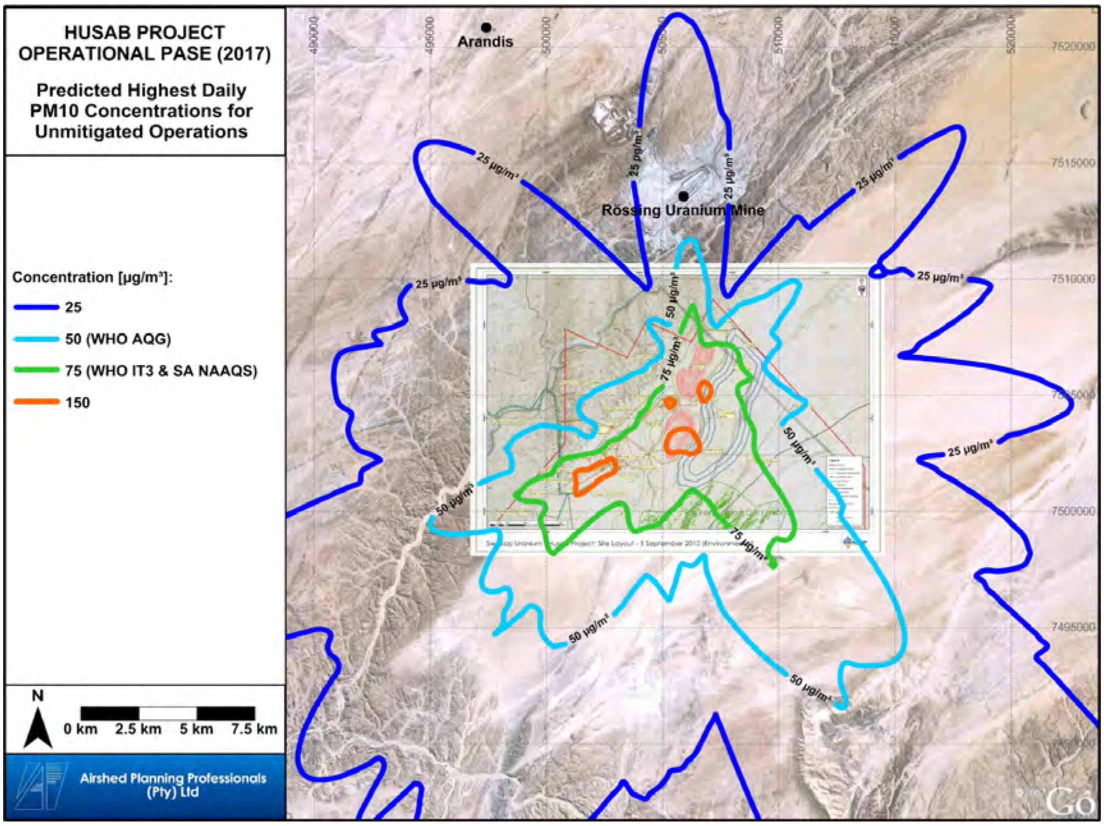

Figure 4-4: **Construction Phase – Unmitigated highest daily PM_{10} concentrations**

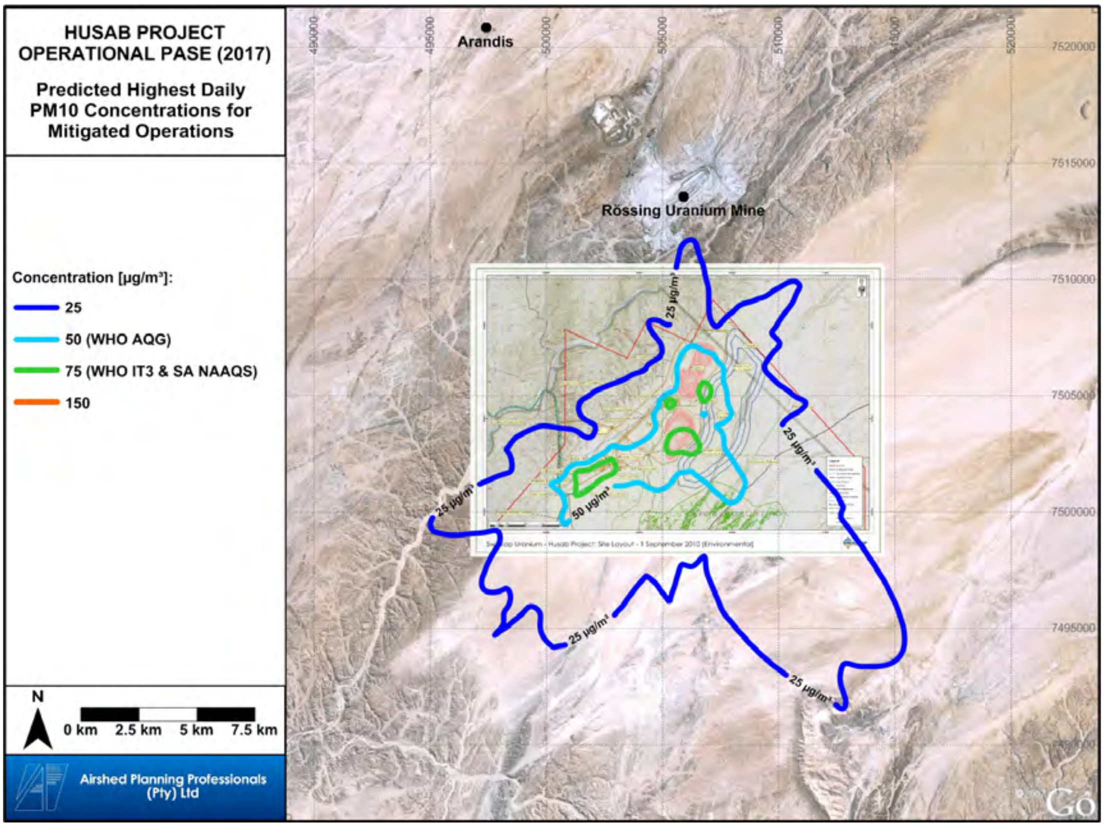

Figure 4-5: Construction Phase – Mitigated highest daily PM_{10} concentrations

4.3.1.2 Operational Phase (2017)

Predicted PM_{10} GLCs for the operational phase are provided in Table 4-17, reflecting both incremental (Husab Project alone) and cumulative (predicted baseline as discussed under Section 3.5). This takes the annual average baseline concentration and double it Isopleth plots indicating PM_{10} impact areas are presented in Figure 4-2 to Figure 4-11 for the Husab Project only.

Incremental: Predicted PM_{10} GLC for with no mitigation applied exceeded the annual limit of 30 µg/m^3 outside the mine boundary (Figure 4-6). Highest daily average PM_{10} GLCs exceeded 75 µg/m^3 over the entire modelling domain (Figure 4-8). Predicted impacts at Arandis were within the annual and daily PM_{10} assessment criteria (daily limit of 75 µg/m³ was exceeded but only for 1 day) but exceeded these at Rössing Uranium Mine and the Big Welwitschia. With mitigation measures in place, the predicted GLCs reduced significantly. Predicted annual average concentrations only exceeded 30 µg/m³ on-site (Figure 4-7). Even though predicted highest daily PM_{10} concentrations exceeded the daily limit outside the mine boundary, these were within compliance at Arandis, Rössing Uranium Mine and the Big Welwitschia (Figure 4-9).

Cumulative: The predicted baseline ambient PM_{10} GLCs are already in non-compliance at Arandis, Rössing Uranium Mine and the Big Welwitschia (Table 3-4). Thus, even with mitigation in place, the predicted cumulative impacts are exceeding the WHO IT-3 highest daily and annual guidelines at all three receptor sites (Table 4-17).

Table 4-17: Predicted PM_{10} concentrations at Arandis, Rössing Uranium Mine and the Big Welwitschia from Operational Phase activities

Sensitive / Discrete Receptor	Predicted Incremental GLC (µg/m³)[(a)]			Predicted Cumulative GLC (µg/m³)[(b)]	
	Annual Average	Highest Daily Average	FOE (days)	Annual Average	Daily Average
	Unmitigated Operational Phase (2017)				
Arandis	13	75	1	78	205
Rössing Uranium Mine (SW Boundary)	37	369	37	197	689
Big Welwitschia	42	271	40	132	415
	Mitigated Operational Phase (2017)				
Arandis	2	10	0	67	140
Rössing Uranium Mine (SW Boundary)	4	45	0	164	365
Big Welwitschia	5	48	0	94	228

Notes:

(a) Impact assessment criteria:
  i. Annual PM_{10} Concentrations – WHO IT3 guideline, 30 µg/m³
  ii. Daily PM_{10} Concentrations – WHO IT3 guideline, 75 µg/m ³ with permitted frequency of exceedence of 4 days per year (as per SA Standard)

(b) Predicted annual average baseline GLCs from Table 3-5 were added to predicted incremental annual average and twice the predicted annual average baseline GLCs were added to highest daily PM10 GLCs as per New Zeeland Ministry for the Environment methodology (MFE, 2001).

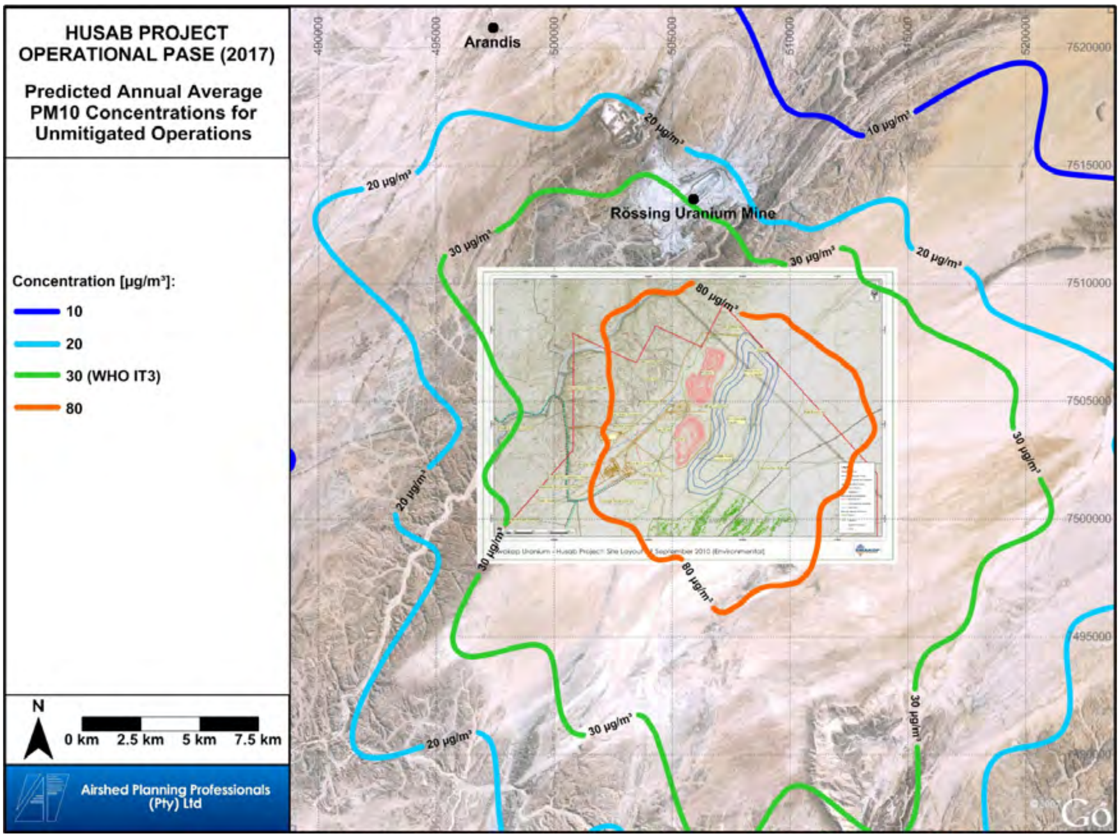

Figure 4-6: Operational Phase (2017) – Unmitigated annual average PM_{10} concentrations

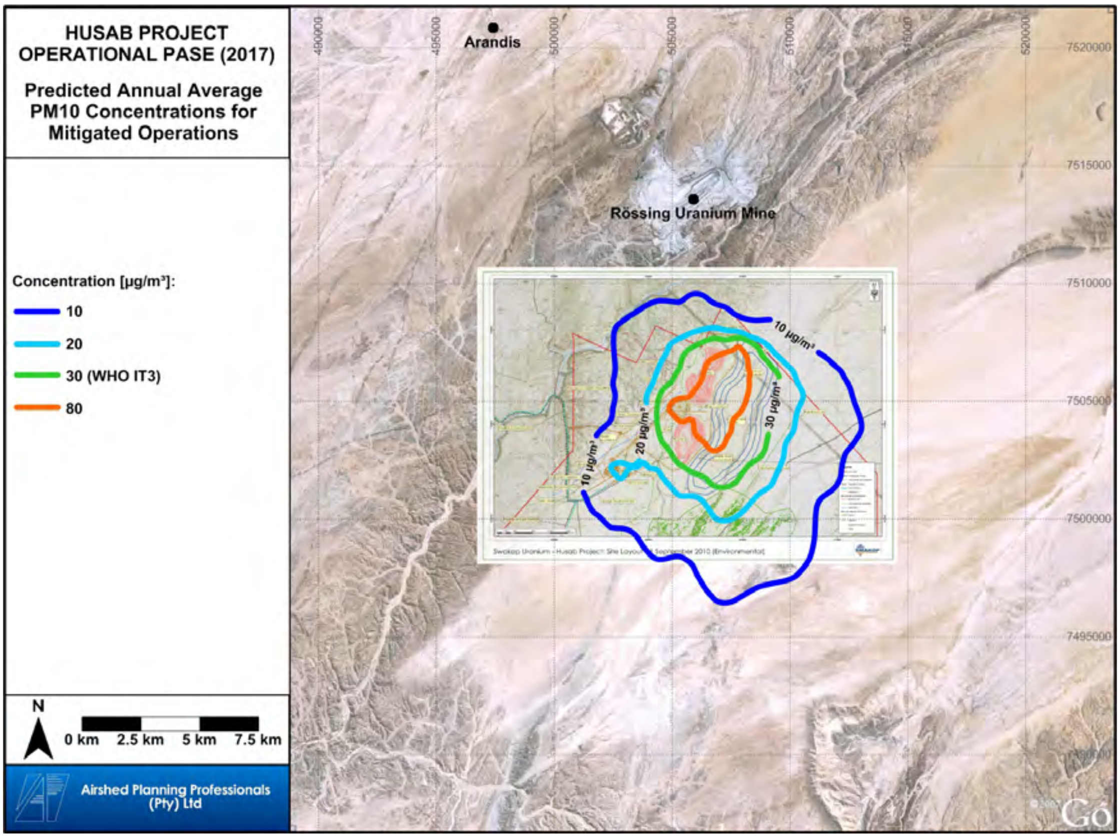

Figure 4-7: Operational Phase (2017) – Mitigated annual average PM_{10} concentrations

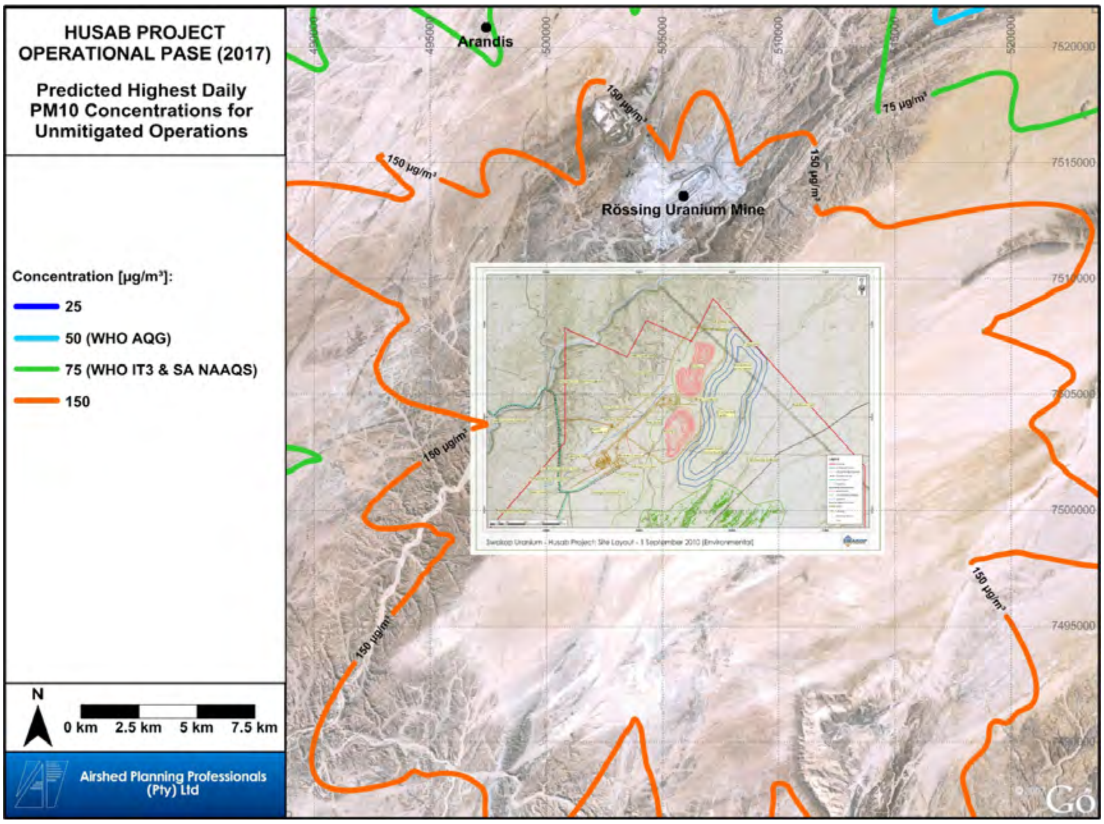

Figure 4-8: Operational Phase (2017) – Unmitigated highest daily PM_{10} concentrations

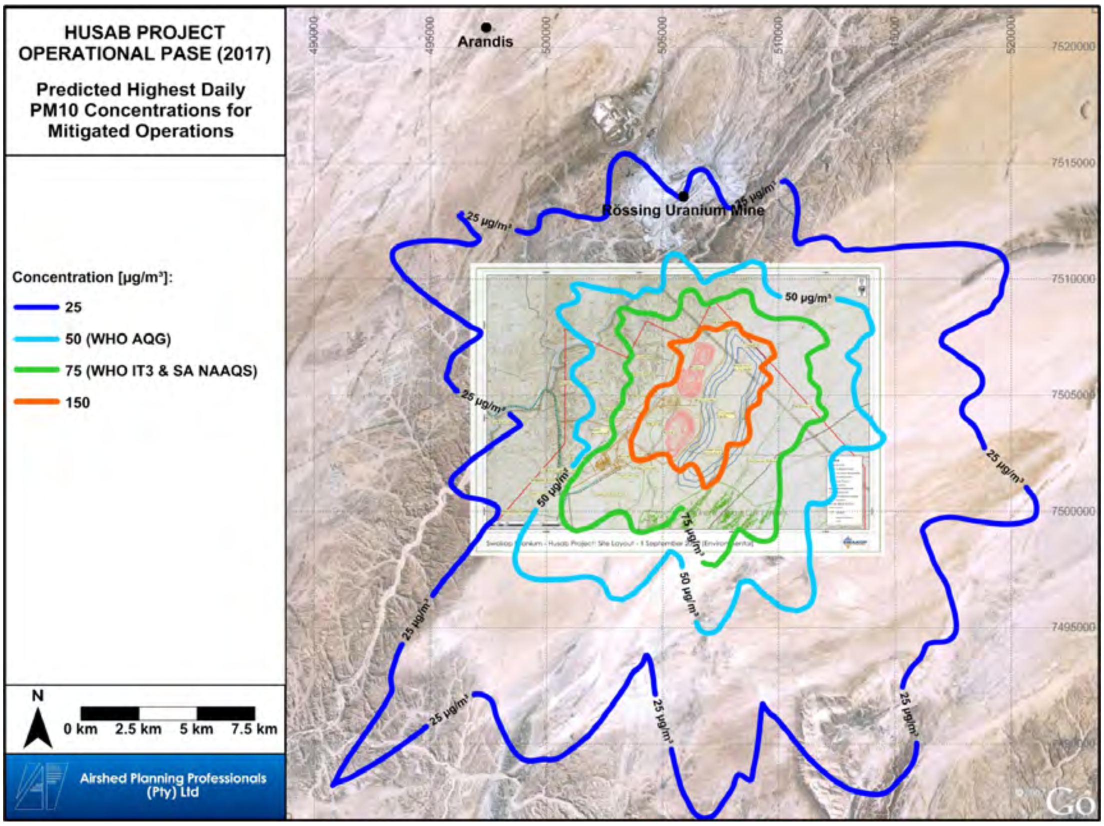

Figure 4-9: **Operational Phase (2017) – Mitigated highest daily PM_{10} concentrations**

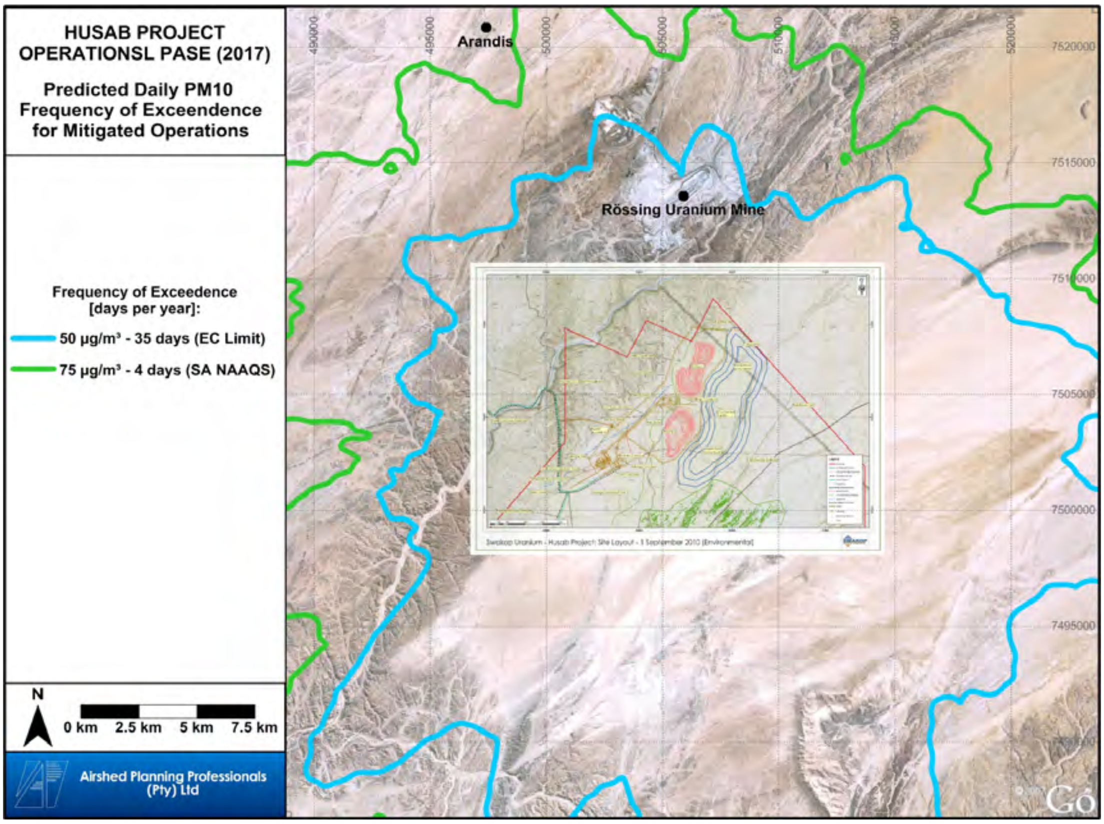

Figure 4-10: **Operational Phase (2017) – Unmitigated highest daily PM_{10} concentrations, frequency of exceedence**

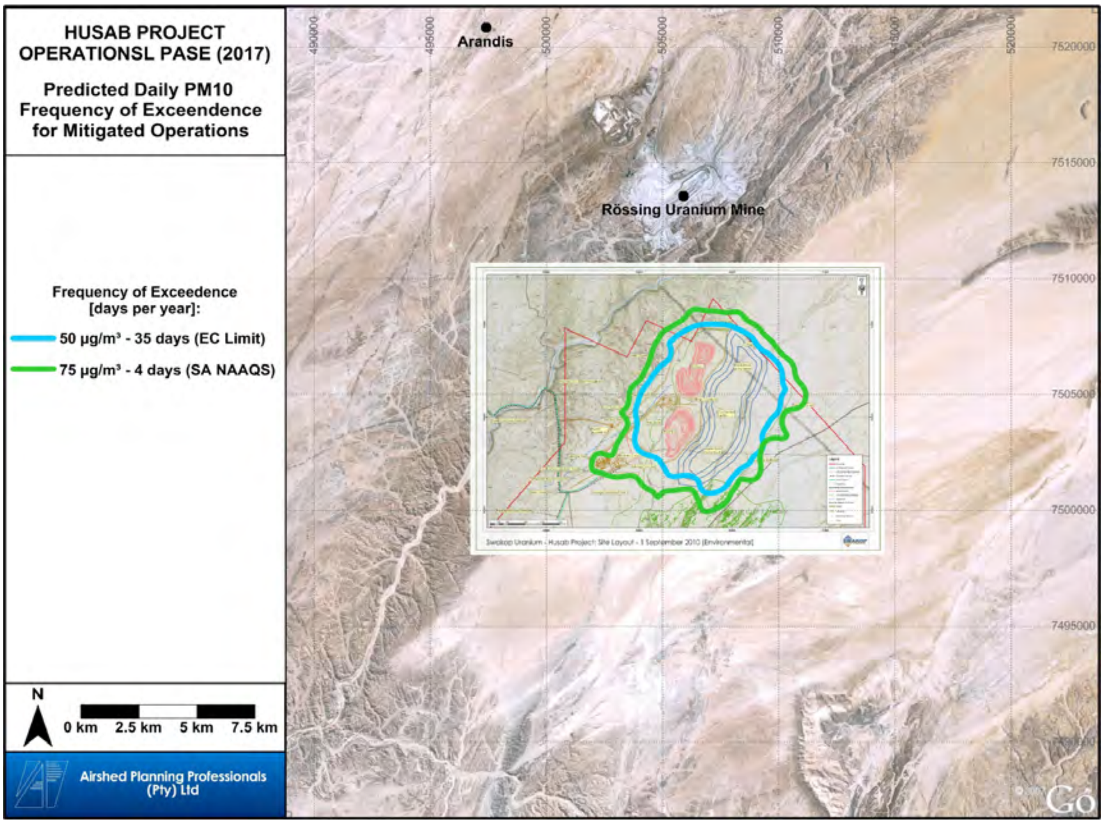

Figure 4-11: Operational Phase (2017) – Mitigated highest daily PM_{10} concentrations, frequency of exceedence

4.3.2 Predicted Dust Deposition Levels

4.3.2.1 Construction Phase

Predicted dust deposition rates for the Construction phase are provided in Table 4-18. Isopleth plots indicating incremental dust deposition impact areas are presented in Figure 4-12 and Figure 4-15.

Incremental: Dust deposition predicted off-site for the unmitigated and mitigated construction phase was low and well within the screening criteria limit of 350 mg/m^2/day (Figure 4-12 and Figure 4-13).

Cumulative: Measured dust fallout from the Husab Project was limited to the mining license area and could not be added to provide an indication of cumulative impacts. Given the low dust fallout collected as part of the Erongo SEA project, cumulative dust fallout is expected to remain below the evaluation criteria.

Table 4-18: Predicted dust deposition at Arandis, Rössing Uranium Mine and the Big Welwitschia from Construction Phase

Sensitive / Discrete Receptor	Predicted Incremental Highest Daily Dustfall (mg/m²-day)[(a)]
	Unmitigated Construction Phase
Arandis	0.05
Rössing Uranium Mine (SW Boundary)	1.53
Big Welwitschia	0.57
	Mitigated Construction Phase
Arandis	0.03
Rössing Uranium Mine (SW Boundary)	0.77
Big Welwitschia	0.28

Notes:

(a) Impact assessment criteria – 30 day average,350 mg/m²-day

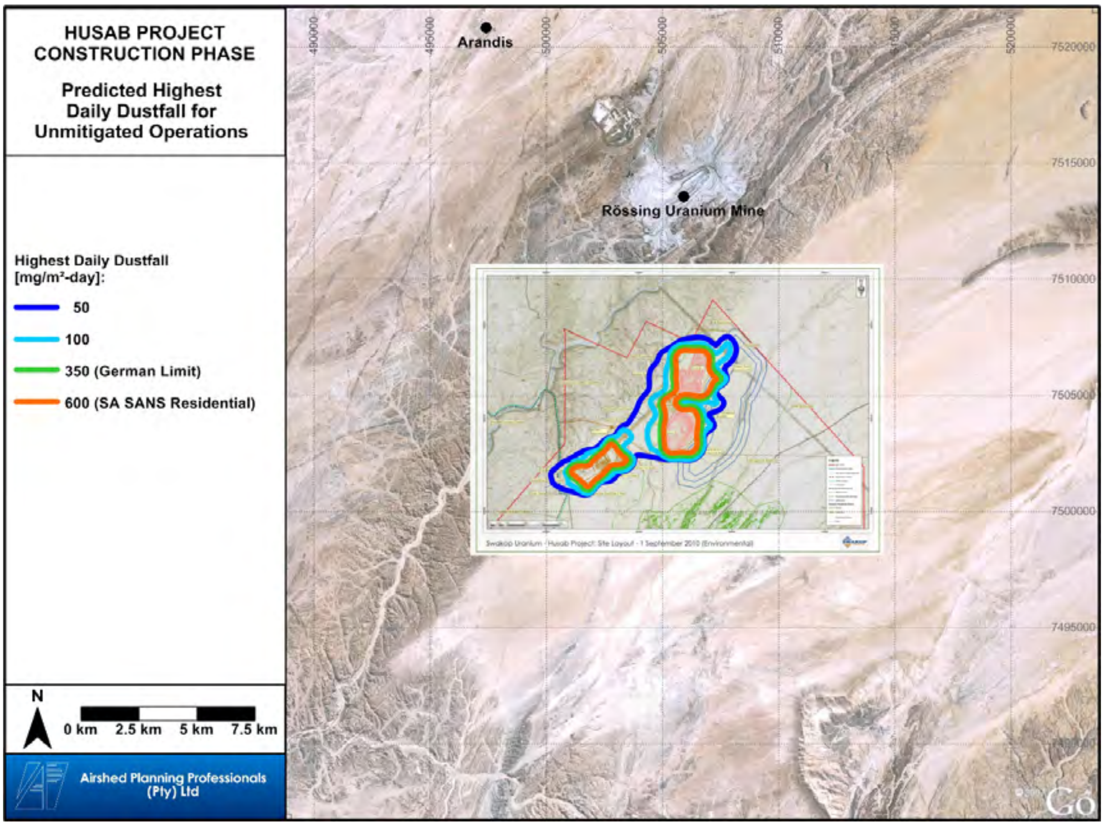

Figure 4-12: Construction Phase – Unmitigated highest daily dustfall

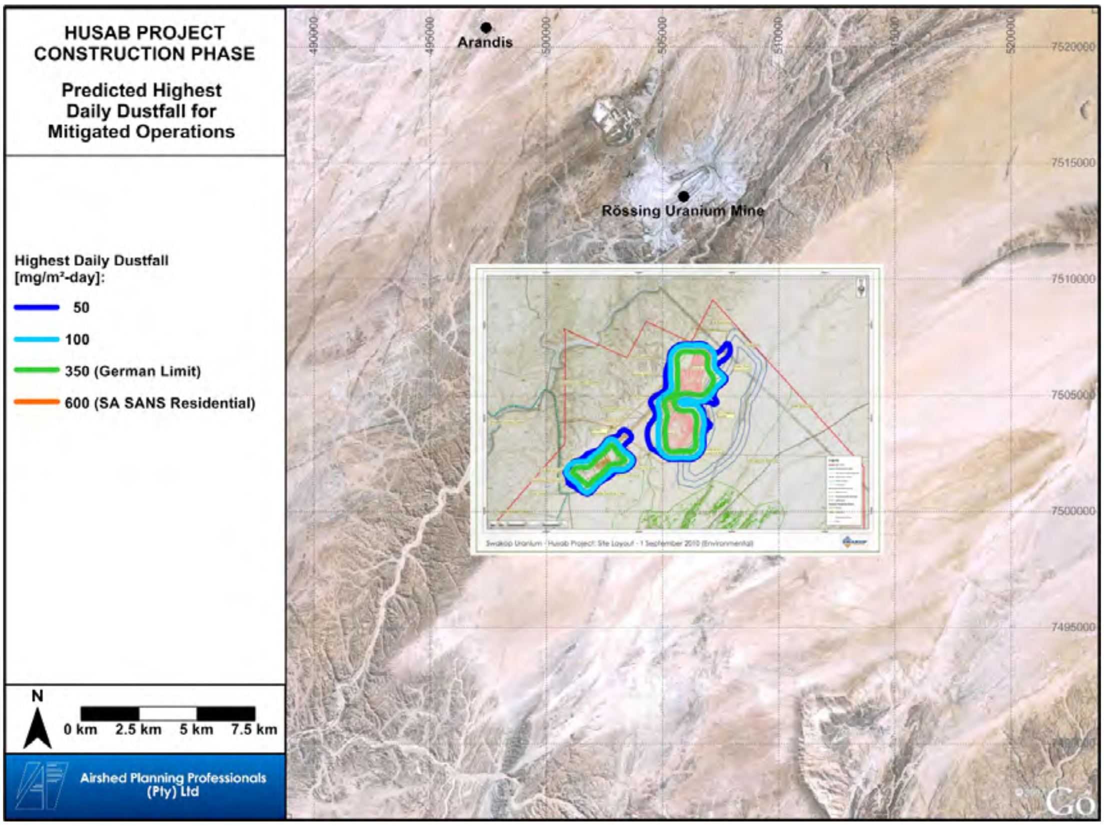

Figure 4-13: Construction Phase – Unmitigated highest daily dustfall

4.3.2.2 Operational Phase

Predicted dust deposition rates for the Operational phase are provided in Table 4-19. Isopleth plots indicating incremental dust deposition impact areas are presented in Figure 4-12 and Figure 4-15.

Incremental: Dust deposition predicted off-site for the unmitigated operational phase was low and within the screening criteria limits of 350 mg/m^2/day and 600 mg/m^2/day (Figure 4-14). With mitigation in place, these impacts reduced even further (Figure 4-15).

Cumulative: With the general trend of low dust fallout rates within the Erongo Region and at the Husab Project, cumulative dust fallout is expected to remain below the evaluation criteria.

Table 4-19: Predicted dust deposition at Arandis, Rössing Uranium Mine and the Big Welwitschia from Operational Phase activities

Sensitive / Discrete Receptor	Predicted Incremental Highest Daily Dustfall (mg/m^2-day)[(a)]
	Unmitigated Operational Phase (2017)
Arandis	0.51
Rössing Uranium Mine (SW Boundary)	7.34
Big Welwitschia	2.70
	Mitigated Operational Phase (2017)
Arandis	0.06
Rössing Uranium Mine (SW Boundary)	1.98
Big Welwitschia	0.49

Notes:
(a) Impact assessment criteria – 30 day average,350 mg/m^2-day

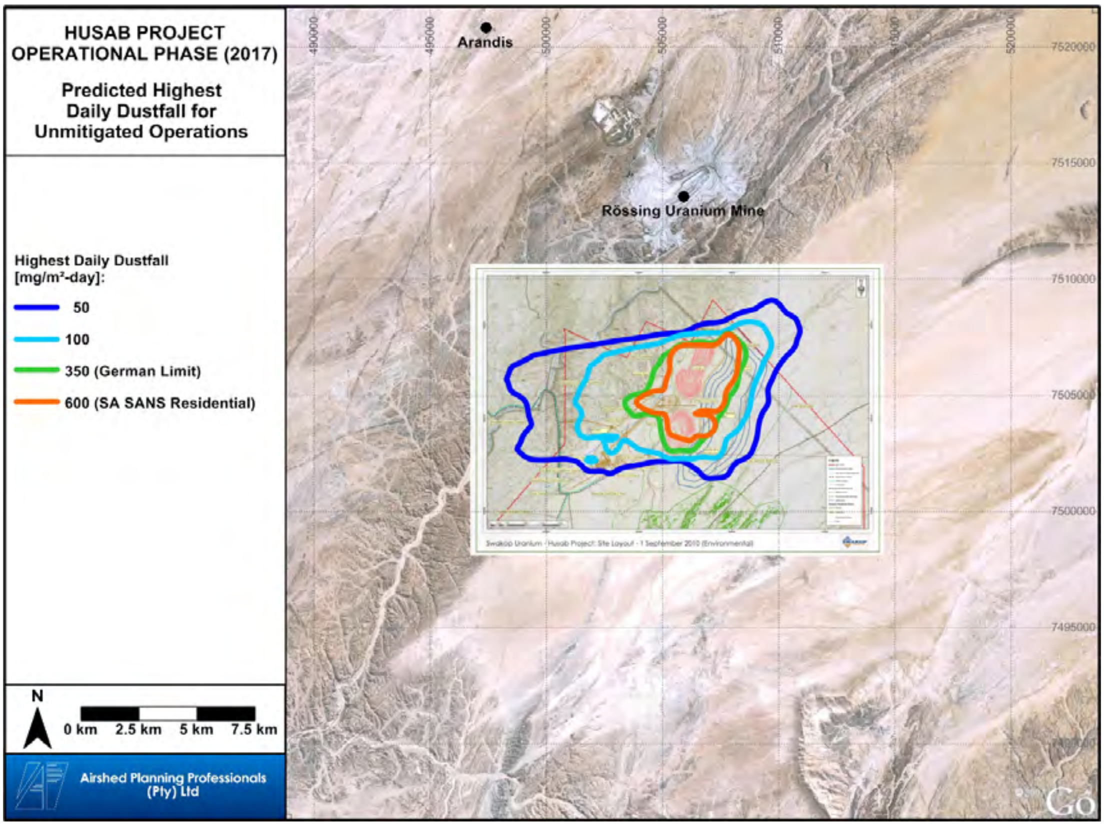

Figure 4-14: Operational Phase (2017) – Unmitigated highest daily dustfall

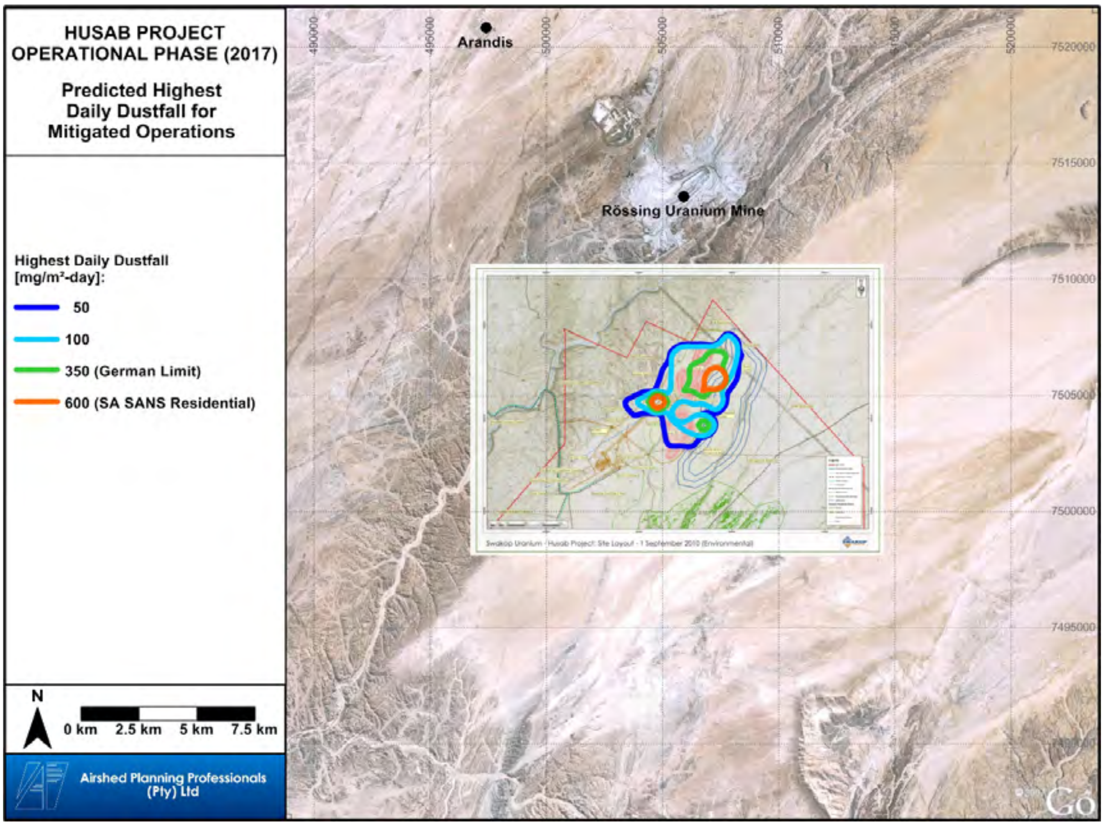

Figure 4-15: Operational Phase (2017) – Mitigated highest daily dustfall

4.3.3 Predicted DPM Concentrations and Impacts

Predicted annual average DPM concentrations are presented in Figure 4-16. Exceedence of the US EPA RfC of 5 µg/m³ was limited to the project area. An annual average DPM concentration of 0.09 µg/m³ was predicted at Arandis.

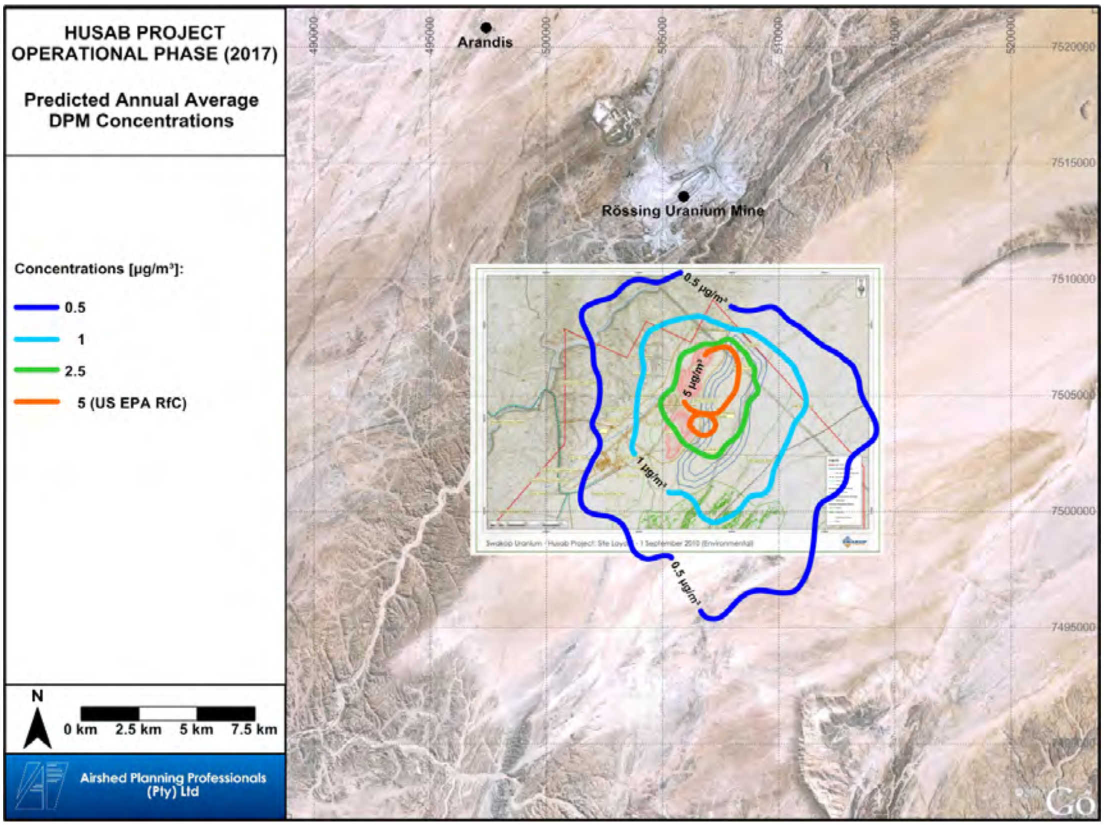

Figure 4-16: Operational Phase (2017) – Annual average DPM concentration

4.3.4 Predicted NO_2 Concentrations and Impacts

NO is rapidly converted in the atmosphere into nitrogen dioxide (NO_2). The rate of this conversion process is determined by both the rate of the physical processes of dispersion and mixing of the plume and the chemical reaction rates.

It appeared from model calculations (Janssen 1988) in comparison to actual measurements that at larger distances from the source, chemical equilibrium is not measured in the plume because the momentary plume is in-homogeneously mixed and consists of parcels of flue gas and parcels of ambient air. The general conclusion may therefore be drawn that the oxidation rate of NO at smaller distances from the source is determined by the chemical reaction rates, whereas the oxidation rate at greater distances from the source (> 5 km) is determined by the mixing rate of the plume with its ambient air. Observed NO_2/NOx for varying travel times have been reported by Janssen (1988). The daytime range was from about 18% to 80%. The night-time range was about 4% to 40%. An important pathway for formation of NO_2 in the atmosphere is the second order reaction of NO with ozone (O_3). This reaction in a homogeneous mixture can be written as (concentrations in ppm):

$$\frac{d[NO_2]}{dt} = k_1[NO][O_3]$$

As a conservative measure, and in the absence of accurate O_3 data, all long- and short term NO_x impacts were assumed to be NO_2

Predicted annual average and highest hourly NO_2 concentrations are presented in Figure 4-17 and Figure 4-18. The frequency of exceedence of hourly NO_2 standards is presented in Figure 4-19. As explained, an overly conservative approach was followed due to limited information assuming all NO_x to be NO_2. Thus even though the frequency of exceedance of the hourly NO_2 limit is outside the mine boundary, in reality this impact area is likely to be much smaller and within the mine boundary.

Highest hourly and annual average NO_2 concentrations of 160 and 1.6 µg/m³ respectively were predicted at Arandis.

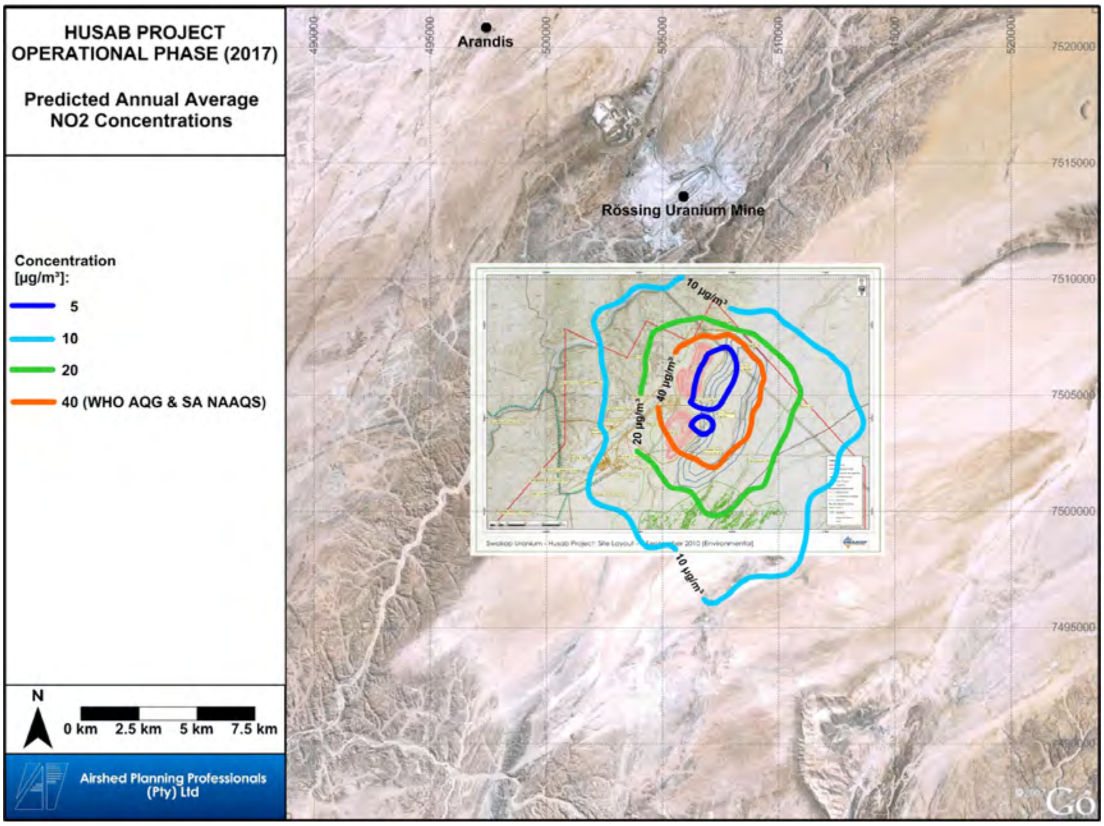

Figure 4-17: Operational Phase (2017) – Annual average NO_2 concentration

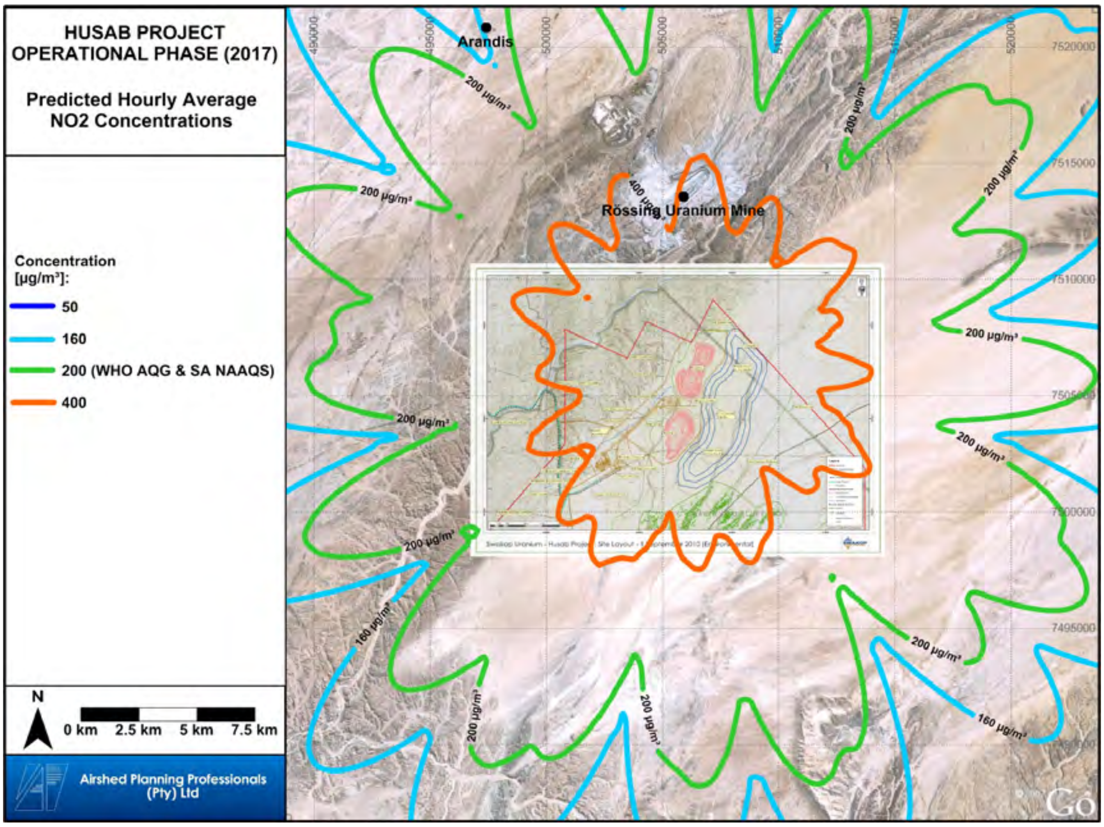

Figure 4-18: Operational Phase (2017) – Highest hourly NO_2 concentration

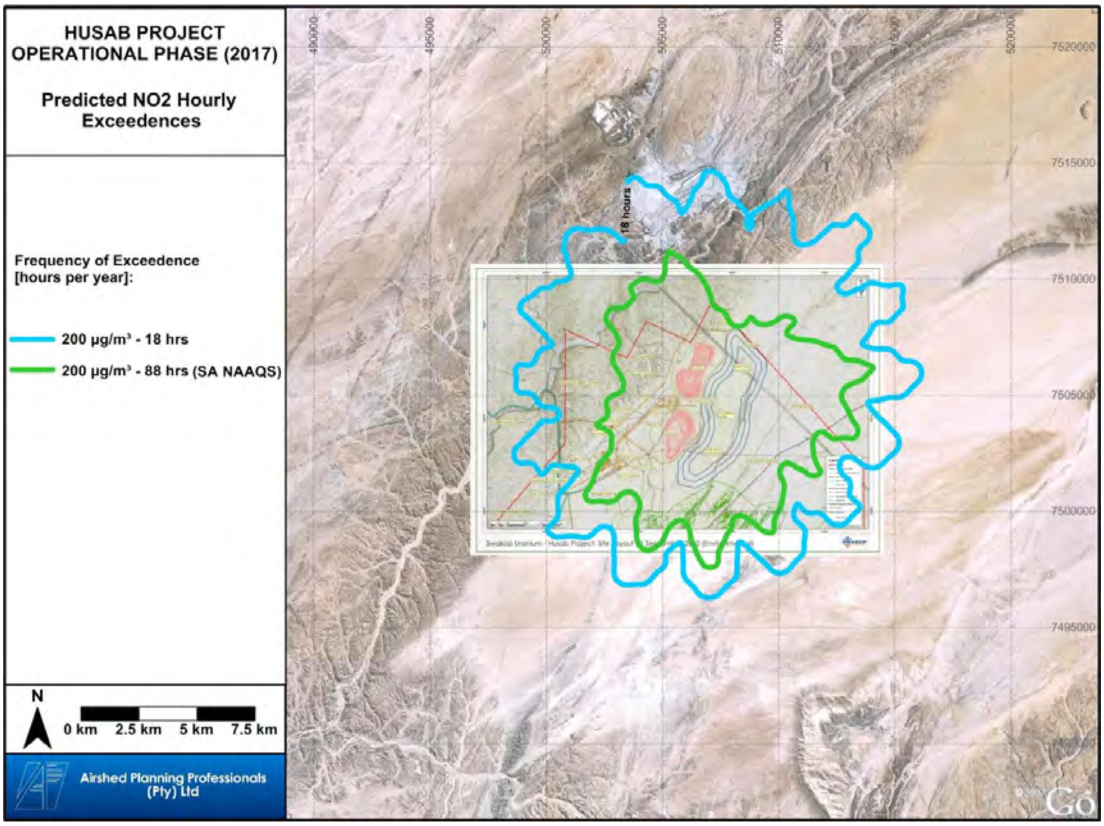

Figure 4-19: Operational Phase (2017) – Highest hourly NO_2 concentration, frequency of exceedence

4.3.5 Predicted SO_2 Concentrations and Impacts

No exceedances of the WHO guidelines, EC or SA limit values for SO_2 were predicted to occur on or off-site. Highest hourly, highest daily and annual average SO_2 concentrations of 7.5, 0.45 and 0.08 µg/m³ respectively were predicted at Arandis.

4.3.6 Predicted SO_3 Concentrations and Impacts

No exceedances of the TSEQ were predicted to occur on or off-site. Highest hourly and annual average SO_3 concentrations of 0.2 and 0.0005 µg/m³ respectively were predicted at Arandis.

4.3.7 Predicted CO Concentrations and Impacts

No exceedances of the WHO guideline or SA limit value of 30 000 µg/m³ for CO were predicted to occur on or off-site. A highest hourly CO concentration of 60 µg/m³ was predicted at Arandis.

4.4 Closure and Post Closure Phase

It is assumed that all mining activities and processing operations will have ceased by the closure phase of the mining project. 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, such as the waste dump. The closure phase is regarded to have a lower potential for impacts than during the construction phase.

Aspects and activities associated with the closure phase of the mining operations at the Husab Project are listed in Table 4-20.

Table 4-20: Activities and aspects identified for the closure phase of mining operations.

Impact	Source	Activity
Generation of TSP and PM10	Tailings facility	Reshaping and rehabilitation of tailings dams to reflect the natural surroundings
	Topsoil stockpiles	Topsoil recovered from stockpiles for rehabilitation and re-vegetation
	Plant site/s	Infrastructure removal at processing plant site
	Unpaved	Vehicle entrainment on unpaved road surfaces

Impact	Source	Activity
	roads	
Gas emissions [(a)]	Blasting	Demolition of infrastructure may necessitate the use of blasting.
	Vehicles	Tailpipe emissions from vehicles utilised during the closure phase.

Notes:

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

4.5 Impact Ranking

Both the criteria used to assess the impacts and the method of the determining the significance of impacts as outlined by Metago were applied in the ranking of predicted air quality impacts indicated in Table 4-21 (incremental impacts) and Table 4-22 (cumulative impacts). The following should be taken note of when interpreting the impact rankings:

(a) Severity/Nature:

a. HIGH when air quality criteria were predicted to be exceeded often;

b. MEDIUM when air quality criteria were predicted to be exceeded occasionally;

c. LOW when air quality criteria were only exceeded on site or not at all;

(b) Duration:

d. HIGH when impacts will continue beyond closure;

e. MEDIUM when impacts limited to the life of the project;

f. LOW when impacts are short term, less than the life of the project;

(c) Spatial Scale:

g. HIGH when predicted impacts and air quality standard exceedences extended beyond the selected study area;

h. MEDIUM when predicted impacts and air quality standard exceedences extended beyond the boundary of the project but not the study area;

i. LOW when predicted impacts and air quality standard exceedences were limited to the boundary of the project;

(d) Probability: At this level of assessment, it is assumed that an exceedence of the evaluation criteria at third party receptors indicates medium to high probability of health impacts. For model and prediction uncertainties see Section 4.3.

Table 4-21: Impact ranking of predicted INCREMENTAL air quality impacts

Scenario	Potential Air Quality Impact	Severity/ Nature[a]	Duration[b]	Spatial Scale[c]	Consequence	Probability[d]	Significance
Construction Phase	PM_{10} - Unmitigated	Low	Medium - High	Low	Low - Medium	Low	Low
	PM_{10} - Mitigated	Low	Medium - High	Low	Low - Medium	Low	Low
Operational Phase (2017)	PM_{10} - Unmitigated	High	Medium - High	Medium	Medium - High	High	High
	PM_{10} - Mitigated	Low	Medium - High	Medium	Low - Medium	Low	Low

Notes:

(a) Severity
   a. Low: No exceedences of evaluation criteria at third party receptors.
   b. High: Exceedences of evaluation criteria at third party receptors.

(b) Duration
   a. Low – Medium: Effects of respiratory health impacts are assumed to continue for the duration of the activity but not longer than the life of mine.
   b. Medium to High: Lasting effects of respiratory health impacts are assumed to continue for longer than the life of mine.

(c) Spatial Scale
   a. Low: Within mine boundary.
   b. Medium: Beyond mine boundary.

(d) Probability
   a. Low: The probability of health impacts considered unlikely as no exceedences of evaluation criteria at third party receptors were predicted.
   b. Medium: The probability of health impacts considered possible as exceedences of evaluation criteria were predicted beyond the mine boundary but not at the third party receptors.
   c. High: At this level of assessment, it is assumed that an exceedence of the evaluation criteria at third party receptors indicates medium to high probability of health impacts.

Table 4-22: Impact ranking of predicted CUMULATIVE air quality impacts

Scenario	Potential Air Quality Impact	Severity/ Nature[a]	Duration[b]	Spatial Scale[c]	Consequence	Probability[d]	Significance
Construction Phase	PM_{10} - Unmitigated	High	Medium - High	Medium	Medium - High	High	High
	PM_{10} - Mitigated	High	Medium - High	Medium	Medium - High	High	High
Operational Phase (2017)	PM_{10} - Unmitigated	High	Medium - High	Medium	Medium - High	High	High
	PM_{10} - Mitigated	High	Medium - High	Medium	Medium - High	High	High

Notes:

(a) Severity
 a. Low: No exceedences of evaluation criteria at third party receptors.
 b. High: Exceedences of evaluation criteria at third party receptors.

(b) Duration
 a. Low – Medium: Effects of respiratory health impacts are assumed to continue for the duration of the activity but not longer than the life of mine.
 b. Medium to High: Lasting effects of respiratory health impacts are assumed to continue for longer than the life of mine.

(c) Spatial Scale
 a. Low: Within mine boundary.
 b. Medium: Beyond mine boundary.

(d) Probability
 a. Low: The probability of health impacts considered unlikely as no exceedences of evaluation criteria at third party receptors were predicted.
 b. Medium: The probability of health impacts considered possible as exceedences of evaluation criteria were predicted beyond the mine boundary but not at the third party receptors.
 c. High: At this level of assessment, it is assumed that an exceedence of the evaluation criteria at third party receptors indicates medium to high probability of health impacts impacts

5 Conclusions

The comparison of predicted pollutant concentrations to ambient air quality guidelines and standards facilitated a preliminary screening of the potential, which exists for human health impacts. The sensitive receptors identified to be included in the assessment are the areas where people reside with specific reference to Arandis (no other settlements are within close proximity to the Husab Project), Rössing Uranium Mine (where many of the Arandis residents work) and the Big Welwitschia (a prominent tourist location).

When interpreting the modelling results it is important to realise that the range of uncertainty of the model predictions could to be -50% to 200%. This means that the model should always predict within this range when the results are compared to measured data. The predicted results are a function of the meteorological data and the source strengths (emissions data). For the purpose of this project, on-site meteorological data were used and the maximum emissions rates (based on the maximum production rates). Thus, the predicted results can be seen as conservative providing a worst-case scenario.

5.1 Baseline Characterisation

- The prevailing wind field is from the north-northwest for most of the time. During night-time an increase of northerly airflow occurred with a decrease in wind speeds. Seasonally the wind field varied significantly with summer and spring months reflecting the predominant north-westerly airflow. During the autumn months the wind field shifts to reflect east north-easterly and west south-westerly airflow. Winter months are characterised by strong easterly and east north-easterly winds. The highest wind speeds occur during the month of July and are associated with the so-called “easterly” winds.
- Temperature ranged from 11ºC in winter to 38 ºC in summer.
- The Husab Project falls within a summer rainfall area with the highest rainfall recorded in October (28 mm) and in February (32 mm).
- High frequency of very stable local atmospheric conditions occurred predominantly from the north to the north-western sector. Stable conditions is likely to result in high ground level concentrations for non-wind dependable low level emitters near the source such as fugitive dust sources associated with vehicle entrainment on roads and crushing and screening.
- Dust fallout in general was low and well within the limit of 350 mg/m^2/day and 600 mg/m^2/day for total daily deposition over a monthly average. Dust fallout levels ranged between 5 mg/m^2/day and 56 mg/m^2/day.
- Predicted background PM_{10} concentrations at the Husab Project indicated daily averages of 220 µg/m^3 and 60 µg/m^3 for annual averages, exceeding the Erongo Region selected evaluation criteria of 75 µg/m^3 and 30 µg/m^3, respectively. Predicted baseline PM_{10} GLCs at

Arandis, Rössing Uranium Mine and the Big Welwitschia were in exceedance of both the daily and annual evaluation criteria.

- The main source of baseline PM_{10} concentrations in the vicinity of the proposed Husab Project is windblown dust from the natural environment (57%) and secondly fugitive dust from Rössing Uranium Mine (39%) located ~ 5km to the north (Liebenberg-Enslin et.al., 2010).

5.2 Impact Assessment

5.2.1 PM_{10} Ground Level Concentrations

5.2.1.1 Incremental Impacts

- **Construction phase:** Annual average ground level PM_{10} concentrations for unmitigated and mitigated construction activities were within 30 µg/m^3 at the mine boundary. For highest daily GLC the predicted impacts were high when no mitigation is applied, exceeding 75 µg/m^3 up to 10km from mining activities. With mitigation measures applied, the impact area shrunk to fall mainly within the mine boundary. The predicted impacts at the three receptor sites were within the required ambient air quality limits for both annual and daily averages. Unmitigated and mitigated PM_{10} impacts during the construction phase have LOW significance ratings.
- **Operational Phase (2017):** Unmitigated PM_{10} GLC for with no mitigation applied exceeded the annual limit of 30 µg/m^3 outside the mine boundary. Highest daily average PM_{10} GLC exceeded 75 µg/m^3 over the entire modelling domain. Predicted impacts at Arandis were within the annual and daily PM_{10} assessment criteria, but were exceeded at Rössing Uranium Mine and the Big Welwitschia. Predicted mitigated annual average concentrations only exceeded 30 µg/m^3 on-site. Even though predicted highest daily PM_{10} concentrations exceeded the daily limit outside the mine boundary, it were within compliance at all three receptor sites (Figure 4-9). Unmitigated PM_{10} impacts during the operational phase have HIGH significance ratings whereas the mitigated scenario reduce to LOW significance.

5.2.1.2 Cumulative Impacts

- **Construction phase:** Predicted baseline PM_{10} GLCs were high, exceeding the evaluation criteria for the Erongo Region. Thus even though the additional contribution from the Husab Project is small, the cumulative impacts exceeded the PM_{10} annual and daily evaluation criteria at all three receptor sites. Without and with mitigation in place, the significance rating is HIGH.
- **Operational Phase (2017):** With background concentrations taken into consideration, already exceeding the evaluation criteria, the cumulative impacts will be in non-compliance at Arandis,

Rössing Uranium Mine and the Big Welwitschia. The significance ranking therefore remains HIGH even with mitigation measures in place.

- It should be noted that this is primarily due to windblown dust from natural background sources with the additional contribution from the Husab Project at Arandis for instance, at about 3% (Liebenberg-Enslin et.al., 2010).

5.2.2 Dust Deposition

5.2.2.1 Incremental Impacts

- **Construction phase:** Dust deposition predicted off-site for the unmitigated and mitigated construction phase was low and well within the screening criteria limit of 350 mg/m^2/day with a LOW significance rating.
- **Operational Phase (Year 2017):** Dust deposition predicted off-site for the unmitigated and mitigated operational phase was low and within the screening criteria limits of 350 mg/m^2/day with LOW significance ratings.

5.2.2.2 Cumulative Impacts

- **Construction phase and Operational Phase (Year 2017):** Collected dust fallout rates at the Husab Project over the 11 month period indicated low deposition well within the evaluation criteria. For the larger region similarly low dust fallout rates were reported in the SEA report. The cumulative dust fallout rates are therefore expected to remain below the evaluation criteria, with a LOW significance.

5.2.3 Gaseous Pollutants

- Predicted annual average DPM concentrations did not exceed the US EPA RfC beyond the mine boundary. Very low concentrations were predicted at Arandis. The significance ranking was LOW.
- NO_2 concentrations exceeded the hourly limit outside the mine boundary (this was based on a very conservative approach assuming all NOx to be NO_2). Highest hourly and annual average NO_2 concentrations at Arandis were however well below the limits. The significance ranking was LOW.
- No exceedances of the limits for SO_2 were predicted to occur on or off-site with very low concentrations predicted at Arandis. The significance ranking was LOW.

- No exceedances of the limits for CO were predicted to occur on or off-site with very low concentrations predicted at Arandis. The significance ranking was LOW.

6 Recommendations and Air Quality Management Measures

The main objective of an Air Quality Management Plan for the proposed Husab Project is to ensure that all operations will be within acceptable air quality limits. In order to define site specific management objectives, the main sources of pollution needed to be identified. Sources can be ranked based on sources strengths (emissions, Section 4.2) and impacts (Section 4.4). Once the main sources have been identified, target control efficiencies for each source can be defined to ensure acceptable cumulative ground level concentrations. The main pollutants of concern identified during the impact assessment were particulates (PM_{10} and TSP).

6.1 Source Ranking by Emissions

A summary of the source group rankings by estimated emissions as discussed in Section 4.2 are presented in Figure 6-1 for operational the operational phase. Since no detail process description for the construction phase was provided, a generic emission factor was applied with no breakdown in source groups possible.

The main pollutant of concern during the construction, operational and closure phases was found to be particulates (PM_{10} and TSP). Unpaved roads resulted in the highest fugitive dust emissions contributing 96% to PM_{10} emissions and 97% to TSP without mitigation measures applied. With mitigation measures applied, the contribution reduced but still remained the most significant emission source. The contributions of the remainder of the source groups are small in comparison (Figure 6-1).

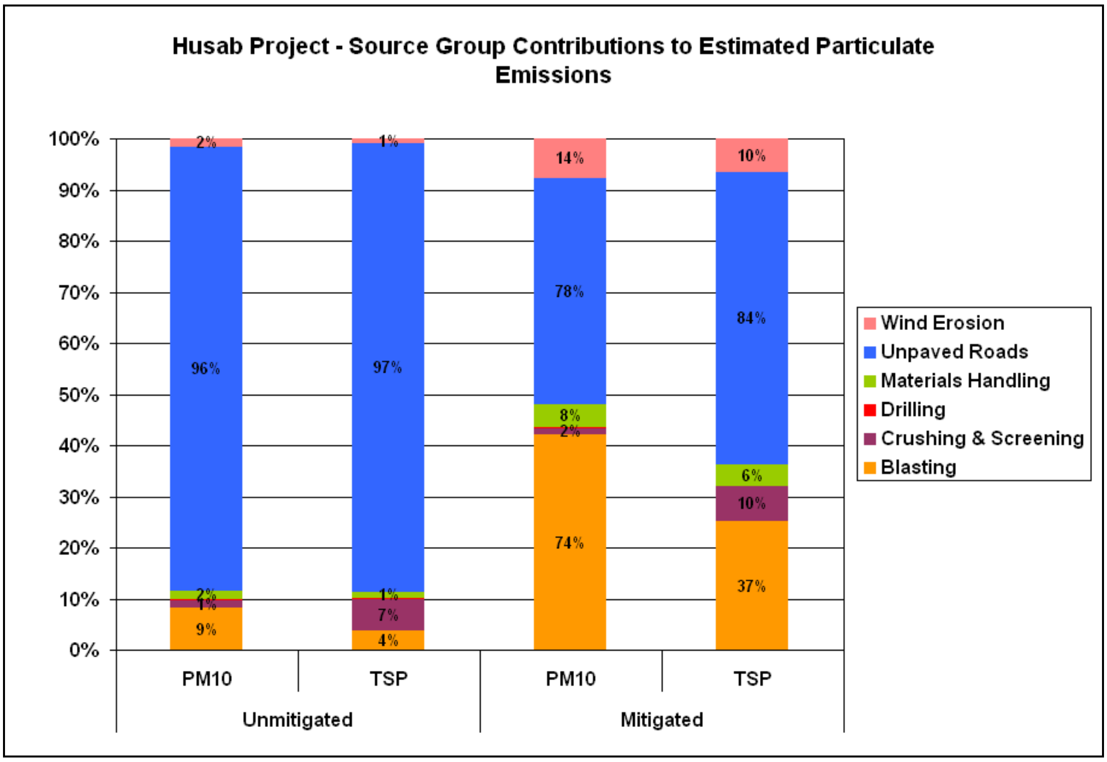

Figure 6-1: Source group contributions to estimated particulate emissions

It can be concluded that the main sources contributing to both TSP and PM_{10} emissions from the Husab Project alone were in order of importance:

- Vehicle entrainment from the unpaved roads;
- Crushing and Screening;
- Blasting; and
- Windblown dust from the waste dump (co-disposal of waste and tailings).

6.2 Source Ranking by Impact

A number of parameters (i.e. local meteorology, release height of emissions, dimensions of source, etc.) influence the way emissions are dispersed and eventually end up at ground level. Thus, the main contributing sources to emissions may not necessarily result in the highest ground level impacts and therefore the main contributing sources to off-site impacts are also evaluated.

Source group contributions to predicted PM_{10} and dustfall impacts are presented in Figure 6-2 for the operational phase.

Ranking was done based on the annual average PM_{10} concentrations and average daily dustfall predicted off-site:

- **PM10 Impacts:**
    - o Without mitigation in place, unpaved roads were the main source of PM_{10} GLC. With mitigation in place, unpaved roads remained the main contributor but to a lesser extent.
    - o Materials handling came out as the second highest source group.
    - o Crushing and screening was the third most significant impacting source. With mitigation it remained the third most significant source.
- **Dustfall Impacts:**
    - o Similar to PM_{10}, unpaved roads resulted in the highest dust fallout. With mitigation in place, unpaved roads remained the main contributor but to a lesser extent.
    - o Crushing & screening and blasting are the second and third most significant contributing source groups to predicted dustfall levels.

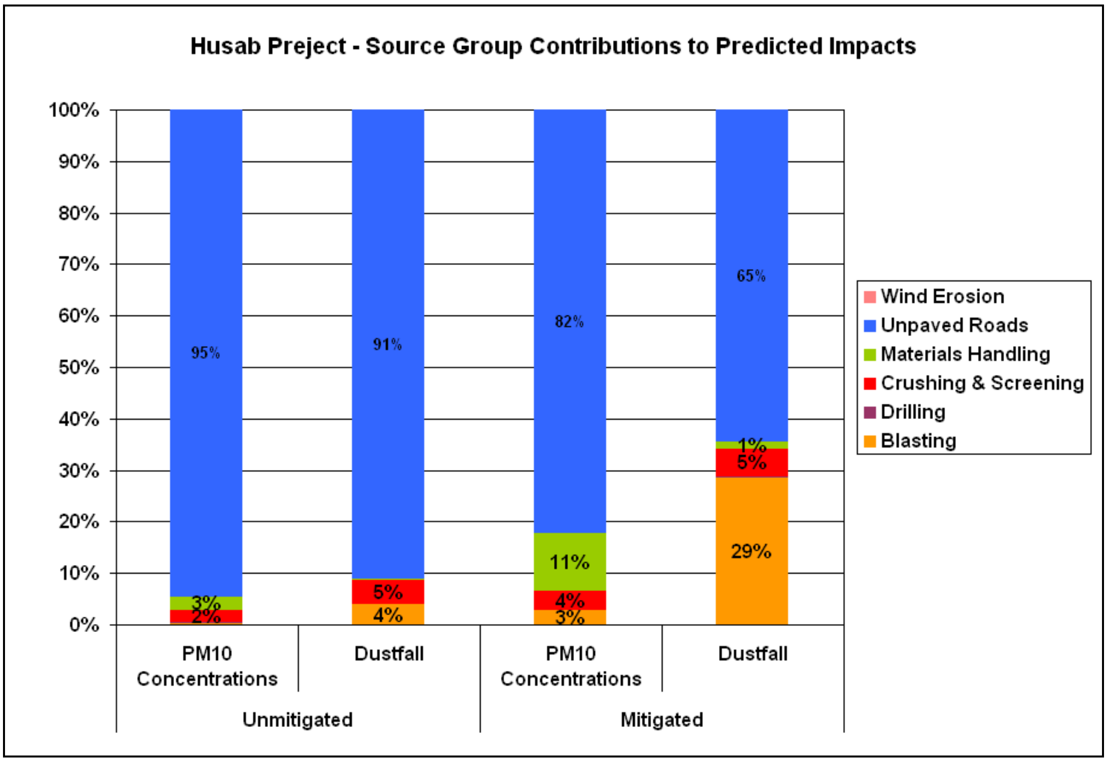

Figure 6-2: Source ranking by predicted impacts for the operational phase

6.3 Target Control Efficiencies

Predicted incremental impacts (impacts associated only with the proposed Husab Project) were high for PM_{10}, and cumulative effects as a result of other sources of emission in the vicinity of the site will result in even higher impacts. Even though the off-site impacts from the Husab Project alone were predicted to be low at Arandis, high impacts were predicted at Rössing Uranium Mine and the Big Welwitschia. It is therefore recommended that the following mitigation target control efficiencies be maintained at the proposed site to ensure the lowest possible cumulative contribution:

- Vehicle entrainment from the unpaved roads – 90% control efficiency through chemical surfactants on permanent haul roads. According to literature spraying of water on road surfaces can only achieve a maximum of 85% control. Water prays in combination with chemicals should however be applied to in-pit haul roads to achieve at least 80% control efficiency.
- Crushing and Screening – 83% reduction through water sprays on ore and extraction hoods with venturi scrubbers.
- Materials handling (unloading of trucks) – at least 50% reduction through effective water sprays.

6.4 Project-specific Management Measures

Based on the main sources of impact, recommendations were made on the required controlled efficiencies needed to reduce the environmental and health impacts to acceptable levels. This section provides a brief description on mitigation measures that can achieve the recommended control efficiencies.

6.4.1 Vehicle Entrainment on Unpaved Haul Roads

A number of mitigation measures that can be applied are discussed below indicating the probable control efficiency that will be achieved by it.

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

- Measures aimed at reducing the extent of unpaved roads, e.g. paving,
- Traffic control measures aimed at reducing the entrainment of material by restricting traffic volumes and reducing vehicle speeds, and
- Measures aimed at binding the surface material or enhancing moisture retention, such as wet suppression and chemical stabilisation (EPA, 1987; Cowhert et al., 1988; APCD, 1995).
- Other factors such as the particle size distribution of the aggregate, the compaction of the surface material and moisture content, and local 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 40km/hr to 24km/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.

It is standard practice at most industrial and mining sites to utilise water trucks on the unpaved roads. This 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).

Watering Rates: 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 and chemical sprays resulting in at least 90% control efficiency would be a requirement to result in a significant reduction in ground level concentrations and dustfall levels. Should only water be applied, the amounts needed to ensure 90% control efficiency on the main haul road (assuming 55 trucks/hour) are 4 $l/m^2/hour$ during daytime when no rainfall occurs. With the high evaporation rate in this region (on average 275 mm/month), an hourly rainfall of at least 1mm is required to reduce the watering application rate to 0.42 $l/m^2/hour$. Given the arid environment where the Husab Project is situated and that only 2 months of the year recorded more than 5mm of rainfall in 2009, this does not seem a feasible option on its own. Due to the temporary in-pit roads, water sprays in combination with chemicals can be applied to ensure at least 75% control efficiency. By adding chemicals, the amount of water needed reduces and the effectiveness improves.

Chemical suppressants: Chemicals have 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). Thus chemicals should be applied on the permanent haul roads at the Husab project.

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). Given the high control efficiency, it is therefore recommended that chemical surfactants be used on the permanent haul roads as is the case at Rössing Uranium. For temporary roads such as in-pit roads, water sprays in combination with chemicals can be used. These combined efforts should result in control efficiencies of at least 90%. It is further recommended that the possibility of implementing conveyor belts between the main areas (i.e. ROM stockpile and processing plant) be investigated for this will reduce the dust emissions significantly.

6.4.2 Crushing and Materials Handling Operations

Primary crushing and screening of alloy and materials transfer to and from trucks were identified as potentially significant sources of emissions at the proposed operation.

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

The control efficiency of pure water suppression can be estimated based on the US-EPA emission factor which relates material moisture content to control efficiency. This relationship is illustrated in Figure 6-3. From the relationship between moisture content and dust control efficiency it is apparent that by doubling the moisture content of the material an emission reduction of 62% could be achieved.

Chemicals mixed into the water will not just save on water consumption but also improve the control efficiency of the application even further.

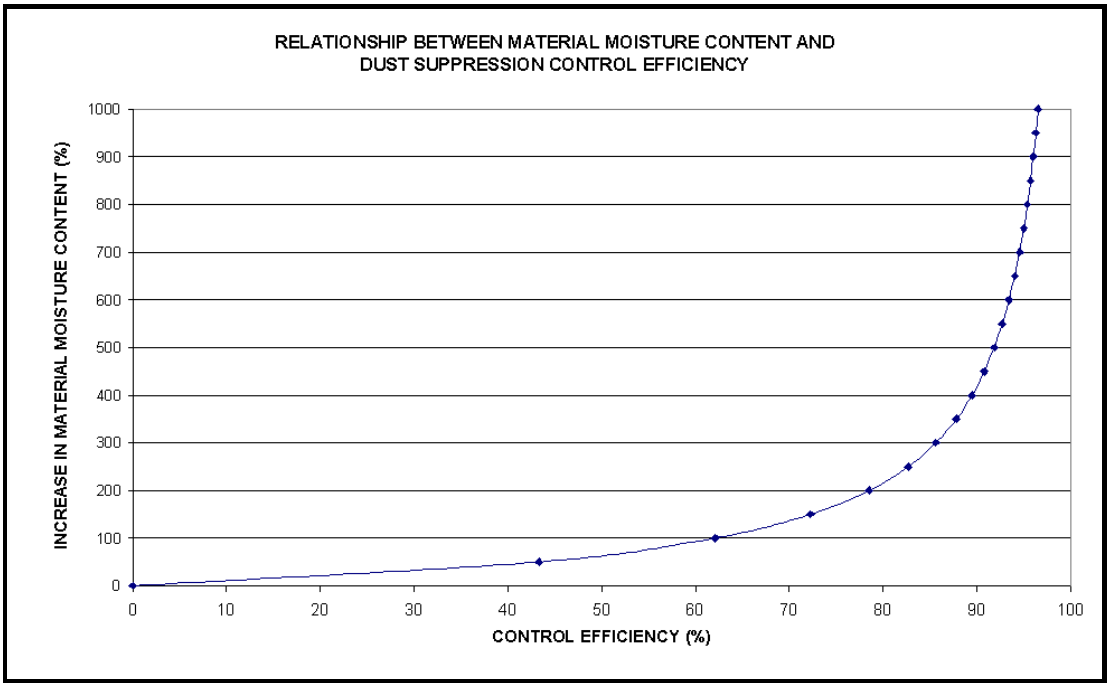

Figure 6-3: Relationship between the moisture content and dust control efficiency.

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

- Of the various nozzle types, the use of hollow cone nozzles tend to afford the greatest control for bulk materials handling applications whilst minimising clogging;
- Optimal droplet size for surface impaction and fine particle agglomeration is about 500µm; finer droplets are affected by drift and surface tension and appear to be less effective; and,
- Application of water sprays to the underside of conveyor belts has been noted by various studies to improve the efficiency of water suppression systems and belt-to-belt transfer points.

It is therefore recommended that water sprays be used at the crushing and screening operations and the main material transfer points. By combining chemicals with water (as with the in-pit haul roads) the amount of water required reduces and the efficiency improves.

The crusher design for the Husab project will include water sprays at all transfer points in the crushing area. For instance, the ore on the trucks will be sprayed with water before off-loading and water sprays will be fitted at the ROM bin with sensors and interlocks to allow these sprays to operate only when a truck is dumping. Ducted dust collection systems with extraction hoods will also be implemented at all major dust generating points where the dust will be vented to a venturi scrubber with a cyclonic separator, dry fan and stack. The combination of water sprays on the ore and extraction system with venturi scrubbers should ensure 83% control efficiency and more.

6.4.3 Monitoring Requirements

6.4.3.1 Performance Indicators

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

Performance indicators are usually selected to reflect both the source of the emission directly and the impact on the receiving environment. Ensuring that no visible dust plume derives from crushing operations represents an example of a source-based indicator, whereas maintaining off-site dustfall levels to below a certain threshold represents an impact- or receptor-based performance indicator. Source-based performance indicators have been included in regulations abroad. The ambient air quality guidelines and standards given for respirable and inhalable particulate concentrations by various countries represent receptor-based objectives.

6.4.3.2 Specification of Source Based Performance Indicators

- For unpaved roads it is recommended that dust fallout in the immediate vicinity of the road perimeter be less than 1 200 mg/m^2-day. This is based on the South African dust fallout limit for industrial areas and given the dry natural background of the Husab Project site and that there are no homesteads nearby this is regarded a feasible and reasonable limit.
- The absence of visible dust plume at all tipping points and at the primary crusher would be the best indicator of effective control equipment in place. In addition the dustfall in the immediate vicinity of various materials handling sources should be less than 1 200 mg/m^2/day.
- Similarly, the absence of a dust plume from the waste dump under strong wind conditions would be a good indicator. Again, dust fallout directly downwind of the waste dump should not exceed 1 200 mg/m^2-day.

6.4.3.3 Receptor based Performance Indicators

Due to the number of mines proposed to operate within the Erongo region, and the location of the proposed Husab Project close to the existing Rössing Uranium Mine, it is recommended that the mine continue with dust fallout monitoring and PM_{10} sampling. This will provide the mine management with measured data to inform management plans and focus the attention on the main areas of concern.

The current monitoring network at the Husab Project area comprises of 8 single dust fallout buckets and one PM_{10} minivol sampler (sampling every 6th day). This should be continued throughout the life of mine. Since the current dust fallout network was designed on limited knowledge as where the mining operations will be the network was redesigned for when the mine is in operation. This is reflected in Figure 6-4.

The proposed dust fallout network was designed based on the proposed mine layout and main areas of impact. These can be described as follows:

- EXT01 should remain at it s current location close to the weather station and PM10 site which will be directly west of the main mining operations;
- EXT02 to be paced to the west of the proposed Zone 1;
- EXT03 directly west of the waste dump and south of Zone 2;
- EXT04 to be located at the ROM complex;
- EXT05 downwind of the waste dump;
- EXT06 downwind of the waste dump;
- EXT07 located next to the main access road; and,
- EXT08 downwind (southeast) from all the mining operations.

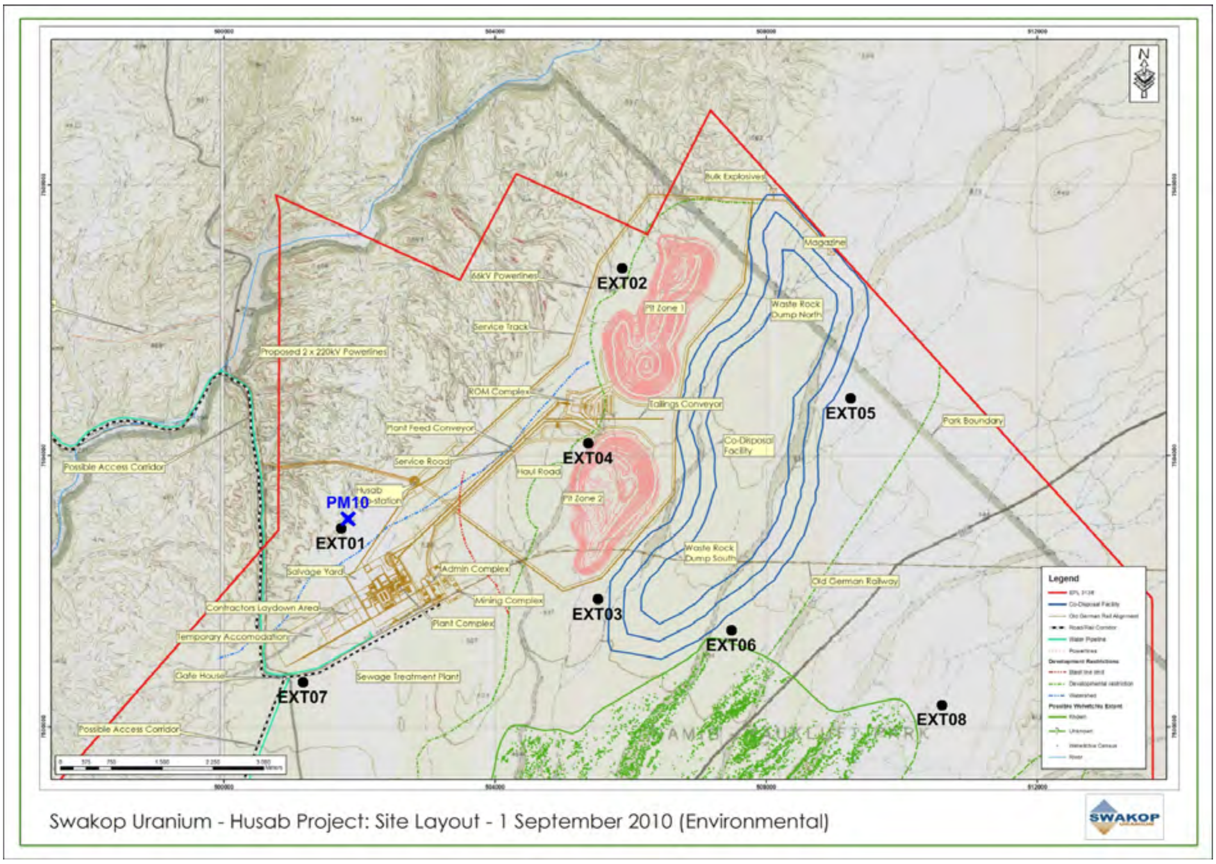

Figure 6-4: **Proposed monitoring network**

The technical difficulties around the PM_{10} sampler is being investigated and will be rectified. It is recommended that the mine continues with the PM_{10} sampling on a 6 day interval. This is to ensure that sampling is not conducted on the same day every week. The PM_{10} and dust fallout results should be kept in a central database with quarterly reports provide on the results.

It is recommended that site inspections and progress reporting be undertaken at regular intervals (at least quarterly) during operations, with annual environmental audits being conducted. Annual environmental audits will form part of the EMS for the Husab Project. Results from site inspections and on-site monitoring efforts should be combined to determine progress against source- and receptor-based performance indicators. Progress should be reported to all interested and affected parties, including authorities and persons affected by pollution. Corrective action or the implementation of contingency measures must be proposed to the stakeholder forum in the event that progress towards targets is indicated by the quarterly/annual reviews to be unsatisfactory.

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8 Appendix A – Fugitive Dust Emission Factors

8.1 Vehicle Entrained Dust from Unpaved Roads

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

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

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

Where,

E = *emissions in lb of particulates per vehicle mile travelled (g/VKT)*

K = *particle size multiplier (dimensionless);*

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

W = *mean vehicle weight (tons)*

The particle size multiplier in the equation (k) varies with aerodynamic particle size range and is given as 1.5 for PM10 and 4.9 for total suspended particulates (TSP). The constants a and b are given as 0.9 and 0.45 respectively for PM10 and as 0.7 and 0.45 respectively for TSP.

8.2 Materials Handling

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

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

where,

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

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

M = *material moisture content (%)*

k = *particle size multiplier (kPM10 = 0.35; kTSP = 0.74)*

8.3 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 8-1). These emission factors include emissions from the loading of crusher hoppers and screening.

Table 8-1: 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%

8.4 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 8-2.

Table 8-2: Australian NPI emission factors for drilling operations

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

8.5 Blasting

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

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

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)*

8.6 Wind Erosion

Significant emissions arise due to the mechanical disturbance of granular material from open areas and storage piles. Parameters which have the potential to impact on the rate of emission of fugitive dust include the extent of surface compaction, moisture content, ground cover, the shape of the area, particle size distribution, wind speed and precipitation. Any factor that binds the erodible material, or otherwise reduces the availability of erodible material on the surface, decreases the erosion potential of the fugitive source. High moisture contents, whether due to precipitation or deliberate wetting, promote the aggregation and cementation of fines to the surfaces of larger particles, thus decreasing the potential for dust emissions. Surface compaction and ground cover similarly reduces the potential for dust generation. The shape of a storage pile or disposal dump influences the potential for dust emissions through the alteration of the airflow field. The particle size distribution of the material on the disposal site is important since it determines the rate of entrainment of material from the surface, the nature of dispersion of the dust plume, and the rate of deposition, which may be anticipated (Burger, 1994; Burger et al., 1995).

The calculation of emission rates for various wind speeds and stability classes representative of the simulation period was carried out using the ADDAS model. This model is based on the dust emission model by Marticorena and Bergametti (1995). The model attempts to account for the variability in source erodibility through the parameterisation of the erosion threshold (based on the particle size distribution of the source) and the roughness length of the surface.

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

$$\boxed{E(i) = G(i) \cdot 10^{(0.134 \cdot \%clay - 6)}}$$

For

$$\boxed{G(i) = 0.261 \cdot \left[\frac{P_a}{g}\right] \cdot u^{*3} \cdot (1+R) \cdot (1-R^2)}$$

And

$$\boxed{R = \frac{u_*^{\,t}}{u^*}}$$

where,

$E_{(i)}$	=	*emission rate (g/m²/s) for particle size class i*
P_a	=	*air density (g/cm³)*
g	=	*gravitational acceleration (cm/s³)*
u_*^t	=	*threshold friction velocity (m/s) for particle size i*
u^*	=	*friction velocity (m/s)*

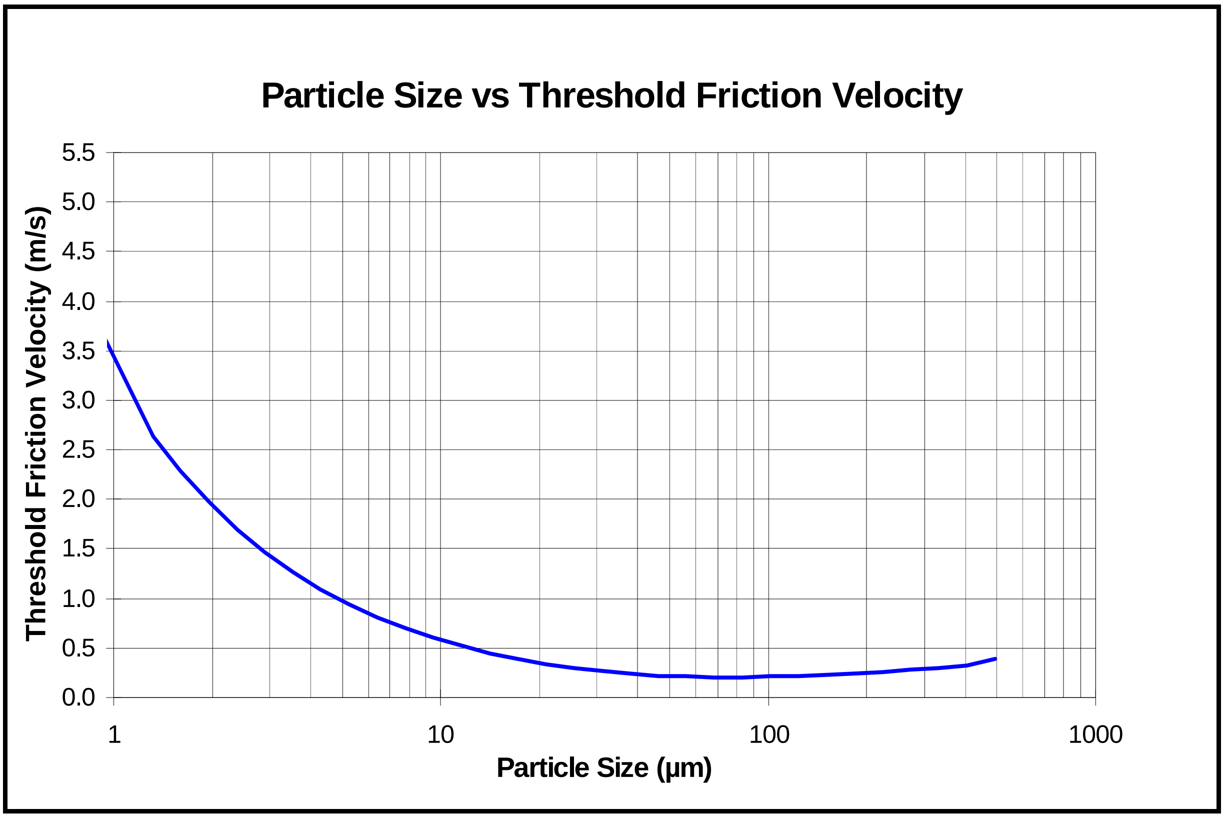

Figure 8-1: Relationship between particle sizes and threshold friction velocities

Dust mobilisation occurs only for wind velocities higher than a threshold value, and is not linearly dependent on the wind friction and velocity. The threshold friction velocity, defined as the minimum friction velocity required to initiate particle motion, is dependent on the size of the erodible particles and the effect of the wind shear stress on the surface. The threshold friction velocity decreases with a decrease in the particle diameter, for particles with diameters >60 µm. Particles with a diameter <60 µm result in increasingly high threshold friction velocities, due to the increasingly strong cohesion forces linking such particles to each other (Marticorena and Bergametti, 1995). The relationship between particle sizes ranging between 1 µm and 500 µm and threshold friction velocities (0.24 m/s to 3.5 m/s), estimated based on the equations by Marticorena and Bergametti (1995), is illustrated in Figure 8-1.

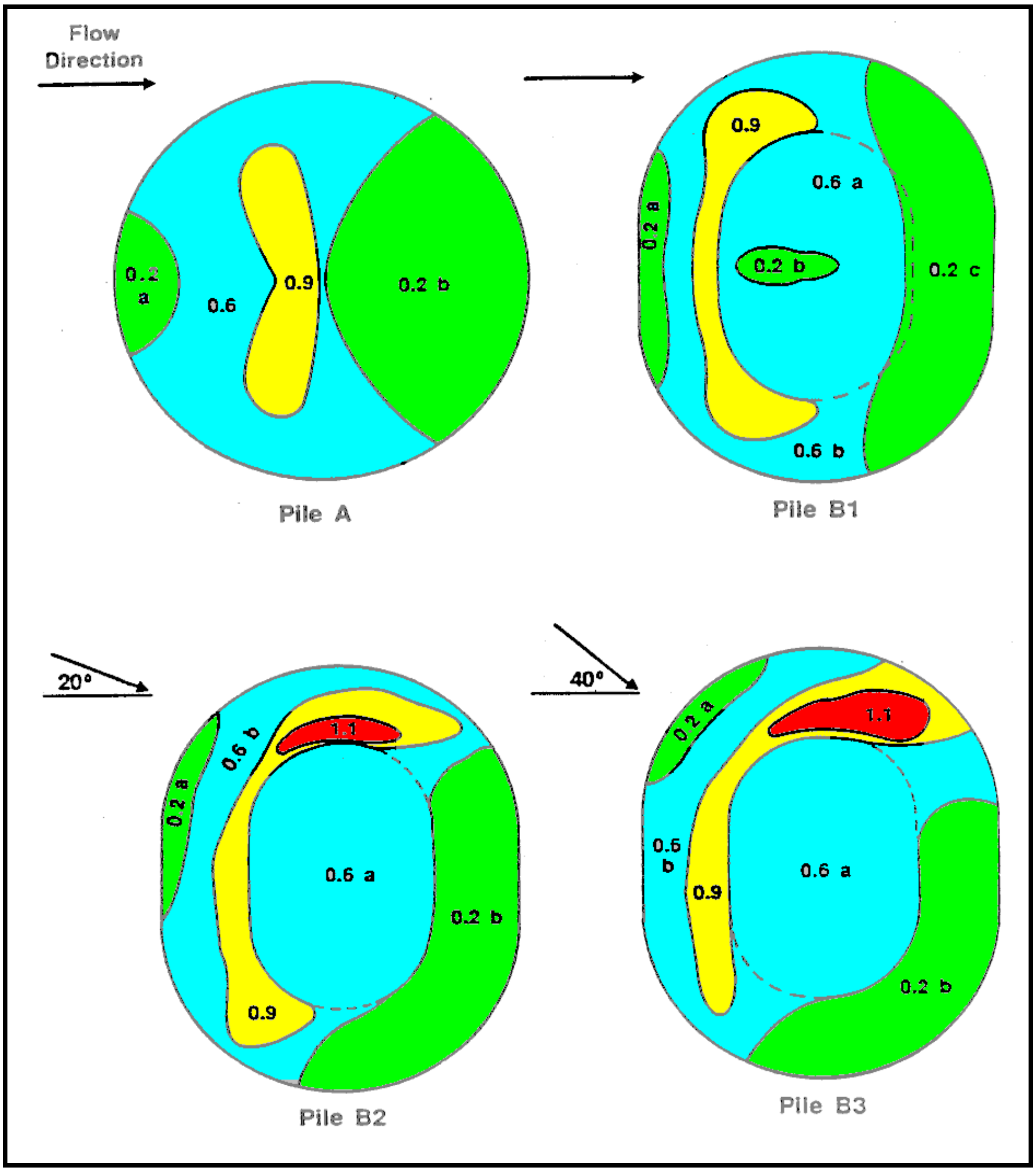

Figure 8-2: Contours of normalised surface wind speeds

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

$$\boxed{U^* = 0.053 \cdot U_{10}^+}$$

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

The wind speed variation over the area is based on the work of Cowherd et al. (1988). With the aid of physical modelling, the US-EPA has shown that the frontal face of an elevated pile (i.e. windward side) is exposed to wind speeds of the same order as the approach wind speed at the top of the area. The ratios of surface wind speed (u_s) to approach wind speed (u_r), derived from wind tunnel studies for two representative pile shapes, are indicated in Figure 8-2 (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).

9 Appendix B – Regional Climate of the Erongo Region

9.1 Synoptic Climatology

The synoptic scale circulation of the region is largely the result of its location between the South Atlantic and Indian Ocean subtropical high-pressure cells. The high pressure (HP) belt acts as a buffer against the travelling depressions and anticyclones of the middle latitudes, as a result these systems are only able to exert an indirect influence on the local weather. The presence of the HP belt is also responsible for the comparative persistence of the plateau-level pressure distribution patterns despite considerable changes in upper air flow patterns and frequent marked changes in the weather. Due to its location to the north of the HP belt, the region is also accessible to the tropical cyclones of the southwest Indian Ocean, the effects of which may vary from drought in some areas to floods in others, depending on the proximity of the cyclone's core (Torrance, 1972).

During winter months, the HP belt shifts northward resulting in the prevalence of the generally dry southeast trade winds and the occurrence of enhanced anticyclonic subsidence and fine conditions. North-easterly and northerly winds gain prominence during summer months. The air mass properties and weather associated with such north-easterly and northerly winds depend largely on their path. Air masses moving overland via East Africa are dry with lapse rates steep enough to give rise to afternoon thunderstorms. Air masses with an oceanic track are much moister producing more general thunderstorms. The rainy season reaches a peak during January and February with the location of the Inter-tropical Convergence Zone (ITCZ) over the northern half Zimbabwe. The ITCZ represents the zone of convergence of the north-eastern monsoons (moist or dry according to its recent track), the southeast trades (generally dry) and the very moist Congo north-westerly airflow. The rainy season usually ends in March as the south-easterly airstream to the south of the ITCZ strengthens in accordance with the movements of the high pressure systems along the southern African coast. The drier air limits the rainfall to thunderstorms and showers, which gradually become more infrequent (Torrance, 1972)..

Coastal lows originate along the west coast and follow the coastline towards the southeast coast. The temperature and wind shifts associated with coastal lows resemble those of cold fronts are ore often mistaken as such. The coastal low is heralded by the onset of the southerly buster (cool, onshore airflow behind the coastal low) during which time temperature drops rapidly and pressure begins to rise. Although coastal lows frequently produce greater surface cooling than cold fronts, these systems are usually shallow (seldom deeper than 1 500 m) and seldom produce any precipitation other than mist and drizzle. The passage of coastal lows over coastal regions results in average to below average surface pressures and the occurrence of cool, very moist conditions and fair to strong winds with a distinctly southerly component at and below the 900 hPa level. The coastal low system is most frequently capped by drier and warmer NNW airflow which arises from the dominant anticyclonic circulation (Preston-Whyte and Tyson, 1989).

9.2 Regional Meteorology

Meteorological mechanisms govern the dispersion, transformation, and eventual removal of pollutants from the atmosphere. The analysis of hourly average meteorological data is necessary to facilitate a comprehensive understanding of the ventilation potential of the site. The vertical dispersion of pollution is largely a function of the wind field. The wind speed determines both the distance of downward transport and the rate of dilution of pollutants. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness.

The wind field of the region represents a combination of the synoptic-scale circulation and the local land-sea breeze circulation. Wind data recorded during 2008 at Swakopmund indicate on average wind speeds below 4 m/s. Periods of high wind incidents (above 10 m/s) did however occur with the highest wind speeds measured during 2008 of 36 m/s (http://weather.namsearch.com). Historical records for Gobabeb indicate a higher frequency of east and south winds during winter months with mean velocities of up to 6 m/s. Winds of up to 14 m/s have also been associated with these winds. During the summer months winds from the northwest are more prevailing and are associated with lower velocities (Goudie, 1972). The wind field varies significantly within the Erongo Region as is indicated in Figure 9-2[1]. The wind direction in the central northern part between Karibib and Rössing Uranum Mine indicate predominant easterly and north-easterly winds and south-westerly winds. The easterly and north-easterly winds are also associated with high velocities. The wind field changes slightly around the Husab Project area and Etango Project areas with a shift towards northerly and north-westerly winds but keeping the strong presence of south-easterly winds. Wind speed for the region also varies but most of the stations records wind speeds between 0-10 m/s. Wind speeds between 13 m/s and 17 m/s have been recorded for short periods with the highest wind speed recorded at Pelican Point of 22.5 m/s during 2008. The maximum wind speed recorded inland was at Valencia Uranium Mine during 2008 of 16.5 m/s.

Air temperature is an important parameter for the development of the mixing and inversion layers. It also determines the effect of plume buoyancy as the larger the temperature difference between ambient air and the plume, the higher the plume will rise. This in turn will affect the rate of dissipation of pollutants before it reaches ground level. The annual average temperature map for the Erongo region is provided in Figure 9-1D. Incoming solar radiation also determines the rate of development and dissipation of the mixing layer. Relative humidity is an inverse function of ambient air temperature, increasing as ambient air temperature decreases. Figure 9-1G shows the relative humidity for the least humid month and Figure 9-1H shows it for the most humid month. The number of sunshine hours in the Erongo Region also increases rapidly from the coast towards the east, ranging from less than 5 hours at Swakopmund to more than 10 hours just a few kilometres inland (Figure 9-1E). Incoming solar radiation increases from sunrise (06:00) to reach a maximum at midday (12:00 –

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[1] The wind roses represent period wind roses for different averaging periods and is merely included to provide an indication of the variation in wind field for the Erongo Region.

13:00) and then decreases till sunset (19:00). Within the Erongo Region solar radiation is on average <5.4 kWhr per m^2 per day at the coast and up to 5.8 kWhr per m^2 per day further east. The Husab Project falls within the 5.6-5.8 kWhr per m^2 per day category (Figure 9-1F).

Precipitation represents an effective removal mechanism of atmospheric pollutants and is therefore frequently considered during air pollution studies. The Husab Project falls within the 0-50 mm/year rainfall belt as is shown in Figure 9-1A. 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 (Figure 9-1B).

Fog is a form of precipitation. Within the Erongo Region, fog can extend up to 110 km inland with an average number of days per annum recorded at Gobabeb of 102 between 1964 and 1967 (Goudie, 1972). Swakopmund also has high incidences of fog days of more than 125 days per year (http://209.88.21.36/Atlas/Atlas_web.htm). The annual fog precipitation at Swakopmund was estimated to be 35-45 mm in relation to 20 mm 40 km inland (Goudie, 1972). Figure 9-1C shows the regional fog index for the Erongo Region.

The Husab Project falls within the west coast arid zone of Southern Africa. Historical meteorological data are limited, with the Gobabeb Research Station (located ~65 km to the south of the Husab Project on the border with the Namib Desert) being in operation since 1962. Information on the climatic conditions of the region is therefore primarily focussed on the Central Namib.

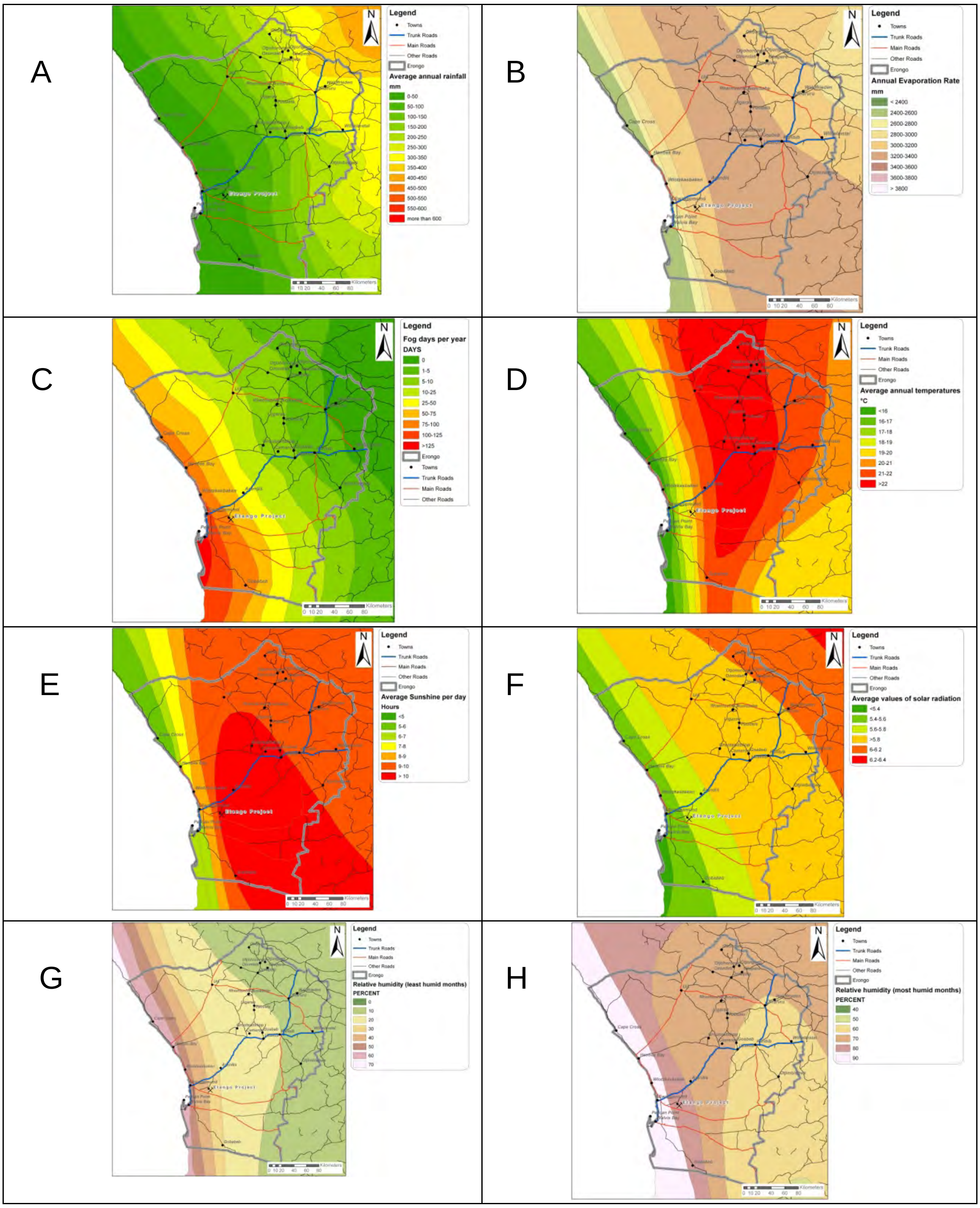

Figure 9-1: Atlas of Namibia Project (2002) on Climate (A) annual average rainfall; (B) average rates of evaporation; (C) approximate numbers of fog days per year; (D) annual average temperature; (E) average hours of sunshine per day; (F) average values of solar radiation; (G) relative humidity values during least humid month; (H) relative humidity values during most humid month.

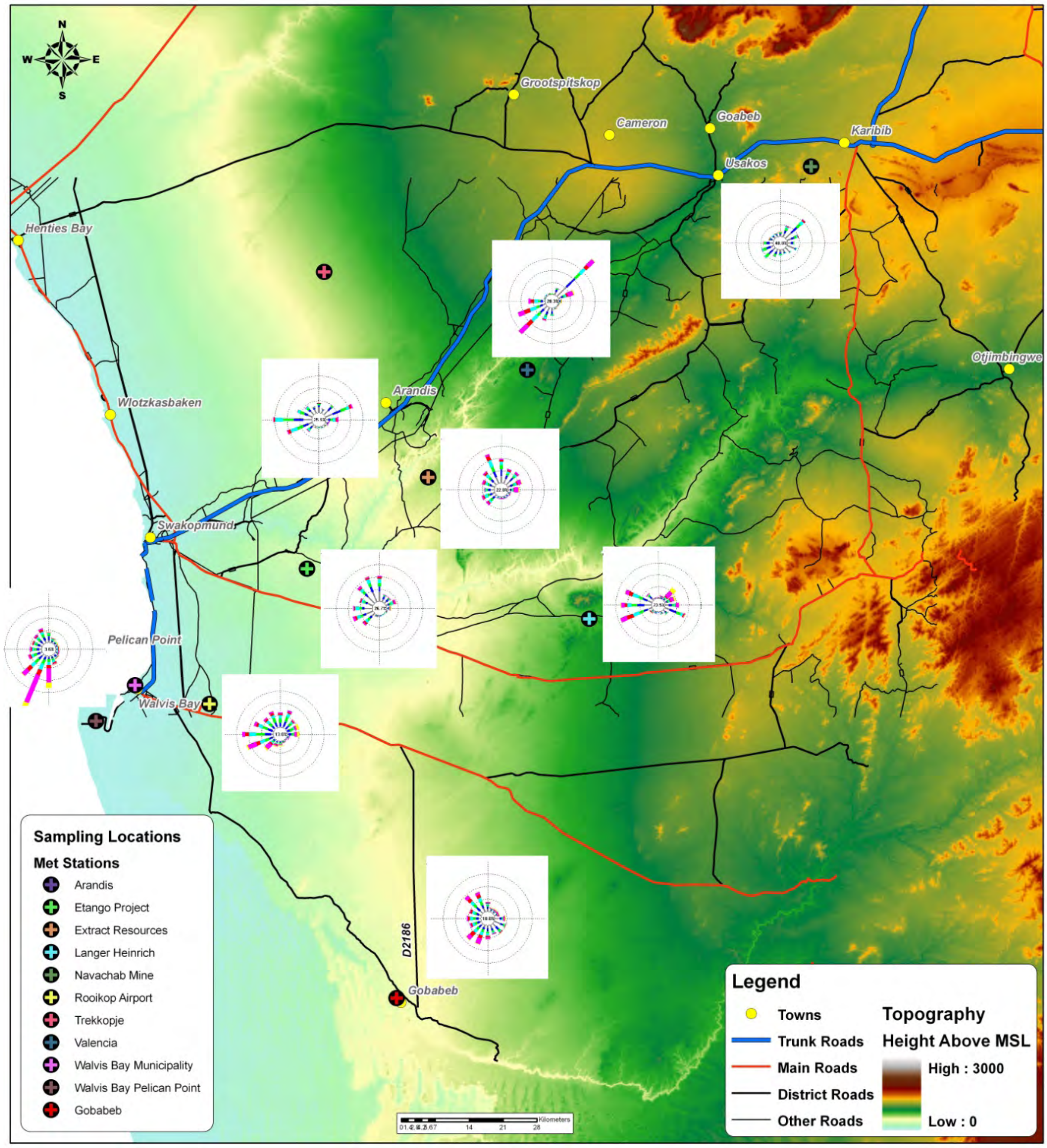

Figure 9-2: Period Wind Roses for various sites within the Erongo Region and for different time periods (data provided by the various mining houses).