Project Done on Behalf of
Ninham Shand Consulting Services

AIR QUALITY IMPACT ASSESSMENT FOR THE PROPOSED EXPANSION PROJECT FOR RÖSSING URANIUM MINE IN NAMIBIA: PHASE 1

Report No.: APP/07/NS-04 Rev 0.0

DATE: December 2007

Author: **RG Thomas**

Airshed Planning Professionals (Pty) Ltd

P O Box 5260
Halfway House
1685

Tel : +27 (0)11 805 1940
Fax : +27 (0)11 805 7010
e-mail : mail@airshed.co.za

REPORT DETAILS

Reference	APP/07/NS04
Status	Report, Revision 0
Report Title	Air Quality Impact Assessment for the Proposed Expansion Project for Rossing Uranium Mine in Namibia: Phase 1
Date Submitted	December 2007
Client	Ninham Shand Consulting Services
Prepared by	Reneé Thomas, BSc Hons (University of Pretoria)
Notice	Airshed Planning Professionals (Pty) Ltd is a consulting company located in Midrand, South Africa, specialising in all aspects of air quality, ranging from nearby neighbourhood concerns to regional air pollution impacts. The company originated in 1990 as Environmental Management Services, which amalgamated with its sister company, Matrix Environmental Consultants, in 2003.
Declaration	Airshed is an independent consulting firm with no interest in the project other than to fulfil the contract between the client and the consultant for delivery of specialised services as stipulated in the terms of reference.
Copyright Warning	
Acknowledgements	The authors would like to express their sincere appreciation for the invaluable discussions and technical input from Rainer Schneeweiss and personnel from Rössing Uranium Limited. The authors would also like to thank Etienne Oosthuizen from Bateman Minerals and Metals (Pty) Limited and Jurgens Hanekom from MECS Global in assisting with information on the proposed Ore Sorter Plant and Acid Plant respectively.

EXECUTIVE SUMMARY

Airshed Planning Professionals (Pty) Limited was appointed by Ninham Shand Consulting Services to undertake an air quality impact assessment for a proposed expansion project (Phase 1) for Rössing Uranium Limited.

The aim of the investigation was to quantify the possible impacts resulting from operational activities on the surrounding environment and human health. To achieve this, a good understanding of the regional climate and local dispersion potential of the site is necessary and subsequently an understanding of existing sources of air pollution in the region and the resulting air quality.

The investigation followed the methodology required for a specialist report, comprising the baseline characterisation and the impact assessment study.

Baseline Assessment

The baseline study encompassed the analysis of on-site meteorological data recorded at Rössing Uranium Mine. Hourly average wind field, temperature, pressure and precipitation data for the period 2006 was used to determine the dispersion potential for the region.

Emissions Inventory

Emissions inventories provide the source input required for the simulation of ambient air concentrations and dust deposition rates. During proposed activities, fugitive emissions from vehicle entrainment, materials handling, drilling and blasting activities were quantified. Emissions from stacks at the Ore Sorter Plant (baghouses) and Acid Plant were provided for proposed operating conditions.

Assumptions and Limitations

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

- Radiation associated with wind blown dust has not been considered as part of the air quality impact assessment and is seen to be covered by the Radiation Specialist. The predicted PM10 concentrations and dust fallout level can however be used to determine the potential impacts from radiation within the modelling domain;
- Emissions from the Acid Plant and Ore Sorting Plant were provided for the impact assessment. The assumption was made that these emissions were accurate and correct;
- Site specific silt loading and silt content on the haul roads could not be obtained for the current study. Typical values for mining operations were therefore used;
- Moisture content of ore mined was assumed to be 2%;
- The truck weight empty and full was taken to be 138 t and 324 t respectively;

- Measured upper air data was not available for the study area. Use was therefore made of calculated ETA data obtained from the South African Weather Services.

Impact Prediction Study

Particulate concentrations and deposition rates due to the operational activities were simulated using the US-EPA approved AERMET/AERMOD dispersion modelling suite. Ambient concentrations were simulated to ascertain highest hourly, highest daily and annual averaging levels occurring as a result of the proposed operations.

Conclusions

Dispersion simulations were undertaken for various scenarios, including:

- *Scenario 1:* Routine operations at the Acid Plant
- *Scenario 2:* Upset operating conditions at the Acid Plant – **Poor Start Up**: Temperature of pass 1 is above strike temperature and temperatures of passes 2 and/or 3 of the converter are below striking temperature. Pass 4 also below strike temperature.
- *Scenario 3:* Upset operating conditions at the Acid Plant – **Controlled Start Up**: All converter passes are at striking temperature (2-4 hours).
- *Scenario 4:* Upset operating conditions at the Acid Plant – **Boiler or other steaming equipment failure:** Normally a tube failure with lots of water entering the gas stream (15 minutes).
- *Scenario 5:* Upset operating conditions at the Acid Plant – **Interruption of acid flow to Acid Towers** (2-5 minutes).
- *Scenario 6:* Upset operating conditions at the Acid Plant – **Poor control of converter temperatures** (2-4 hours).
- *Scenario 7:* Upset operating conditions at the Acid Plant – **Poor control of acid concentrators** (1 hour).
- *Scenario 8:* Upset operating conditions at the Acid Plant – **Poor control of acid temperatures.**
- *Scenario 9:* Waste from the Ore Sorter plant is transported to waste storage area Option 1 via conveyor belt.

- *Scenario 10:* Waste from the Ore Sorter plant is transported to waste storage area Option 2 via conveyor belt.

- *Scenario 11:* Waste from the Ore Sorter plant is transported to waste storage area Option 3 via conveyor belt.

- *Scenario 12:* Waste from the Ore Sorter plant is transported to waste storage area Option 4 via conveyor belt.

- *Scenario 13:* Waste from the Ore Sorter plant is transported to waste storage area Option 1 via trucks.

- *Scenario 14:* Waste from the Ore Sorter plant is transported to waste storage area Option 2 via trucks.

- *Scenario 15:* Waste from the Ore Sorter plant is transported to waste storage area Option 3 via trucks.

- *Scenario 16:* Waste from the Ore Sorter plant is transported to waste storage area Option 4 via trucks.

The main findings from this investigation may be summarised as follows:

- All predicted sulphur dioxide (SO_2) ground level concentrations at the mine boundary and at Arandis, were in line with or below the relevant standards/guidelines for all averaging periods (for all scenarios).

- The hourly predicted ground level concentrations at the mine boundary and at Arandis were well below the effect screening level (as stipulated by the California Office of Environmental Health Hazard Assessment) for all scenarios.

- Highest hourly predicted carbon monoxide (CO) ground level concentrations due to blasting activities were within all relevant guidelines/standards.

- The predicted hydrogen sulphide (H_2S) ground level concentrations due to blasting activities were within effect screening levels for all averaging periods.

- *Incremental inhalable particulate matter (PM10) Impacts* – The highest daily predicted PM10 ground level concentrations at the mine boundary (for all scenarios) was in line with the current South African standard, but exceeded the proposed South African guideline, European Community (EC) limit and World Health Organisation (WHO) guideline. The main operations that contribute to these exceedances were the vehicle entrainment activities on the unpaved haul road from

SK4 pit to the waste dump and to the crusher. The EC daily PM10 limit allows for 35 exceedances of the 50 µg/m³ concentration level in a calendar year. The frequency of exceedance for the proposed operations was predicted to be 35 days for the simulated year of 2006.

- *Cumulative PM10 Impacts* – The annual average PM10 ground level concentrations due to the expansion (Phase 1) were predicted to increase by 90 µg/m³ (at Pit Field Staff), 50 µg/m³ to 800 µg/m³ (at Reduction Staff), 0.9 µg/m³ to 10 µg/m³ (at Recovery Staff), 0.8 µg/m³ to 8 µg/m³ (at Extraction Staff) and 1.5 µg/m³ to 6 µg/m³ (at Tailings Dam).

- *Incremental Dust Deposition* – The predicted dust deposition due to proposed operations was well below the proposed South African Residential Target Level (600 mg/m²/day) at the mine boundary and at Arandis for all scenarios.

- *Cumulative Dust Deposition* – The predicted dust fallout at the fallout plates on site was predicted to increase by 15 mg/m²/day to 100 mg/m²/day due to the expansion (Phase 1).

Recommendations

- It is recommended that a dust fallout network should be established to monitor increases in dust fallout in the surrounding area due to the proposed expansion activities;

- It is recommended that the Air Quality Management Plan as stipulated in Section 7 of the report, be implemented during the operational phases of the expansion (Phase 1);

- In addition, it is recommended that stack monitoring be undertaken once the proposed Acid Plant is in operation in order to verify the emissions from the process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

AIR QUALITY IMPACT ASSESSMENT FOR THE PROPOSED EXPANSION PROJECT FOR RÖSSING URANIUM MINE IN NAMIBIA: PHASE 1

1. INTRODUCTION

Airshed Planning Professionals (Pty) Limited was appointed by Ninham Shand Consulting Services to undertake an air quality impact assessment for a proposed expansion project for Rössing Uranium Limited. The expansion project will comprise of two phases.

The current study is undertaken for Phase 1 of the project. This phase will comprise of:

- The establishment of an on-site sulphur burning sulphuric acid production plant;
- The establishment of a radiometric ore sorter plant with associated reject rock disposal facilities;
- An open pit development (SK4), within the larger area designated as SK.

Specialist investigations conducted as part of an air quality assessment typically comprise two components, viz. a baseline study and an air quality impact and compliance assessment study.

The *baseline study* includes the review of the site-specific atmospheric dispersion potential, relevant air quality guidelines and limits and existing ambient air quality in the region. In this investigation, use was made of readily available surface meteorological data recorded in the study area in the characterisation of the baseline condition.

The *ambient air quality impact assessment* comprised the establishment of an emissions inventory for the proposed development, the simulation of ambient air pollutant concentrations and dustfall rates occurring due to project development and operation, and the evaluation of the resultant potential for impacts and non-compliance.

1.1 Terms of Reference

The terms of reference of the *baseline study component* are as follows:

- The regional climate and site-specific atmospheric dispersion potential;
- Identification of the potential sensitive receptors within the vicinity of the proposed site;
- Preparation of hourly average meteorological data for the wind field model;
- Obtain and process topographical data for input into the dispersion model;
- Identification of existing sources of emission and characterisation of ambient air quality and dustfall levels in the region based on existing observational data (if available);

- The legislative and regulatory context, including emission limits and guidelines, ambient air quality guidelines and dustfall classifications.

The terms of reference for the *air quality impact assessment component* include the following:

- Compilation of an emissions inventory, comprising the identification and quantification of potential routine and upset sources of emission;
- Dispersion simulations of ambient concentrations and dust fallout from the activities;
- Analysis of dispersion modelling results (*non-radioactive*) from both mining and acid plant operations, including:
    - Assessment of the predicted incremental ground level concentrations;
    - Assessment of the predicted cumulative ground level concentrations (if sufficient information is available).
    - Evaluation of potential for human health and environmental impacts

1.2 Site Description

The Rössing Uranium Mine is located just north of the Namib-Naukluft Park in the Erongo Region of Namibia (Figure 1-1).

On a regional scale the Rössing/Khan formations starts about 40 km directly east of Swakopmund and stretch northeast for approximately 70 km. Rössing Uranium Mine is located within the Rössing formations. The altitude at the Rössing Uranium Mine is ~630 mamsl (meters above mean sea level). The Khan River runs through the Rössing/Khan formations, cutting through the southern mine boundary of the mine.

1.3 Sensitive Receptors

Given that the project will be associated with low level fugitive emissions (e.g. from mining operations, and vehicle entrainment) and elevated emissions (stacks from the ore sorter and sulphuric acid production plant), the proposed project has the potential of impacting on receptors in the near and medium fields.

Residential areas in the vicinity of the proposed operations include Arandis located ~2 km northwest of the mine boundary. Larger residential developments within a 50km radius are Swartkopmund (east-southeast of the mine).

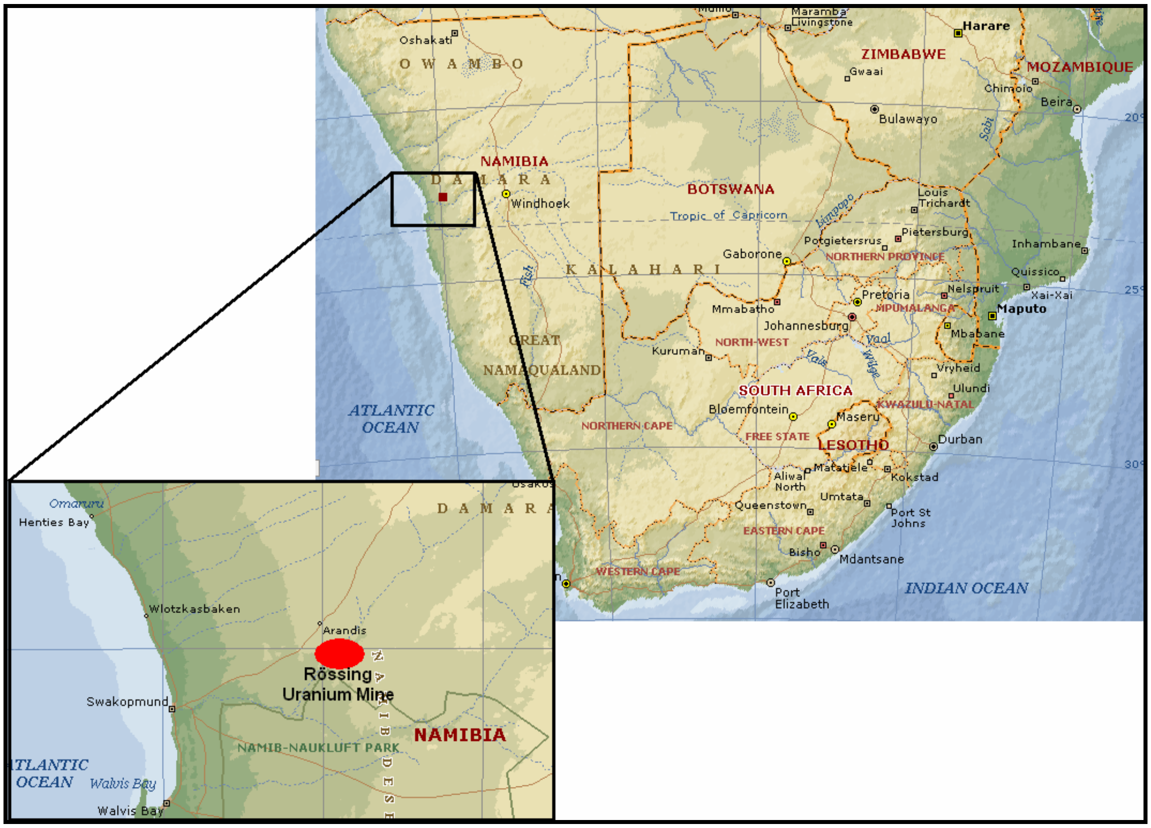


Figure 1-1: Location of the Rössing Uranium Mine in Namibia

1.4 Methodological Approach

1.4.1 Atmospheric Dispersion Model Selection

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

It was decided to employ the most recently US Environmental Protection Agency's (US EPA) approved regulatory model. The most widely used US EPA model has been the Industrial Source Complex Short Term model (ISCST3). This model is based on a Gaussian plume model. However this model has been replaced by the new generation AERMET/AERMOD suite of models. AERMOD is a dispersion model, which was developed under the support of the AMS/EPA Regulatory Model Improvement Committee (AERMIC), whose objective has been to include state-of the-art science in regulatory models (Hanna *et al.,* 1999). The AERMOD is a dispersion modelling system with three components, namely: AERMOD

(AERMIC Dispersion Model), AERMAP (AERMOD terrain pre-processor), and AERMET (AERMOD meteorological pre-processor).

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

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

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

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

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

Similar to the ISC model, a disadvantage of the model is that spatial varying wind fields, due to topography or other factors cannot be included. Although the model has been shown to be an improvement on the ISC model, especially short-term predictions, the range of uncertainty of the model predictions is -50% to 200%. The accuracy improves with fairly strong wind speeds and during neutral atmospheric conditions.

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

1.4.2 Meteorological Data Requirements

AERMOD requires two specific input files generated by the AERMET pre-processor. AERMET is designed to be run as a three-stage processor and operates on three types of data (upper air data, on-site measurements, and the national meteorological database). On-site surface meteorological data, for the period 2006 was used for the simulations. Calculated upper air ETA data was obtained from the South African Weather Services for the point 22°30’S; 15°00’E.

1.4.3 Source Data Requirements

The AERMOD model is able to model point, area, volume and line sources. The materials handling operations were simulated as volume sources. Point source releases from the Sulphuric Acid Plant and Ore Sorting Plant (viz. stacks) were simulated for operational activities.

1.4.4 Modelling Domain

The dispersion of pollutants was modelled for an area covering ~12 km (north-south) by ~14 km (east-west). This area was divided into a grid with a resolution of ~83 m (north-south) by ~92 m (east-west), and a total of 22 500 receptor points. . The AERMOD model simulates ground-level concentrations for each of the receptor grid points.

1.4.5 Topography

The topography is relatively undulating (Figure 1-2) at the site and was included for dispersion modelling purposes (Figure 1-3).

Figure 1-2: Undulating topography at the Rössing site.

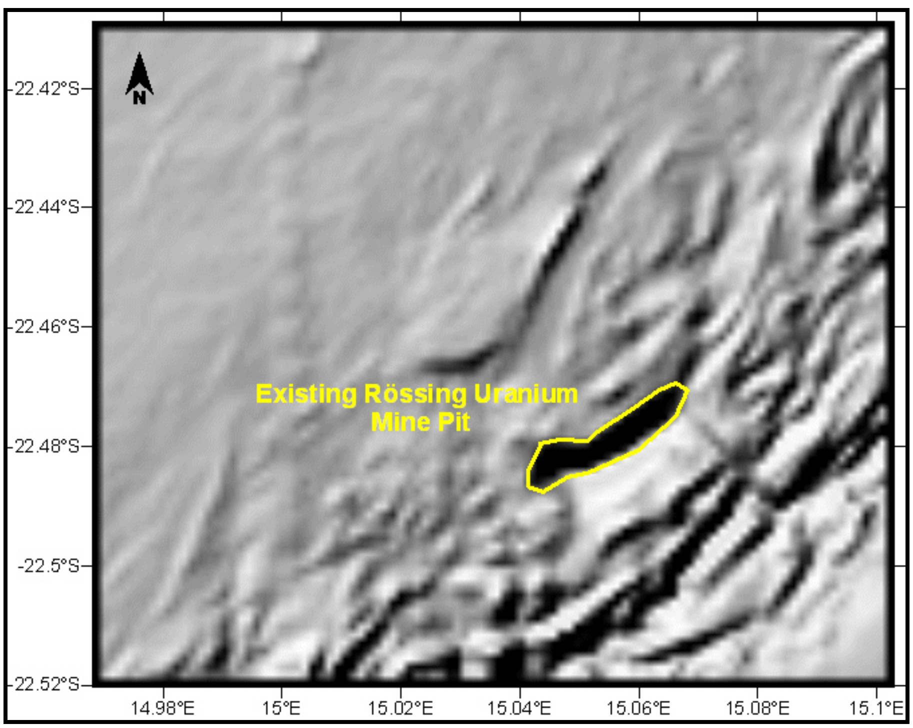


Figure 1-3: Shaded relief profile of the study area.

1.5 Assumptions and Limitations

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

- Radiation associated with wind blown dust has not been considered as part of the air quality impact assessment and is seen to be covered by the Radiation Specialist. The predicted PM10 concentrations and dust fallout level can however be used to determine the potential impacts from radiation within the modelling domain;
- Emissions from the Acid Plant and Ore Sorting Plant were provided for the impact assessment. The assumption was made that these emissions were accurate and correct;
- Site specific silt loading and silt content on the haul roads could not be obtained for the current study. Typical values for mining operations were therefore used;
- Moisture content of ore mined was assumed to be 2%;
- The truck weight empty and full was taken to be 138 t and 324 t respectively;
- Measured upper air data was not available for the study area. Use was therefore made of calculated ETA data obtained from the South African Weather Services.

1.6 Outline of Report

Legal requirement and human health criteria applicable to the proposed expansion (Phase 1) of the Rössing Mine are presented in Section 2. The synoptic climatology and atmospheric dispersion potential of the area are discussed in Section 3 and information on existing sources and baseline air quality given in Section 4. Section 5 presents the emissions inventory for the proposed expansion. Dispersion model results are presented and the main findings of the air quality compliance and impact assessments documented in Section 6. Air Quality Management measures are provided in Section 7 and recommendations and conclusions are presented in Section 8.

2. LEGAL REQUIREMENTS AND HUMAN HEALTH CRITERIA

In addressing the impact of air pollution emanating from proposed mine and associated process plant, some background on the health effects of the various pollutants 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 of each pollutant.

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 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.

2.1 Namibia 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.

This Act 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. These air pollution guidelines have been provided for a number of criteria pollutants namely, sulphur dioxide, oxides of nitrogen, carbon monoxide, ozone, lead and particulate matter. The adoption of a revised guideline for sulphur dioxide was promulgated on 21 December 2001 in terms of the Act. The second schedule to the Act has 72 Scheduled Processes listed. Given the preliminary nature of the proposed plant, it does not appear to fall within any of these scheduled processes.

The South African air pollution act has been revised and recently commenced with. The new act, the National Environmental Management: Air Quality Act (AQA), 2004 (Act No. 39 of 2004) took effect on 11 September 2005, with the exclusion of sections 21, 22, 36 to 49, 51(1)(e), 51(1)(f), 51(3) and 61. Schedule 2 of the AQA provides ambient air quality standards that were based on the previously adopted Department of Enviromental Affairs and Tourism (DEAT) guidelines. These are currently being revised with the publication of the new ambient air quality standards (*Government Gazette No. 28899, 9 June 2006*) for public comment. These standards are based on those issued by the South African National Standards (SANS) during 2004[1].

It is not clear how the legal developments in South Africa have affected the Namibian legislation. Compliance of the operation would therefore be measured against the old DEAT guidelines (as used in the original APPA of 1965) and the newly proposed AQA standards, which have been based on the SANS limit values (SANS 1929), which are more in line with international trends.

2.2 World Bank Requirements

The World Bank Group (WBG) has no sector specific guidelines for Uranium mining and/or production but has guidelines for Coal Mining and Production, and General Environmental Guidelines. These are provided in the Pollution Prevention and Abatement Handbook of 1999. The conditions for coal mining are fairly general and consist primarily of good practice and Best Available Technology (BAT) to be applied.

The WBG stipulates that a mining plan and a mine closure plan must be prepared and approved before mining commences. The development plan describes in detail the mining methods and sequence and nature of extraction. This plan must include for instance (both are not limited to) the removal and storage of topsoil, early restoration of worked-out areas, reduction of dust by early re-vegetation and by good maintenance of roads and work areas, control of the release of chemicals, and control of methane gas (a greenhouse gas) to less than 1% of volume. The mine closure plan should include the reclamation of open pits, waste piles, beneficiation tailings, sedimentation basins, and abandoned mine, mills, and camp sites. These plans should include (but not limited) use of overburden for backfill, contour

[1] The South African Bureau of Standards (SABS) was initially engaged to assist the Department of Environmental Affairs and Tourism (DEAT) in the facilitation of the development of ambient air quality standards. This process resulted in the publication of: (a) SANS 69 - South African National Standard - Framework for setting & implementing national ambient air quality standards, and (b) SANS 1929 - South African National Standard - Ambient Air Quality - Limits for common pollutants. The latter document includes air quality limits for particulate matter less than 10 µm in aerodynamic diameter (PM10), dust fall, sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide, lead and benzene. The SANS documents were approved by the technical committee for gazetting for public comment. They were made available for public comment during the May/June 2004 period and were finalised and published during the last quarter of 2004. In the first publication of the AQA, DEAT did not adopt these targets, but rather decided to include the previous CAPCO guidelines as standards in the second schedule, with a view of replacing these with alternative thresholds in the future. The new ambient air quality standards have been published (Government Gazette No. 28899, 9 June 2006) for public comment. The proposed standards adapted the SANS 1929 limit values for sulphur dioxide, nitrogen dioxide, carbon monoxide, particulate matter, ozone, lead and benzene.

slopes, and plant indigenous vegetation. All mine shafts should be closed and sealed on mine closure.

Emission guidelines should be developed as part of the Environmental Assessment process, hence based on pollution impacts. However the WBG has established emission guidelines which can consistently be achieved by well-designed, well-operated and well-maintained pollution control systems. It should be noted that dilution of air emissions in order to achieve these guidelines are unacceptable. All of the maximum levels should be achieved for at least 95% of the time on an annual basis.

Controls may be required on individual sources. For crushing operations, fabric filters or other systems should be used ensuring particulate emission concentrations of less than 50 mg/Nm³.

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. To ensure the guidelines and standards used in the current study are in line with the most current international best practice, these guidelines and standards are compared to the World Health Organisation (WHO) guidelines which have recently been revised (October 2005). The newly updated Environmental Health and Safety (EHS) guidelines published by the WB's International Finance Corporation (IFC) in April 2007 reference the WHO guidelines in the absence of national legislate standards. Since the Namibian legislation pertaining to air quality management is based on the South African APPA, the guidelines as was stipulated under the APPA will be referenced as well as the new proposed South African ambient air quality standards.

The main pollutant of concern from the proposed mine and processing plant is particulates, sulphur dioxide (SO_2) and sulphuric acid mist. Other pollutants due to blasting activities consists of hydrogen sulphide (H_2S) and carbon monoxide (CO).

2.3.1 Suspended Particulate Matter

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

The nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne particulates. Larger particles are deposited in the nasal region by impaction on the hairs of the nose or at the bends of the nasal passages. Smaller particles (PM10) pass through the nasal region and are deposited in the tracheobronchial and pulmonary regions. Particles are removed by impacting with the wall of the bronchi when they are unable to follow the gaseous streamline flow through subsequent bifurcations of the bronchial tree. As the airflow decreases near the terminal bronchi, the smallest particles are removed by Brownian motion, which pushes them to the alveolar membrane (CEPA/FPAC Working Group, 1998; Dockery and Pope, 1994).

Air quality guidelines for particulates are given for various particle size fractions, including total suspended particulates (TSP), inhalable particulates or PM10 (i.e. particulates with an aerodynamic diameter of less than 10 µm), and respirable particulates of PM2.5 (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. PM10 and PM2.5 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.

PM10 limits and standards issued nationally and abroad are documented in Table 2-1. In addition to the PM10 standards published in schedule 2 of the Air Quality Act, the Act also includes standards for total suspended particulates (TSP), viz. a 24-hour average maximum concentration of 300 µg/m³ not to be exceeded more than three times in one year and an annual average of 100 µg/m³.

Table 2-1: Air quality standard for inhalable particulates (PM10)

Authority	Maximum 24-hour Concentration (µg/m³)	Annual Average Concentration (µg/m³)
SA standards (Air Quality Act)	180(a)	60
RSA SANS limits (SANS:1929,2004)	75(b) 50(c)	40(d) 30(e)
World Bank Group	(f)	(f)
World Health Organisation	50(g)	20(g)
European Community (EC)	50(h)	30(i) 20(j)
United Kingdom	50(k)	40(l)
United States EPA	150(m)	50(n)

Notes:

(a) Not to be exceeded more than three times in one year.
(b) Limit value. Permissible frequencies of exceedance, margin of tolerance and date by which limit value should be complied with not yet set.
(c) Target value. Permissible frequencies of exceedance and date by which limit value should be complied with not yet set.
(d) Limit value. Margin of tolerance and date by which limit value should be complied with not yet set.
(e) Target value. Date by which limit value should be complied with not yet set.
(f) World Bank Group, 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.
(g) WHO (2000) issued linear dose-response relationships for PM10 concentrations and various health endpoints with no specific guideline provided. WHO (2005) made available during early 2006 proposes several interim target levels (see Table 2-2 and 2-3).
(h) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Compliance by 1 January 2005. Not to be exceeded more than 25 times per calendar year. (By 1 January 2010, no violations of more than 7 times per year will be permitted.)

(i) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Compliance by 1 January 2005

(j) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Compliance by 1 January 2010

(k) UK Air Quality Standard. (http://www.defra.gov.uk/environment/airquality/regulations.htm. Not to be exceeded more than 35 times per year.

(l) UK Air Quality Standard. (http://www.defra.gov.uk/environment/airquality/regulations.htm.

(m) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than once per year on average over three years.

(n) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). The annual standard revoked, effective 17 December 2006.

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). The air quality guidelines and interim targets issued by the WHO in 2005 for particulate matter are given in Tables 2-2 and 2-3.

Table 2-2: WHO air quality guideline and interim targets for particulate matter (annual mean) (WHO, 2005)

Annual Mean Level	PM10 (µg/m^3)	PM2.5 (µg/m^3)	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: WHO air quality guideline and interim targets for particulate matter (daily mean) (WHO, 2005)

Annual 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)*	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)**	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

* 99th percentile (3 days/year)

** 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 Dust Deposition

Foreign dust deposition standards issued by various countries are given in Table 2-4. 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 locally. 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 2-4: 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: Hawaii Kentucky	 200 175	

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)
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)	

Locally dust deposition is evaluated according to the criteria published by the South African Department of Environmental Affairs and Tourism (DEAT). In terms of these criteria dust deposition is classified as follows:

SLIGHT - less than 250 mg/m^2/day

MODERATE - 250 to 500 mg/m^2/day

HEAVY - 500 to 1200 mg/m^2/day

VERY HEAVY - more than 1200 mg/m^2/day

The Department of Minerals and Energy (DME) uses the uses the 1 200 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.

"Slight" dustfall is barely visible to the naked eye. "Heavy" dustfall indicates a fine layer of dust on a surface, with "very heavy" dustfall being easily visible should a surface not be cleaned for a few days. Dustfall levels of > 2000 mg/m^2/day constitute a layer of dust thick enough to allow a person to "write" words in the dust with their fingers.

A perceived weakness of the current dustfall guidelines is that they are purely descriptive, without giving any guidance for action or remediation (SLIGHT, MEDIUM, HEAVY, VERY HEAVY). It has recently been proposed (as part of the SANS air quality standard setting processes) that dustfall rates be evaluated against a four-band scale, as presented in Table 2-5. Proposed target, action and alert thresholds for ambient dust deposition are given in Table 2-6.

According to the proposed 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.

Table 2-5: Bands of dustfall rates proposed for adoption

BAND NUMBER	BAND DESCRIPTION LABEL	DUST-FALL RATE (D) (mg m^{-2} day^{-1}, 30-day average)	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 2-6: Target, action and alert thresholds for ambient dustfall

LEVEL	DUST-FALL RATE (D) (mg m^{-2} day^{-1}, 30-day average)	AVERAGING PERIOD	PERMITTED FREQUENCY OF EXCEEDANCES
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.

2.3.3 Sulphur Dioxide

Sulphur dioxide (SO_2) is an irritating gas that is absorbed in the nose and aqueous surfaces of the upper respiratory tract and is associated with reduced lung function and increased risk of mortality and morbidity. Adverse health effects of SO_2 include coughing, phlegm, chest discomfort and bronchitis. Ambient air quality guidelines and standards issued for various countries and organisations for SO_2 are given in Table 2-7.

Table 2-7: Ambient air quality guidelines and standards for SO_2 for various countries and organisations

Authority	Maximum 10-minute Average (µg/m³)	Maximum 1-hourly Average (µg/m³)	Maximum 24-hour Average (µg/m³)	Annual Average Concentration (µg/m³)
SA standards (Air Quality Act)	500	-	125	50
RSA SANS limits (SANS:1929,2004)	500	350	125	50
World Bank Group	(a)	(a)	(a)	(a)
World Health Organisation (2000)	500(b)		125(b)	50(b) 10-30(c)
World Health Organisation (2005)	500(d)		20(d)	(d)
European Community (EC)	-	350(e)	125(f)	20(g)
United Kingdom	-	350(h)	125(i)	20(j)
United States EPA	-	-	365(k)	80

Notes:

(a) World Bank Group, 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) WHO Guidelines for the protection of human health (WHO, 2000).

(c) Represents the critical level of ecotoxic effects (issued by WHO for Europe); a range is given to account for different sensitivities of vegetation types (WHO, 2000).

(d) WHO Air Quality Guidelines, Global Update, 2005 – Report on a Working Group Meeting, Bonn, Germany, 18-20 October 2005. Documents new WHO guidelines primarily for the protection of human health. The 10-minute guideline of 500 µg/m³ published in 2000 remains unchanged but the daily guideline is significantly reduced from 125 µg/m³ to 20 µg/m³ (in line with the precautionary principle). An annual guideline is given at not being needed, since "compliance with the 24-hour level will assure lower levels for the annual average".

(e) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Limit to protect health, to be complied with by 1 January 2005 (not to be exceeded more than 24 times per calendar year).

(f) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Limit to protect health, to be complied with by 1 January 2005 (not to be exceeded more than 3 times per calendar year).

(g) EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Limited value to protect ecosystems. Applicable two years from entry into force of the Air Quality Framework Directive 96/62/EC.

(h) UK Air Quality Standard (http://www.defra.gov.uk/environment/airquality/regulations.htm). Not to be exceeded more than 24 times per year.

(i) UK Air Quality Standard (http://www.defra.gov.uk/environment/airquality/regulations.htm). Not to be exceeded more than 3 times per year.

(j) UK Air Quality Standard for protection of ecosystems (http://www.defra.gov.uk/environment/airquality/regulations.htm).

(k) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than once per year.

It is important to note that the WHO AQGs published in 2000 for SO_2 have recently 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 2-8.

Table 2-8: WHO air quality guidelines and interim guidelines for SO_2 (WHO, 2005)

	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**

(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).

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 2-9.

Table 2-9: Ambient air quality guidelines and standards for CO for various countries and organisations

Authority	Maximum 1-hourly Average (µg/m³)	Maximum 8-hour Average (µg/m³)
SA standards (Air Quality Act)	40 000	10 000
RSA SANS limits (SANS:1929,2004)	30 000	10 000
World Bank Group	(a)	(a)
World Health Organisation (2000)	30 000(b)	10 000(b)
European Community (EC)	-	10 000(c)
United Kingdom	-	10 000(d)
United States EPA	40 000(e)	10 000(e)

Notes:
(a) World Bank Group, 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) 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). Limit value to be complied with by 1 January 2005.
(d) UK Air Quality Standard (http://www.defra.gov.uk/environment/airquality/regulations.htm). Maximum daily running 8-hourly mean.
(e) US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than one per year.

2.3.5 Non-Criteria Pollutants – Health Thresholds

Reference has been made to various effects screening and health risk criteria to ensure that the potential for risks due to all pollutants being considered could be gauged. (Effect screening levels are generally published for a much wider range of pollutants compared to health risk criteria.)

Risk Assessment Information System (RAIS) inhalation reference and the Office of Environmental Health Hazard Assessment (OEHHA) concentrations were considered (Table 2-10). Where various effect screening and health risk thresholds are available for one pollutant, the most stringent threshold is used in the screening of predicted pollutant concentrations.

Table 2-10: Health risk criteria for non-carcinogenic exposures via the inhalation pathway.

	WHO Guidelines -2000		RAIS Inhalation Reference Concentrations		Californian OEHHA (adopted as of August 2003)		US ATSDR Maximum Risk Levels (MRLs)		
Constituent	**Acute & Sub-acute Guidelines (ave period given) µg/m³**	**Chronic Guidelines (year +) µg/m³**	**Sub-chronic Inhalation RfCs µg/m³**	**Chronic Inhalation RfCs µg/m³**	**Acute RELs (ave period given) µg/m³**	**Chronic RELs µg/m³**	**Acute (1-14 days) µg/m³**	**Intermediate (>14-365 days) µg/m³**	**Chronic (365+ days) µg/m³**
Hydrogen sulphide	7 (GV) 30-min [(a)] 150 (GV) 24 hrs 260 (GV) 1-week		10 [(c)]	2 [(b)]	425 (1 hr)	10	533	53	
Sulphuric acid					120 (1 hr)	1			

Abbreviations:

WHO – World Health Organisation

RAIS – Risk Assessment Information System

OEHHA – Office of Environmental Health Hazard Assessment
ATSDR – US Federal Agency for Toxic Substances and Disease Registry
TC – tolerable concentration
GV – guideline value
RfC – inhalation reference concentration
MRL – maximum risk level
REL – reference exposure level

(a) Given for odour.
(b) Source: Integrated Risk Information System (IRIS)
(c) Source: Health Effects and Environmental Affects Summary Table (HEAST) 1995

3. ATMOSPHERIC DISPERSION POTENTIAL

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

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

3.1 Meso-scale Climatology and Atmospheric Dispersion Potential

3.1.1 Meso-Scale Wind Field

The analysis of meteorological data observed for the site provides the basis for the parameterisation of the meso-scale ventilation potential of the site, and to provide the input requirements for the dispersion simulations. 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. A comprehensive data set for at least one year of detailed hourly average wind speed, wind direction and temperature data are needed for the dispersion simulations. Meteorological data for the period October 2006 to August 2007 was obtained from Rössing Uranium Mine.

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.

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

The period, daytime and nighttime wind roses for Rössing Mine are provided in Figure 3-1 with the seasonal wind roses provided in Figure 3-2.

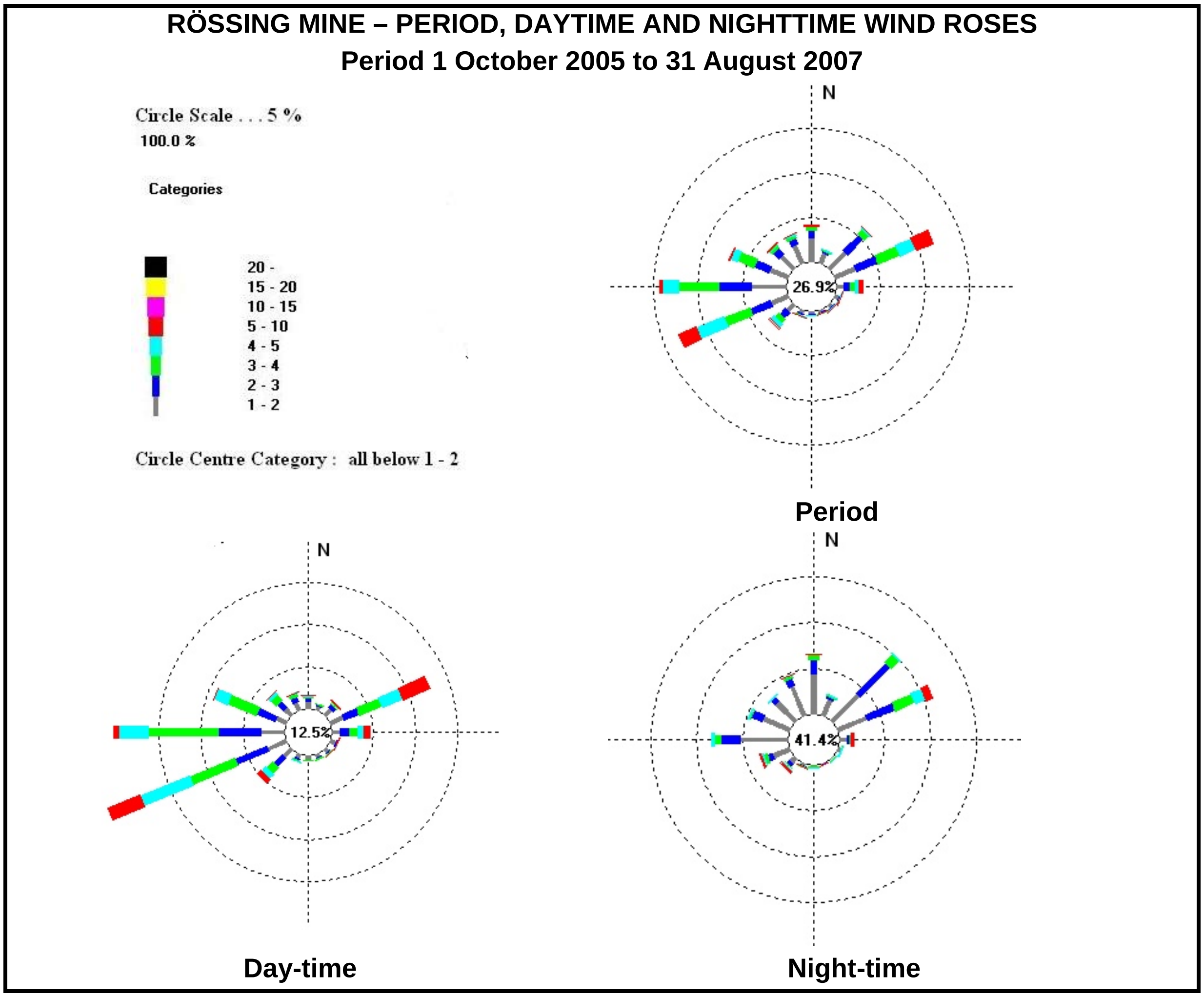


Figure 3-1: Period, daytime and nighttime wind roses for Rössing Mine (1 October 2005 to 31 August 2007).

The prevailing wind direction at Rössing for the 2 year period is from the west (14% of the time), the west-southwest (13%) and the east-northeast (13%). This wind direction also dominates daytime and nighttime wind patterns. These wind components are characterised by low to moderate strong wind speeds. Wind speeds exceeding 5 m/s occurred for 5.4% of the time with the maximum recorded at 8.5 m/s. During the day the westerly and west-southwesterly winds were more dominant with a distinct decrease during nighttime from this direction. Nocturnal flow reflected increases from the northeasterly sector and the north and associated lower wind speeds. As is typical of nighttime conditions an increase in calm conditions from 13% (during daytime) to 41% was noted.

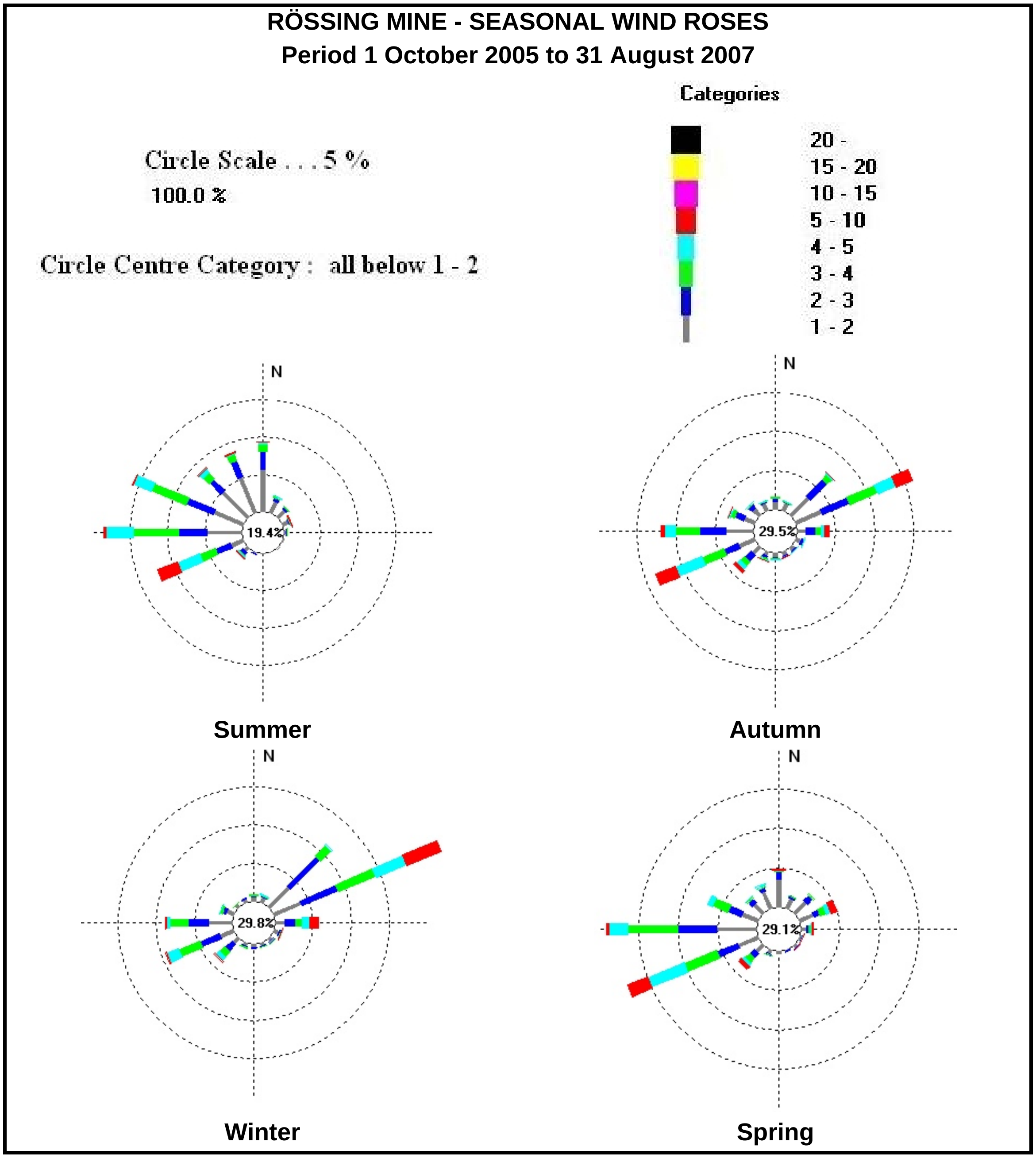


Figure 3-2: Seasonal-average wind roses for Rössing Mine (1 October 2005 to 31 August 2007).

Seasonal average wind roses reflected distinct shifts in the wind field between the summer, autumn, winter and spring months. During the summer months the average wind direction was from the westerly sector, ranging from the west-southwest to the north with almost no flow from the southeast. A shift from the northerly to northeasterly flow was evident during the autumn months with an increase in the west-southwesterly flow. Similar wind field patterns are presented for the winter months with more frequent flow from the northeast. Springtime indicate a reduction of inland windflow with frequent winds from the westerly sector. The frequencies of calms are given as 19.4%, 29.5%, 29.8% and 29.1% for summer, autumn, winter and spring, respectively.

3.1.2 Ambient 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.

As the earth cools during nighttime the air in direct contact with the earth's surface are forced to cool accordingly. This is clearly evident from Figures 3-3, reflecting the diurnal temperature profiles at Rössing. The coldest time of the day appears to be between 06h00 and 08h00, which is just before or after sunrise. After sunrise surface heating occurs and as a consequence the air temperature gradually increases to reach a maximum at approximately 15h00 in the afternoon.

The annual monthly maximum, minimum and mean temperatures are given as 38°C, 5°C and 22°C respectively (Table 3-1). A maximum temperature of 38.3°C for Rössing Mine was recorded during October and November and a minimum temperature of 5.3°C was recorded in July.

Table 3-1: Maximum, minimum and mean monthly temperatures at Rössing Mine (January to November 2006).

°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Monthly max (°C)	34.6	38.3	35.5	36.6	33.6	33.0	32.0	33.7	36.8	38.3	38.3	33.5	38.3
Monthly min (°C)	14.3	14.7	11.4	12.0	10.5	10.1	5.3	7.3	8.0	8.6	11.2	12.0	5.3
Monthly mean (°C)	21.9	22.6	25.4	25.5	20.4	21.6	18.3	18.7	20.5	21.8	21.8	20.1	21.5

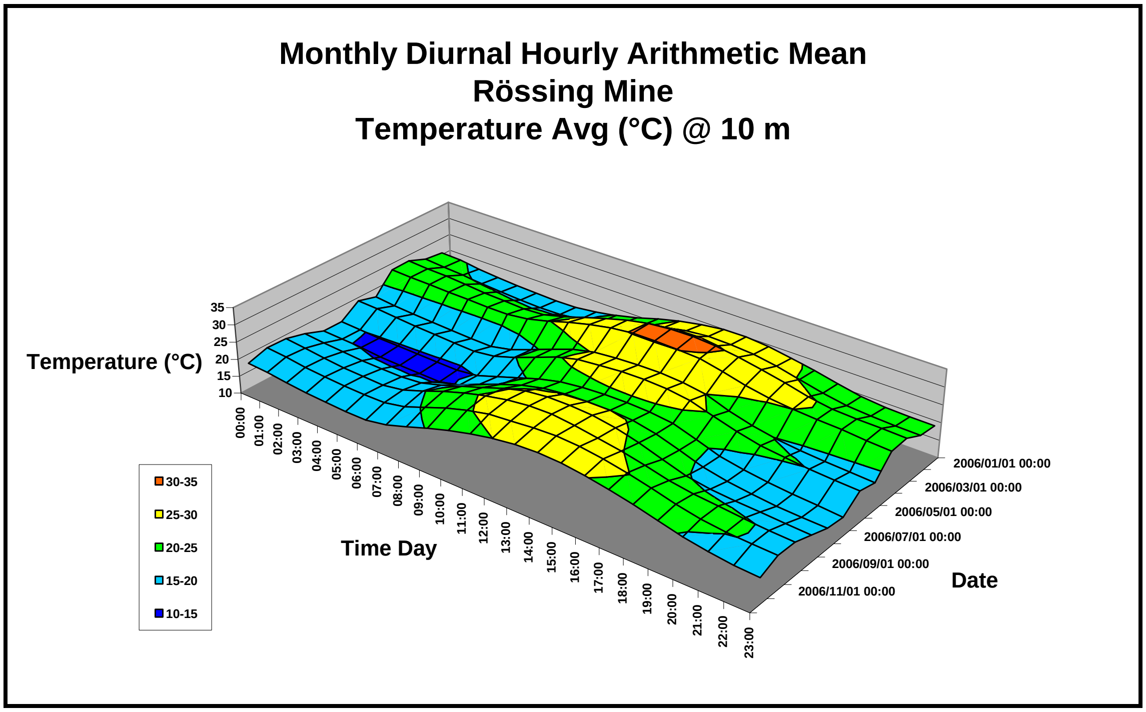


Figure 3-3: Diurnal and monthly variation of ambient air temperatures at Rössing Mine.

3.1.3 Atmospheric Stability

The atmospheric boundary layer constitutes the first few hundred metres of the atmosphere. This layer is directly affected by the earth's surface, either through the retardation of flow due to the frictional drag of the earth's surface, or as result of the heat and moisture exchanges that take place at the surface. During the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface and the extension of the mixing layer to the lowest elevated inversion. Radiative flux divergence during the night usually results in the establishment of ground based inversions and the erosion of the mixing layer.

Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table 3-2. The hourly standard deviation of wind direction, wind speed and predicted solar radiation were used to determine hourly-average stability classes.

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 to 6 hours after sunrise. This situation is more pronounced during the winter months due to strong night-time inversions and slower developing mixing layer. During the night a stable layer, with limited vertical mixing, exists. During windy and/or cloudy conditions, the atmosphere is normally neutral.

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

Table 3-2: Atmospheric Stability Classes.

Designation	Stability Class	Atmospheric Condition
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

4. EXISTING SOURCES OF EMISSION AND BASELINE AIR QUALITY

4.1 Existing Sources of fugitive dust

The identification of existing sources of emissions at the site is fundamental to the assessment of the potential for cumulative impacts and synergistic effects given the proposed operation and its associated emissions.

The Rössing Uranium Mine is ~2 165 ha and consists of the open pit, uranium extraction plant, tailings dam, waste rock dumps (Figure 4-1) and infrastructure.

Figure 4-1: Waste rock dumps at Rössing Uranium Mine

The open pit at Rössing Uranium Mine is ~3 060 m long by ~900 m wide and 390 m deep (Figure 4-2). The pit life is estimated to terminate by 2016 or beyond depending market prices, operating costs and realised output from the ore body. Operations within the pit area that contribute to fugitive dust (Figure 4-3) consist of drilling (Figure 4-4) and blasting activities (Figure 4-5) as well as vehicle entrainment (Figure 4-6) and materials handling (Figure 4-7).

Figure 4-2: The current open pit at Rössing Uranium Mine

Figure 4-3: Fugitive emissions within the pit.

Figure 4-4: Drilling operations in the pit.

Figure 4-5: Emissions from a blast at Rössing Uranium Mine.

Figure 4-6: Vehicle activity within the pit travelling along a dusticided road surface.

Figure 4-7: Material handling operations.

The wind erosion from the tailings dam and vehicle entrainment on-site is a potential significant source of fugitive emissions. Control methods have been applied to the tipping site for ore (Figure 4-8 and Figure 4-9) and the main haul roads on-site (Figure 4-10) in an attempt to reduce the emissions from these sources. Materials handling operations at the coarse ore stockpile (Figure 4-11) and crusher also add to the fugitive emissions in the area.

Figure 4-8: Water sprayers at the tipping site for the mined ore.

Figure 4-9: Truck tipping ore.

Figure 4-10: Treated (with Dust-A-Side) road surface

Figure 4-11: Coarse ore stockpile.

4.2 Current Air Quality Levels

Four dust fallout plates are positioned ~680 m southeast of the tailing dam. The position of these dust fallout plates is given in Table 4-1. The measured dust fallout for the period October 2006 to October 2007 is given in Table 4-2.

The highest measured dust fallout was for the S/EAST 5 monitor (11 670 mg/m²/day) for the period January 2007 with the lowest measured at NORTH 3 (1 370 mg/m²/day) for the same period.

Table 4-1: Location of the dust fallout plates.

Equipments	Latitude	Longitude
N/East 1	S 22^{0}27.965	E 015^{0}02.523
N/East 2	S 22^{0}27.947	E 015^{0}02.525
North 5	S 22^{0}27.909	E 015^{0}02.506
S/East 5	S 22^{0}28.031	E 015^{0}02.514

Table 4-2: Measure dust fallout for the period October 2006 to October 2007.

Date	Fallout Plates Dust Sampling (mg/m²/day)			
	N/EAST 1	N/EAST 2	NORTH 3	S/EAST 5
Oct-06	4930	3446	2350	6516
Nov-06	4376	3192	3018	6349
Dec-06	4160	3063	2615	6678
Jan-07	9270	6070	1370	11670
Feb-07	8770	4440	1650	13950
Mar-07	5900	4220	2510	9790
Apr-07	4880	2870	2960	7890
May-07	4680	5360	2250	4050
Jun-07	5551	3726	2413	5583
Jul-07	3945	2644	1804	3417
Aug-07	3095	1969	1926	2072
Sep-07	4106	2818	2440	3133
Oct-07	3463	2121	2031	2310

Use is also made of personal monitors at Rössing Uranium Mine to monitor inhalable particulate matter. A total of 963 monitors are currently in use at the mine. A summary of the average measurements of inhalable particulate concentrations for staff exposed to "outside" air (staff not within buildings) is given in Table 4-3. The location of these areas is given in Figure 4-12.

Table 4-3: Measure inhalable particulate matter at the Rössing site.

Monitoring Area	2005 Average µg/m³	2006 Average µg/m³
Pit Field Staff	220	310
Reduction Staff	350	320
Extraction Staff	150	240
Recovery Staff	280	190
Tailings Dam Operators	270	130

The highest measured PM10 concentrations are at the Reduction Staff with 350 µg/m³ and 320 µg/m³ for the period 2005 and 2006 respectively. The lowest measured PM10 ground level concentrations occurred at the Extraction Staff (150 µg/m²) for 2005 and at the Tailings Dam Operators (130 µg/m³) for 2006.

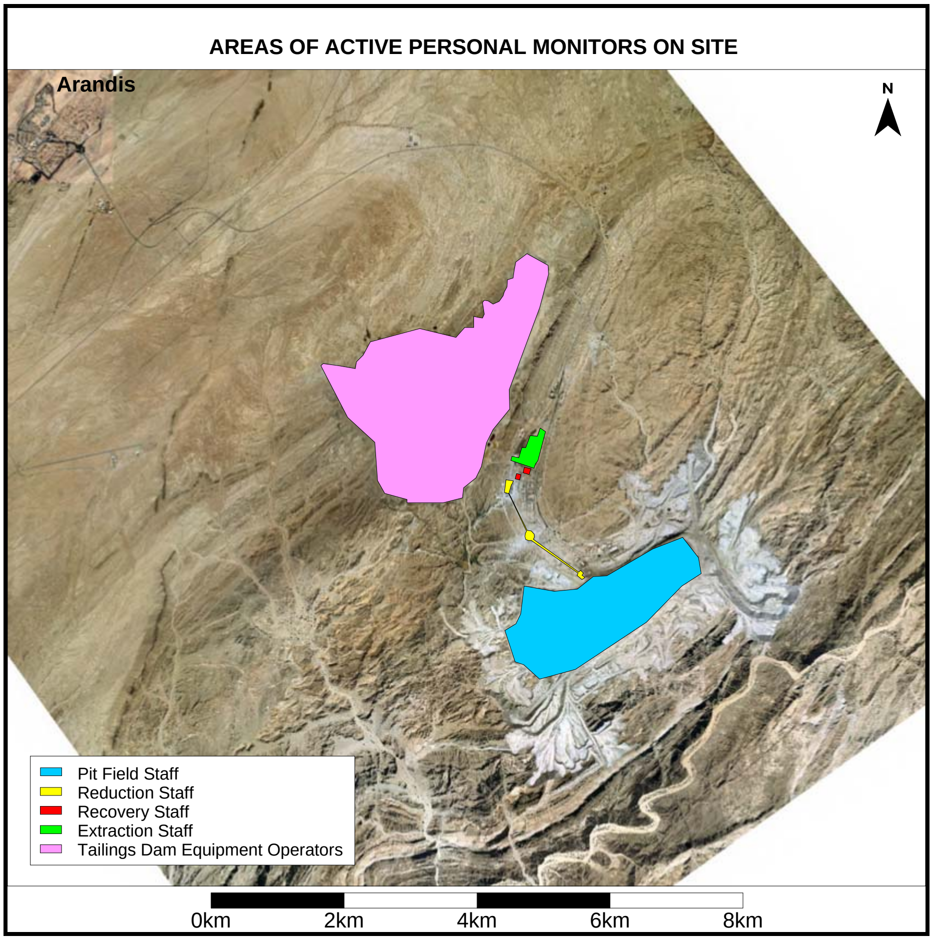


Figure 4-12: Location of areas where personal monitors are in use to measure inhalable particulate matter.

5. EMISSIONS INVENTORY FOR THE PROPOSED EXPANSION AT RÖSSING URANIUM – PHASE 1

An emissions inventory comprises the identification and quantification of sources of emissions. An emissions inventory forms the basis for assessing the impact of pollutants from operations on the receiving environment.

The nature and significance of air quality impacts associated with expansion activities at Rössing Uranium Mine (Phase 1) forms the focus of the current section. The approach typically followed includes:

- Identification of sources of emissions;
- Identification of types of pollutants being released;
- Determination of pertinent source parameters; and,
- Quantification of each source's emissions.

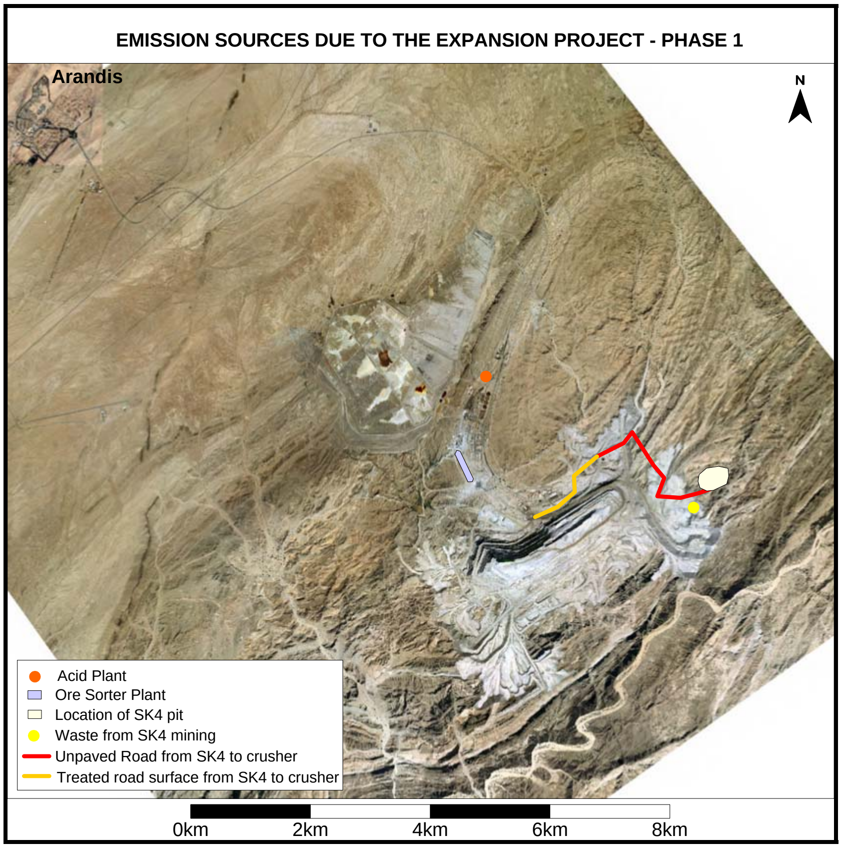


Figure 5-1: Location of emission sources due to the Rössing Uranium Mine expansion – Phase 1.

The main source of emissions due to this expansion phase consists of (Figure 5-1):

- Open pit activities for the SK4 ore body;
- Vehicle entrainment due to material transportation;
- Materials handling;
- Emissions from the acid plant; and,
- Emissions from the Ore Sorter Plant.

5.1 Construction Phase

The construction phase will comprise land clearing and site development operations. In order to determine the significance of the potential for impacts it is necessary to quantify atmospheric emissions and predicted airborne pollutant concentrations and dustfall rates occurring as a result of such emissions.

The construction phase will comprise a series of different operations including land clearing, topsoil removal, material loading and hauling, stockpiling, grading, bulldozing, compaction, (etc.). Each of these operations has its own duration and potential for dust generation. It is anticipated therefore 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. It is therefore often necessary to estimate area wide construction emissions, without regard to the actual plans of any individual construction process. Should detailed information regarding the construction phase be available, the construction process would have been broken down into component operations for emissions quantification and dispersion simulations. Due to the lack of detailed information (e.g. number of dozers to be used, size and locations of raw materials stockpiles and temporary roads, rate of on-site vehicle activity), emissions were instead estimated on an area wide basis. The quantity of dust emissions is assumed to be proportional to the area of land being worked and the level of construction activity.

The US-EPA documents emissions factors which aim to provide a general rule-of-thumb as to the magnitude of emissions which may be anticipated from construction operations. Based on field measurements of total suspended particulate, the approximate emission factors for construction activity operations are given as:

$$E = 2.69 \text{ Mg/hectare/month of activity } (269 \text{ g/m}^2\text{/month})$$

These emission factors are most applicable to construction operations with (i) medium activity levels, (ii) moderate silt contents, and (iii) semiarid climates. Estimated emissions during the construction phase were calculated to be as follows:

Development	TSP Emissions (t)	PM10 Emissions (t)
Acid Plant	32.28	11.30
Ore Sorter Plant	129.12	45.19

PM10 was assumed to represent ~35% of the TSP emissions given that this is the approximate PM10 component of vehicle-entrainment releases and such releases are anticipated to represent the most significant source of dust during construction operations.

5.2 Operational Phase

5.2.1 Sulphuric Acid Plant

The parameters required for the acid plant for dispersion modelling purposes was provided by Rössing personnel (Table 5-1). Emissions were provided for routine and upset operations. Two stack heights were assessed in the impact assessment (viz. 50m and 75m).

Table 5-1: Parameters for the acid plant stack

Operating Conditions	Stack Ht (m)	Stack Diameter (m)	Exit Gas Temperature		Volumetric Flow		Exit Velocity
			°C	K	Normal (m³/hr)	Actual (m³/hr)	(A)m/s
Routine	50 75	2	77	350.15	84405	108198	9.6 [(a)]
Upset: Poor startup	50 75	2	70	343.15	55952	70329	6.2
Upset: Controlled startup (2-4 hours)	50 75	2	75	348.15	55148	70329	6.2
Upset: Boiler or other steaming equipment failure (15 min)	50 75	2	80	353.15	83642	108198	9.6
Upset: interruption of acid flow to acid tower (2 -5 min)	50 75	2	80	353.15	83642	108198	9.6
Upset: poor control of converter temperatures (2-4 hours)	50 75	2	80	353.15	83642	108198	9.6
Upset: poor control of acid	50 75	2	80	353.15	83642	108198	9.6

Operating Conditions	Stack Ht (m)	Stack Diameter (m)	Exit Gas Temperature		Volumetric Flow		Exit Velocity
			°C	K	Normal (m^3/hr)	Actual (m^3/hr)	(A)m/s
concentrators (1 hour)							
Upset: poor control of acid temperatures	50 75	2	70	343.15	86080	108198	9.6

(a) Calculated from the volumetric flow rate

Table 5-2: Routine and upset emissions for the acid plant.

Operating Conditions	SO_3/H_2SO_4 emissions (mg/Nm³) [(a)]	SO_2 emissions (ppm)
Routine	<30	250
Upset: Poor startup	50-100	1500
Upset: Controlled startup (2-4 hours)	50 decreasing to 30	500
Upset: Boiler or other steaming equipment failure (15 min)	30	250
Upset: interruption of acid flow to acid tower (2 -5 min)	30 increasing to 50	250
Upset: poor control of converter temperatures (2-4 hours)	30	1500
Upset: poor control of acid concentrators (1 hour)	30-100	250
Upset: poor control of acid temperatures	30-100	250

(a) For dispersion modelling purposes, the highest value was selected from the range of emissions provided in order to assess the worst case impacts.

5.2.2 Ore Sorter Plant

The Ore Sorter Plant is made up of four screeners and two ore sorting clusters. Three baghouses are proposed to be installed at the screeners and two baghouses at the Ore Sorters. The conveyor transfer points within the plant are proposed to have insertable filters and thus were treated as controlled conveyor transfer points for the current study.

The parameters and emissions from the proposed baghouses were provided by Bateman personnel for the current assessment (Table 5-3). It should be noted that a comprehensive design of the Ore Sorter Plant has not been undertaken to date, and the figures provided are a preliminary estimation of the proposed operations.

Table 5-3: Parameters and emissions from the proposed Ore Sorter Plant.

Baghouse	Stack Height	Exit Velocity	PM10 Emissions	Flow Rate		Diameter	Temp
	m	m/s	mg/Nm³	Nm³/hr	Am³/hr	m	°C
At Screener 1	20	15	20	14400	15718.68	0.608788	25
At Screener 2	20	15	20	14400	15718.68	0.608788	25
At Screener 3 & 4	20	15	20	14400	15718.68	0.608788	25
At Ore Sorter	20	15	20	57600	62874.73	1.217576	25
At Ore Sorter	20	15	20	57600	62874.73	1.217576	25

The following predictive equation is used to estimate controlled emissions from anticipated conveyor transfer operations as obtained from the US-EPA emission factors:

$$E_{TSP} = 0.000046$$
$$E_{PM10} = 0.000024$$

where,

E_{TSP} = Total Suspended Particulate emission factor (kg dust / t transferred)
E_{PM10} = Inhalable Particulate emission factor (kg dust / t transferred)

The TSP and PM10 emissions from conveyor transfer operations at the ore sorter plant were estimated to be in the order of 1.5 tpa and 0.8 tpa respectively.

Various scenarios were assessed for the transportation of waste from the Ore Sorter Plant. Four sites were assessed as well as various transport options (viz. conveyor transfer and truck transportation) (Figure 5-2).

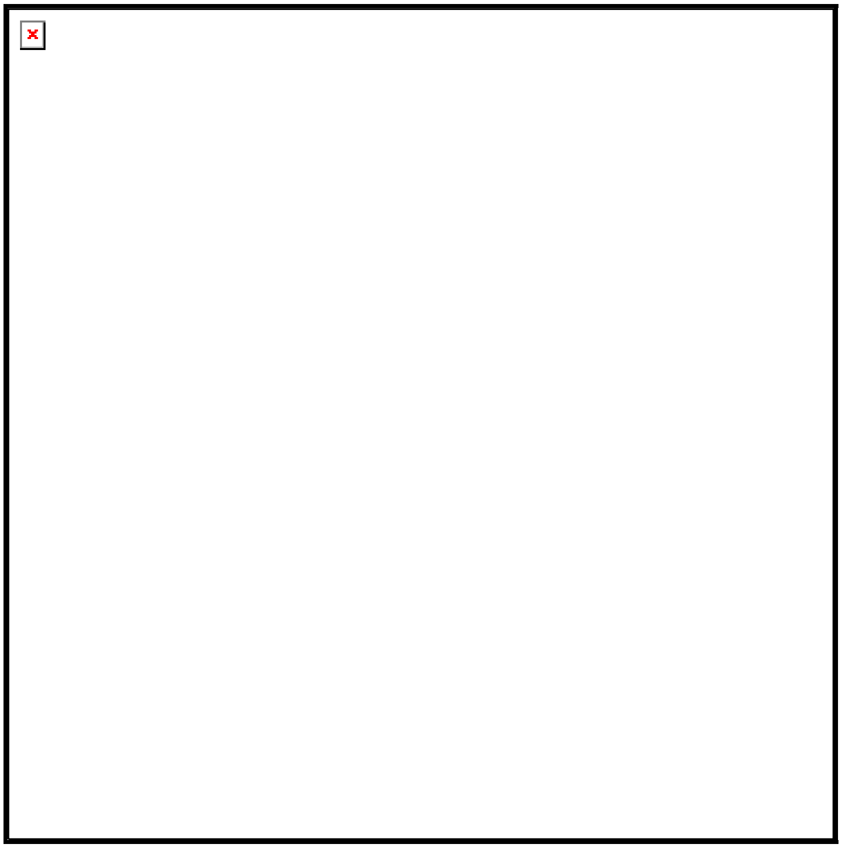


Figure 5-2: Location of various waste sites for the Ore Sorter Plant waste.

5.2.3 Vehicle-Entrained Emissions from Unpaved Roads

Vehicle-entrained dust emissions from unpaved haul roads represent a significant source of fugitive dust. The force of the wheels of vehicles travelling on unpaved roadways causes pulverisation of surface material. Particles are lifted and dropped from the rotating wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to affect the road surface once the vehicle has passed. The quantity of dust emissions from unpaved roads varies linearly with the volume of traffic. In addition to traffic volumes, emissions also depend on a number of parameters which characterise the condition of a particular road and the associated vehicle traffic, including average vehicle speed, mean vehicle weight, average number of wheels per vehicle, road surface texture, and road surface moisture (EPA, 1998).

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

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

where,

E = emissions in lb of particulates per vehicle mile travelled (lb/VMT) – 1 lb/VMT = 281.9 g/VKT (vehicle kilometres travelled)
k = particle size multiplier (dimensionless)
s = silt content of road surface material (%)
W = mean vehicle weight (tonnes)

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). *a* and *b* are given as 0.9 and 0.45 respectively for PM10 and as 0.7 and 0.45 respectively for TSP.

The silt content should preferably be measured to reflect site-specific conditions. As the silt content could not be determined for the current study, generic US-EPA silt loadings specified for mining operations were used:

Unpaved Road Type	Silt Content Range	Average Silt Content
Mine road	4.9% to 5.3%	5.1%

The average silt contents (5.1% for mine road) were used in the emission estimates. Information required to quantify vehicle entrained emissions was as follows:

- Weight of empty truck – 138 t;
- Full weight of truck – 324 t;
- Waste from ore sorter plant – 10 080 tpd;
- Waste from mine – 300 000 tpm
- Ore – 150 000 tpm

5.2.4 Vehicle-Entrained Emissions from Treated Road Surfaces

The main haul roads on-site are treated with Dust-A-Side and regularly watered to maintain these surfaces. In order to quantify vehicle entrained emissions from these surfaces, use was made of the paved road size-specific emission factor equation of the US-EPA:

$$E = k(\frac{sL}{2})^{0.65}(\frac{W}{3})^{1.5} - C$$

where,

E = particulate emission factor in grams per vehicle kilometre travelled (g/VKT)
k = particle size multiplier (dimensionless)
s = silt loading of road surface material (g/m²)

W = mean vehicle weight (tonnes)
C = emission factor for 1980's vehicle fleet exhaust, break wear and tire wear

The particle size multiplier in the equation (k) varies with aerodynamic particle size range and is given as 4.6 for PM10 and 24 for total suspended particulates (TSP). Generic US-EPA silt loading was used (7.4 g/m²) in the emission estimates. The emission factor for *C* is 0.1317 g/VKT for PM10 and TSP respectively.

5.2.5 Fugitive Dust Emissions from Materials Handling Operations

The following predictive US-EPA equation was used to estimate emissions from tipping operations:

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

where,

E_{TSP} = Total Suspended Particulate emission factor (kg dust / t transferred)
U = mean wind speed (m/s)
M = material moisture content (%)
k = particle size multiplier (dimensionless)

The particle size multiplier varies with aerodynamic particle sizes and is given as a fraction of TSP. For PM30 the fraction is 74%, with 35% of TSP given to be equal to PM10, and the PM2.5 fraction is 11% of TSP (EPA, 1998a). Hourly emission factors, varying according to the prevailing wind speed, were used as input in the dispersion simulations.

5.2.6 Blasting and Drilling Operations

Blasting and drilling operations represent intermittent sources of fugitive dust emissions. Single valued emission factors, published by the US-EPA for the quantification of fugitive dust emissions due to drilling operations, is given as follows:

$$\mathbf{E_{TSP} = 0.59 \text{ kg of dust / hole drilled}}$$

The area drilled per blast was given to be ~ 80m by ~100m, with drill spacing of 6m by 7m. The TSP and PM10 emissions due to drilling activity was estimated to be 6.46 tpa and 3.36 tpa respectively.

Estimating the TSP emissions from blasting is difficult, given the complex and variable nature of each blast.

The equation is:

$$E_{TSP} = 0.00022 A^{1.5} \quad \textbf{kg/blast}$$

where,

E_{TSP} = Total Suspended Particulate emissions in kg/blast

A = horizontal area (m^2), with blast depth of ≤ 21 m.

It should be noted that this equation does not provide any allowances for the moisture content in the material blasted, the depth of the holes or whether the blast is a throw blast or simply a shattering blast. Therefore, it must be considered a very rough estimate of the quantity of TSP that will be generated.

Given that there would be 1 blast per week, the TSP and PM10 emissions were estimated to be 7.56 tpa and 3.93 tpa respectively.

It was provided that ~ 0.487 kg of ammonium nitrate explosive would be used per ton of material blasted. The US-EPA provides emission factors for ammonium nitrate explosive emission releases:

Emission factors(kg/t)		
CO	**Methane**	**H_2S**
32	0.7	16

The calculated emissions due to the explosive were therefore calculated to be as follows:

Emissions (tpa)		
CO	**Methane**	**H2S**
149.61	3.27	74.80

The emissions from blasting activities were modelled to predict the impact from this source. Particulate emissions from blasting activities were included in the assessment of the cumulative impact (for highest daily and annual averaging periods) from the associated SK4 activities.

5.3 Closure and Post-Closure Phase

All mining activities will have ceased by the closure phase of the project. The potential for impacts during this phase will therefore depend on the extent of rehabilitation efforts during closure and thus ultimately the rehabilitation efforts during operation. It is expected that all disturbed areas will be rehabilitated back to their pre-mining land capability potential as far as practicable.

Aspects and activities associated with the closure phase of the proposed project are as follows:

- Fugitive dust from the demolition and stripping away of all facilities
- Wind entrainment from the tailings dam

During the post-closure phase, atmospheric emissions will be restricted to possible wind-blown dust from the tailings dam and exposed surfaces. The extent of such emissions will be dependent on how successfully these storage and open areas were managed.

6. COMPLIANCE AND AIR QUALITY IMPACT ASSESSMENT

6.1 Dispersion Model Results

Simulations were undertaken to determine particulate matter (PM10) concentrations and total daily dust deposition from operations at Rössing Uranium Mine. In addition, sulphur dioxide (SO_2) and sulphuric acid impacts were assessed from stack emissions from the proposed Acid Plant operational activities. Other pollutants such as carbon monoxide (CO), and hydrogen sulphide (H_2S) occurring due to blasting activities were also considered. Due to the temporary nature of the construction and demolition phases, these were not simulated for the current study.

It should be noted that isopleth plots reflecting hourly/daily averaging periods contain only the highest predicted ground level concentrations for that averaging period, over the entire period for which simulations were undertaken. *It is therefore possible that even though a high hourly/daily concentration is predicted to occur at certain locations, that this may only be true for one day during the entire period.*

The following scenarios were assessed in the current study:

- *Scenario 1:* Routine operations at the Acid Plant
- *Scenario 2:* Upset operating conditions at the Acid Plant – **Poor Start Up**: Temperature of pass 1 is above strike temperature and temperatures of passes 2 and/or 3 of the converter are below striking temperature. Pass 4 also below strike temperature.
- *Scenario 3:* Upset operating conditions at the Acid Plant – **Controlled Start Up**: All converter passes are at striking temperature (2-4 hours).
- *Scenario 4:* Upset operating conditions at the Acid Plant – **Boiler or other steaming equipment failure:** Normally a tube failure with lots of water entering the gas stream (15 minutes).
- *Scenario 5:* Upset operating conditions at the Acid Plant – **Interruption of acid flow to Acid Towers** (2-5 minutes).
- *Scenario 6:* Upset operating conditions at the Acid Plant – **Poor control of converter temperatures** (2-4 hours).
- *Scenario 7:* Upset operating conditions at the Acid Plant – **Poor control of acid concentrators** (1 hour).

- *Scenario 8:* Upset operating conditions at the Acid Plant – **Poor control of acid temperatures.**

- *Scenario 9:* Waste from the Ore Sorter plant is transported to waste storage area Option 1 (Figure 5-1) via conveyor belt.

- *Scenario 10:* Waste from the Ore Sorter plant is transported to waste storage area Option 2 (Figure 5-1) via conveyor belt.

- *Scenario 11:* Waste from the Ore Sorter plant is transported to waste storage area Option 3 (Figure 5-1) via conveyor belt.

- *Scenario 12:* Waste from the Ore Sorter plant is transported to waste storage area Option 4 (Figure 5-1) via conveyor belt.

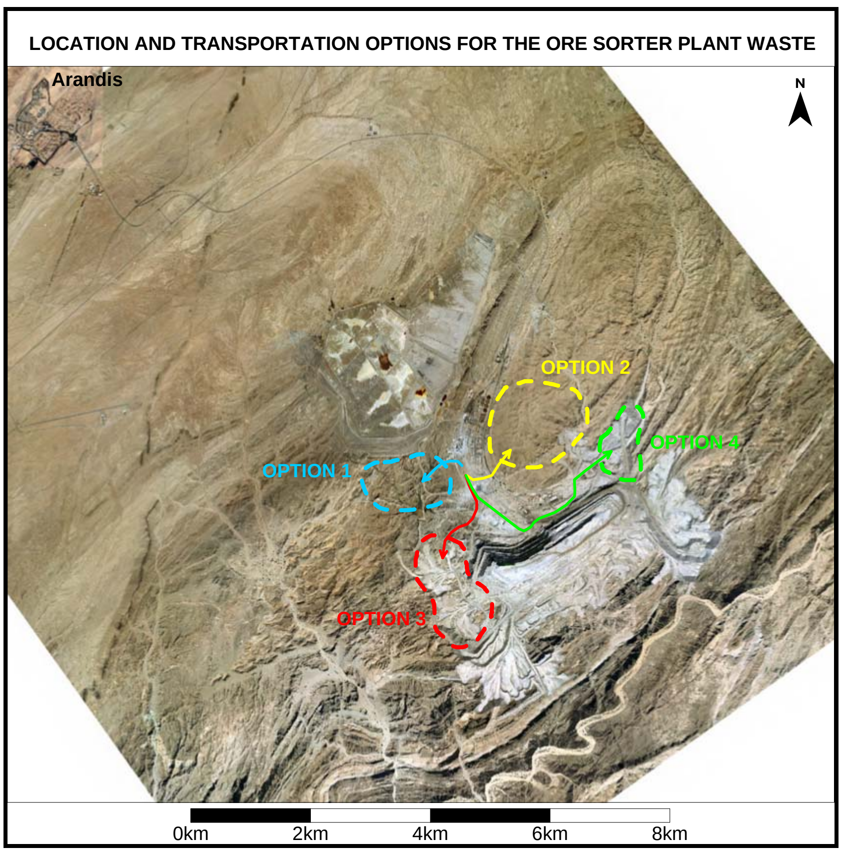


Figure 6-1: Various options for the location of the Ore Sorter Plant waste.

- *Scenario 13:* Waste from the Ore Sorter plant is transported to waste storage area Option 1 (Figure 5-1) via trucks.

- *Scenario 14:* Waste from the Ore Sorter plant is transported to waste storage area Option 2 (Figure 5-1) via trucks.

- *Scenario 15:* Waste from the Ore Sorter plant is transported to waste storage area Option 3 (Figure 5-1) via trucks.

- *Scenario 16:* Waste from the Ore Sorter plant is transported to waste storage area Option 4 (Figure 5-1) via trucks.

Isopleth plots presented in this section are provided in Table 6-1.

Table 6-1: Isopleth plots presented in the current section.

Pollutant	Scenario	Averaging period	Figure
SO_2	*1*	Highest hourly Highest daily Annual average	6-2 to 6-3 6-4 to 6-5 6-6 to 6-7
	2	Highest Hourly	6-8 to 6-9
	3	Highest Hourly	6-10 to 6-11
	4	Highest Hourly	6-12 to 6-13
	5	Highest Hourly	6-14 to 6-15
	6	Highest Hourly	6-16 to 6-17
	7	Highest Hourly	6-18 to 6-19
	8	Highest Hourly	6-20 to 6-21
SO_3	*1*	Highest hourly Highest daily	6-22 to 6-23 6-24 to 6-25
	2	Highest Hourly	6-26 to 6-27
	3	Highest Hourly	6-28 to 6-29
	4	Highest Hourly	6-30 to 6-31
	5	Highest Hourly	6-32 to 6-33
	6	Highest Hourly	6-34 to 6-35
	7	Highest Hourly	6-36 to 6-37
	8	Highest Hourly	6-38 to 6-39
PM10	*9*	Highest daily Annual average	6-40 6-41
	10	Highest daily Annual average	6-42 6-43

Pollutant	Scenario	Averaging period	Figure
	11	Highest daily Annual average	6-44 6-45
	12	Highest daily Annual average	6-46 6-47
	13	Highest daily Annual average	6-48 6-49
	14	Highest daily Annual average	6-50 6-51
	15	Highest daily Annual average	6-52 6-53
	16	Highest daily Annual average	6-54 6-55
Dust Deposition	*9*	Maximum daily	6-56
	10	Maximum daily	6-57
	11	Maximum daily	6-58
	12	Maximum daily	6-59
	13	Maximum daily	6-60
	14	Maximum daily	6-61
	15	Maximum daily	6-62
	16	Maximum daily	6-63

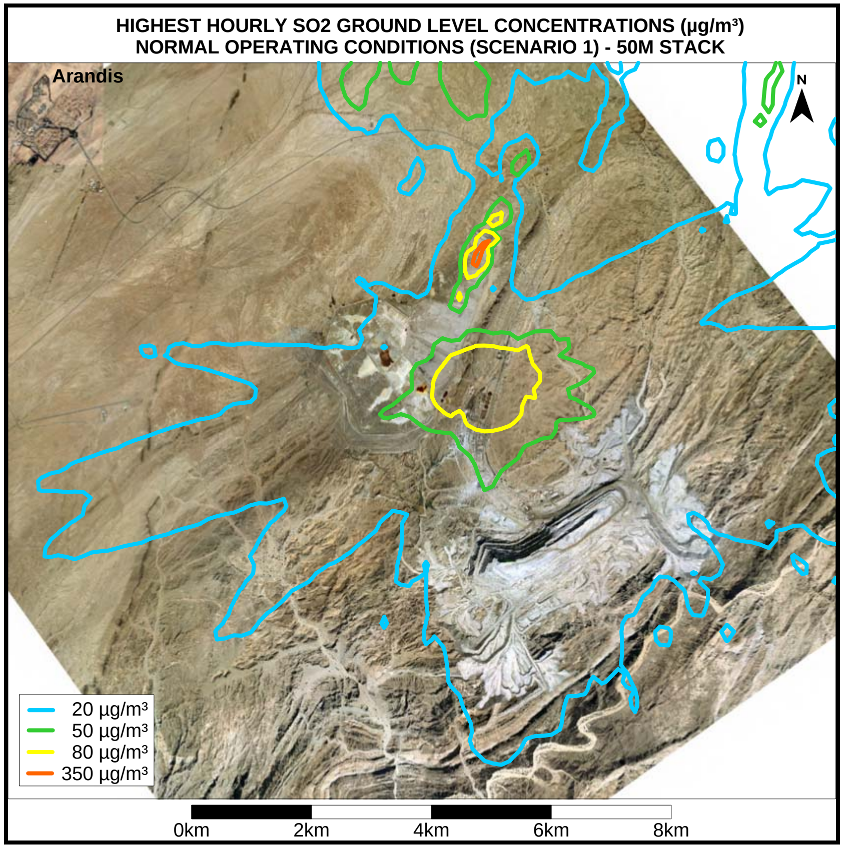


Figure 6-2: Highest hourly SO_2 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (50 m stack height).

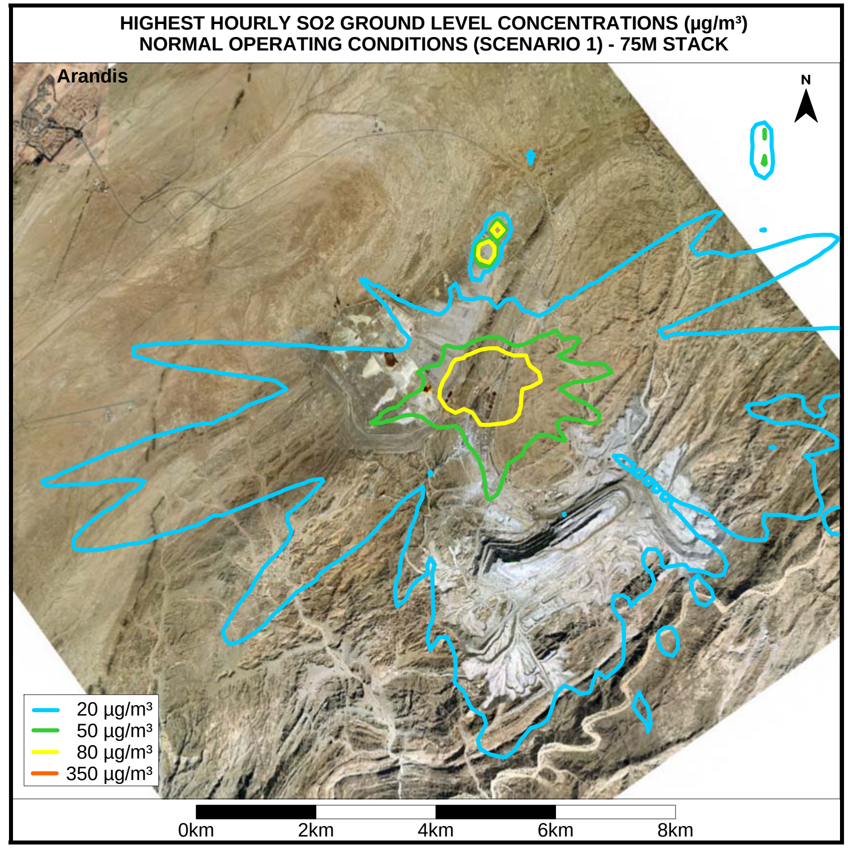


Figure 6-3: Highest hourly SO_2 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (75 m stack height).

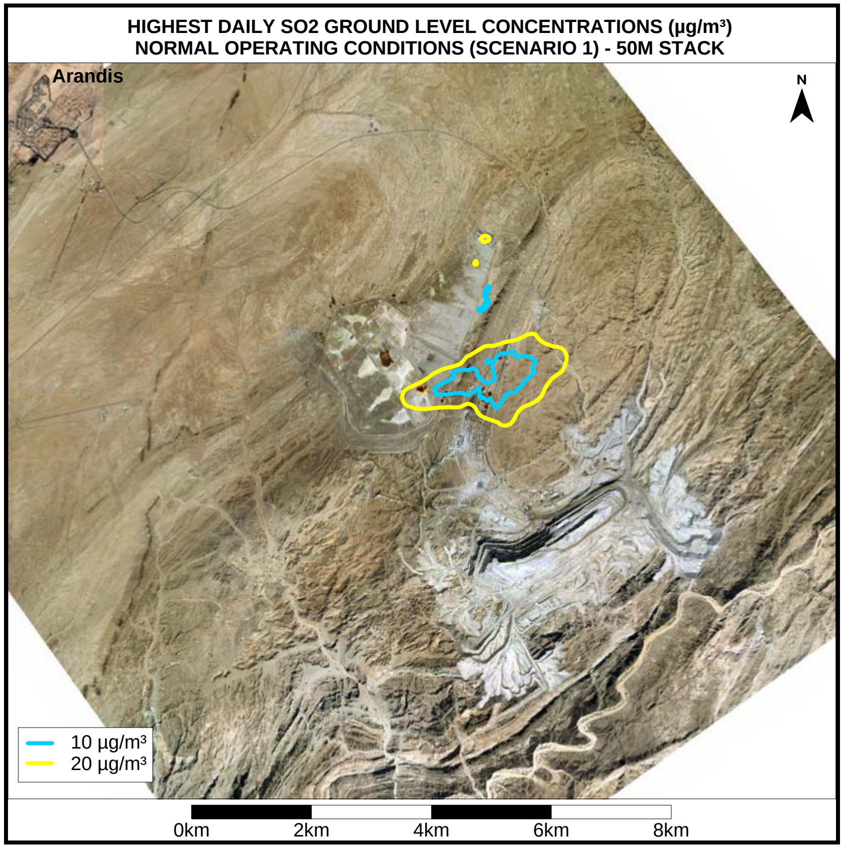


Figure 6-4: Highest daily SO_2 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (50 m stack height).

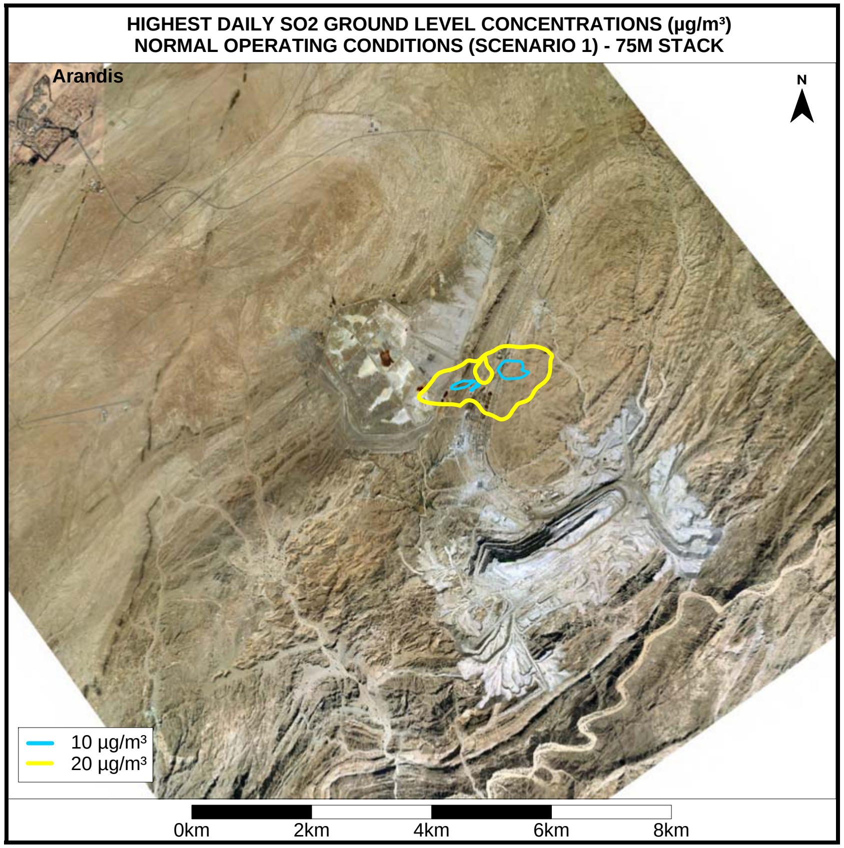


Figure 6-5: Highest daily SO_2 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (75 m stack height).

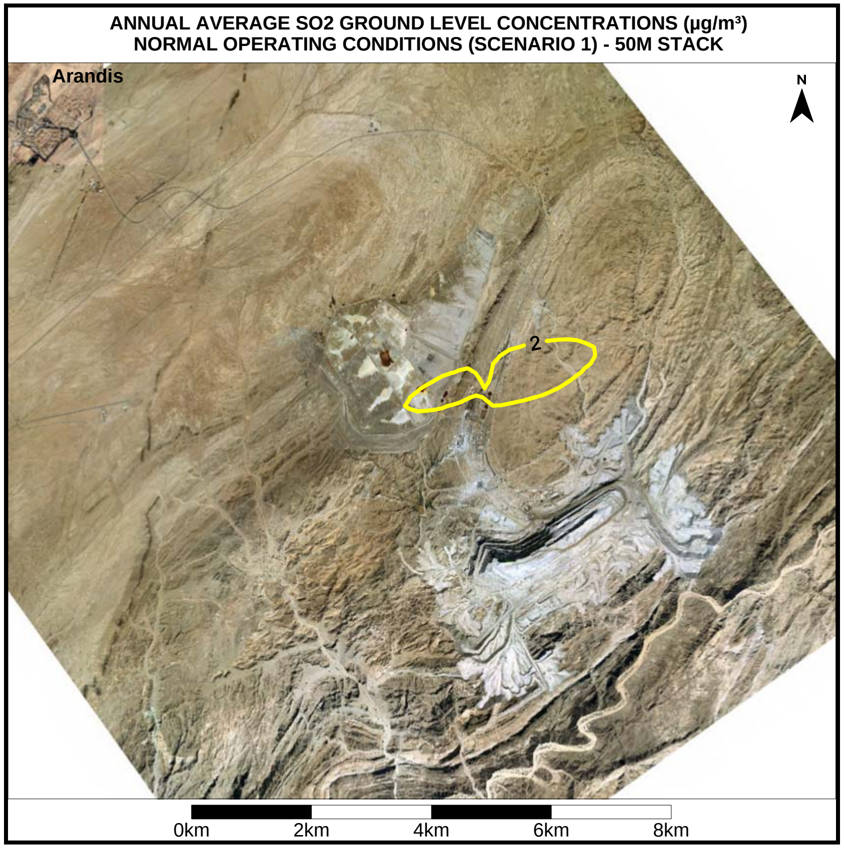


Figure 6-6: Annual average SO_2 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (50 m stack height).

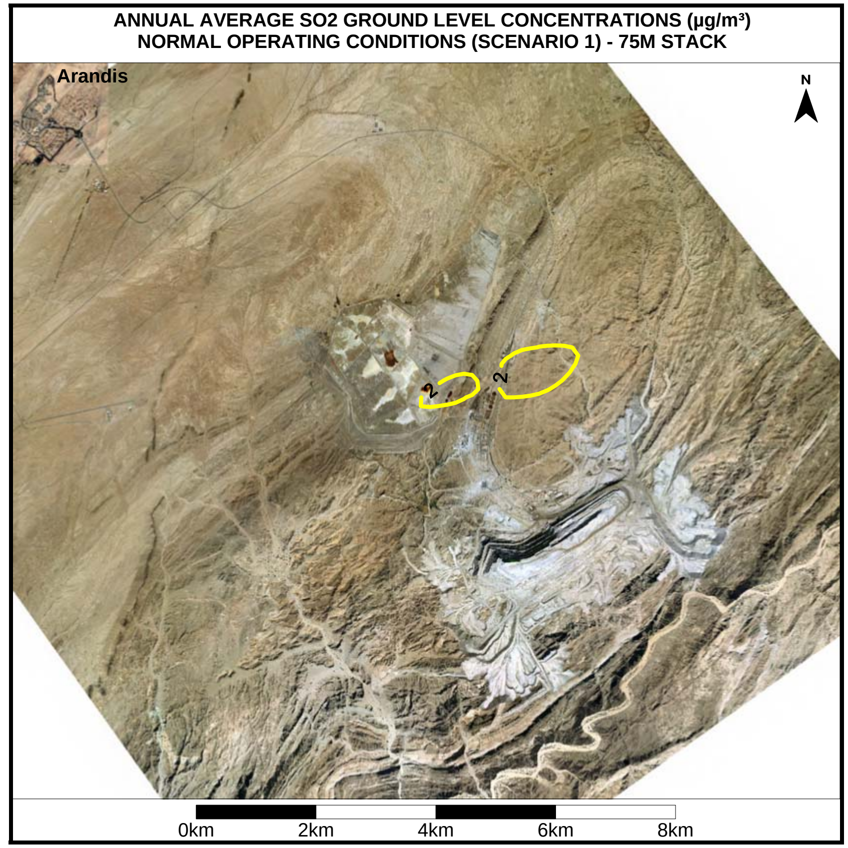


Figure 6-7: Annual average SO_2 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (75 m stack height).

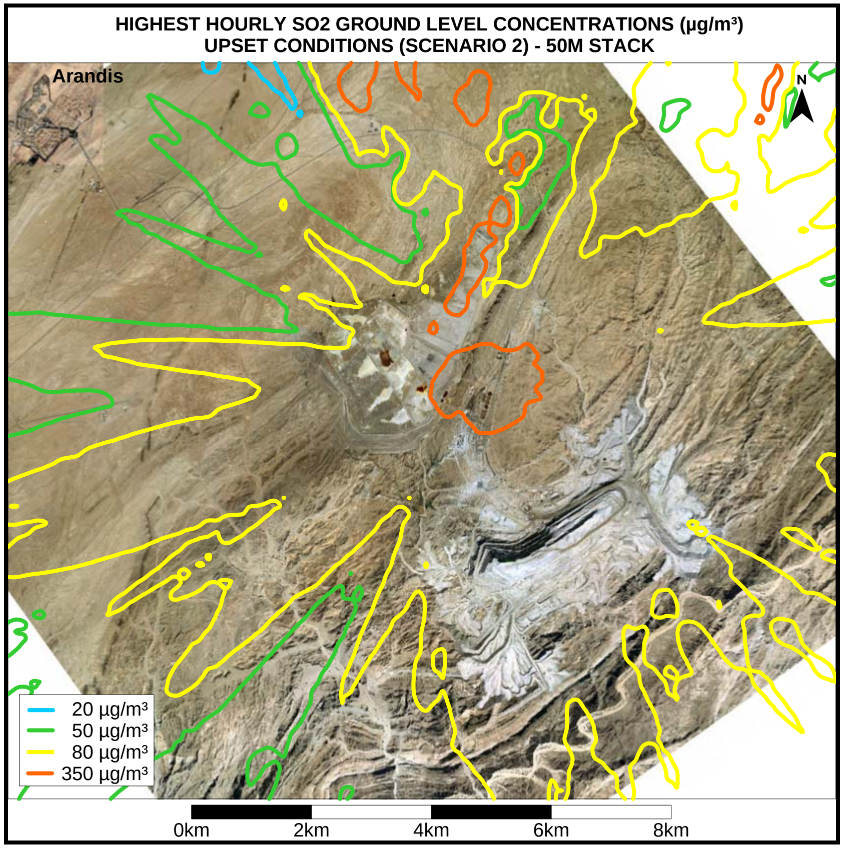


Figure 6-8: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 2* (50 m stack height).

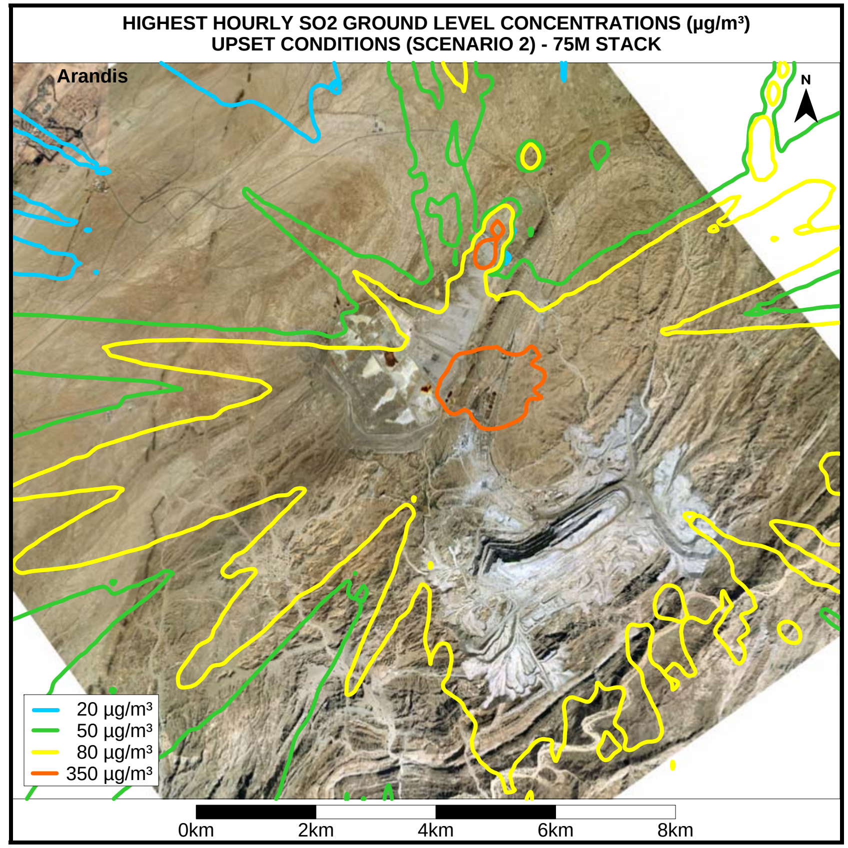


Figure 6-9: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 2* (75 m stack height).

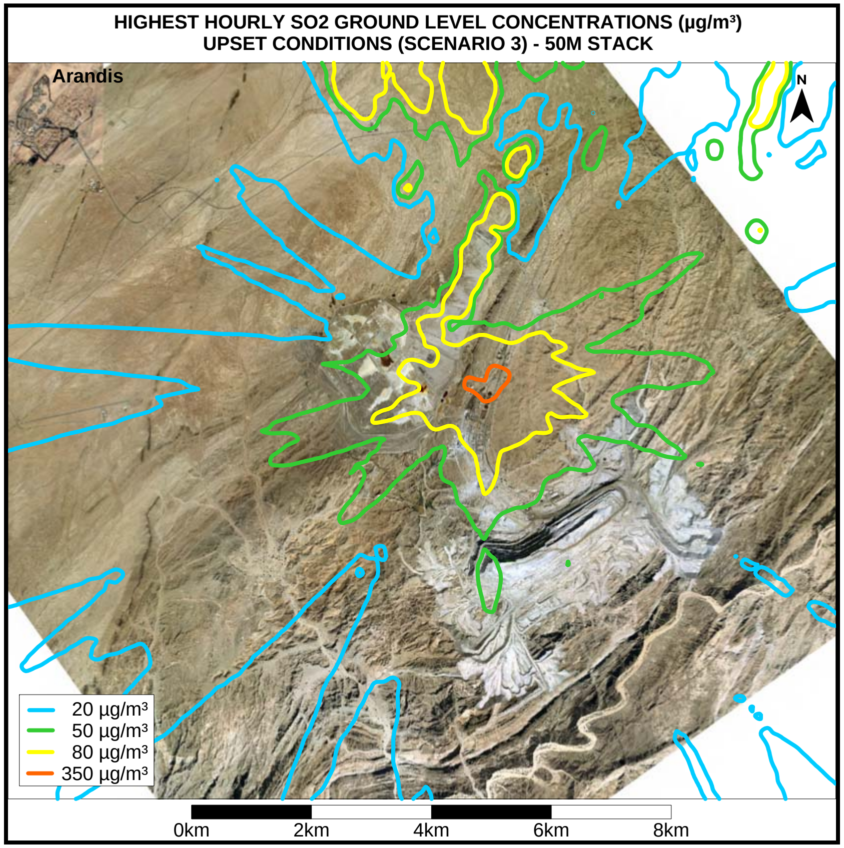


Figure 6-10: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 3* (50 m stack height).

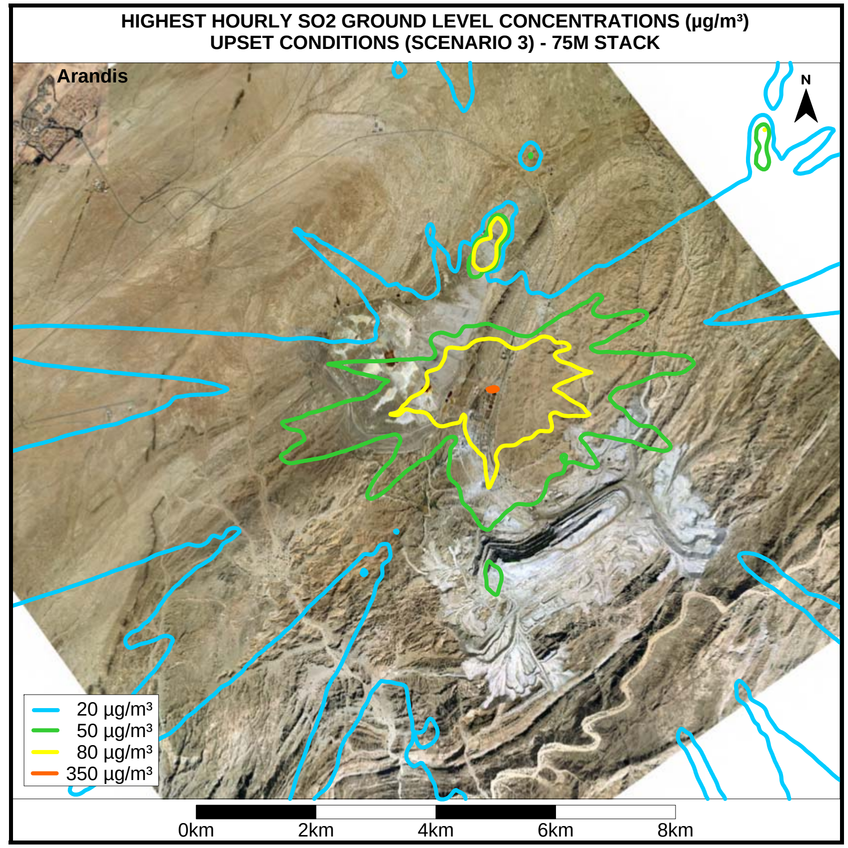
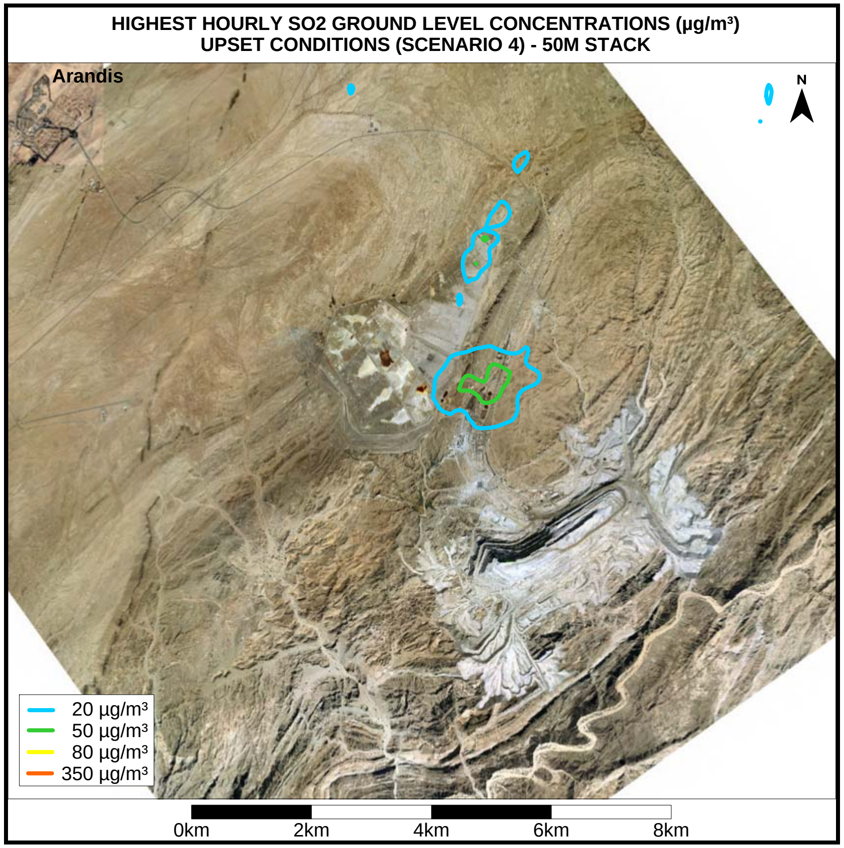


Figure 6-11: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 3* (75 m stack height).



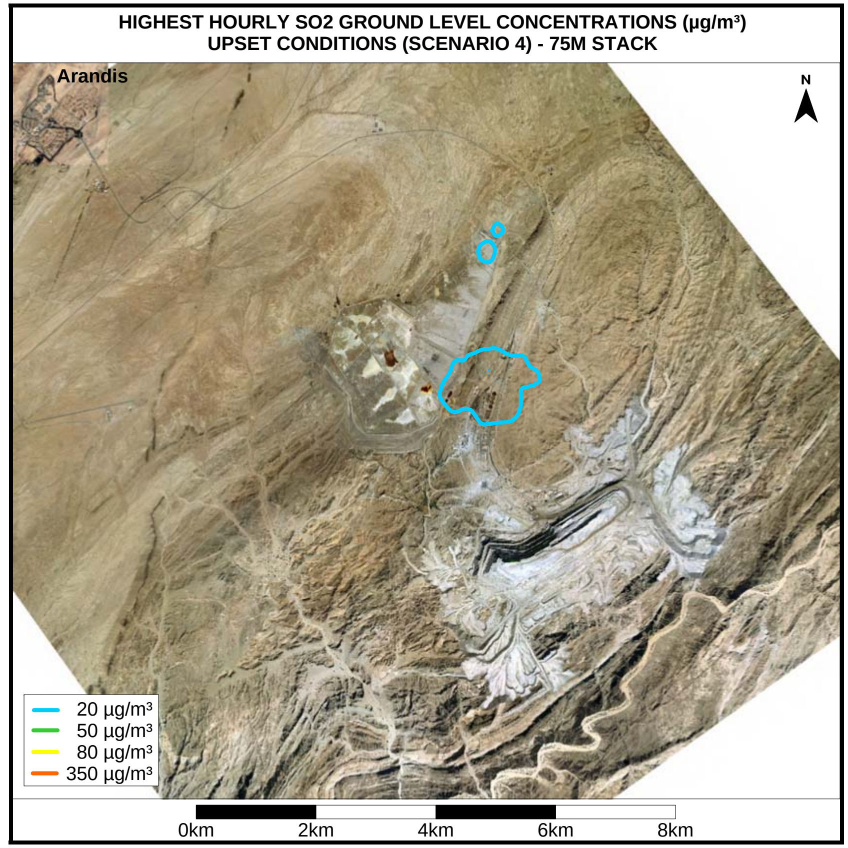


Figure 6-12: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 4* (50 m stack height).

Figure 6-13: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 4* (75 m stack height).

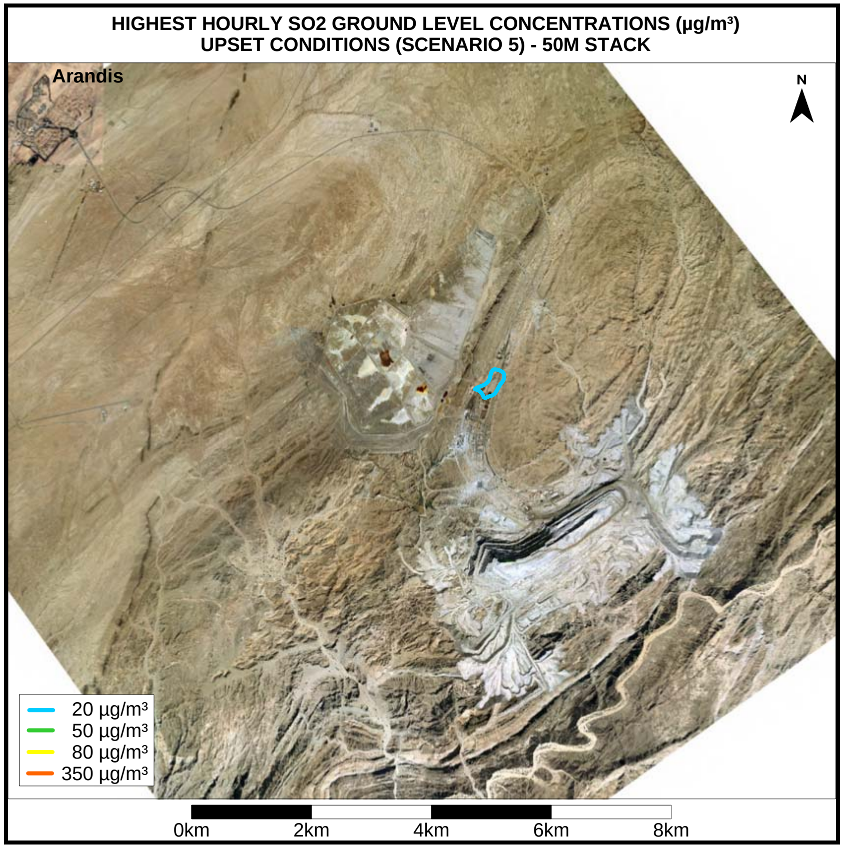


Figure 6-14: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 5* (50 m stack height).

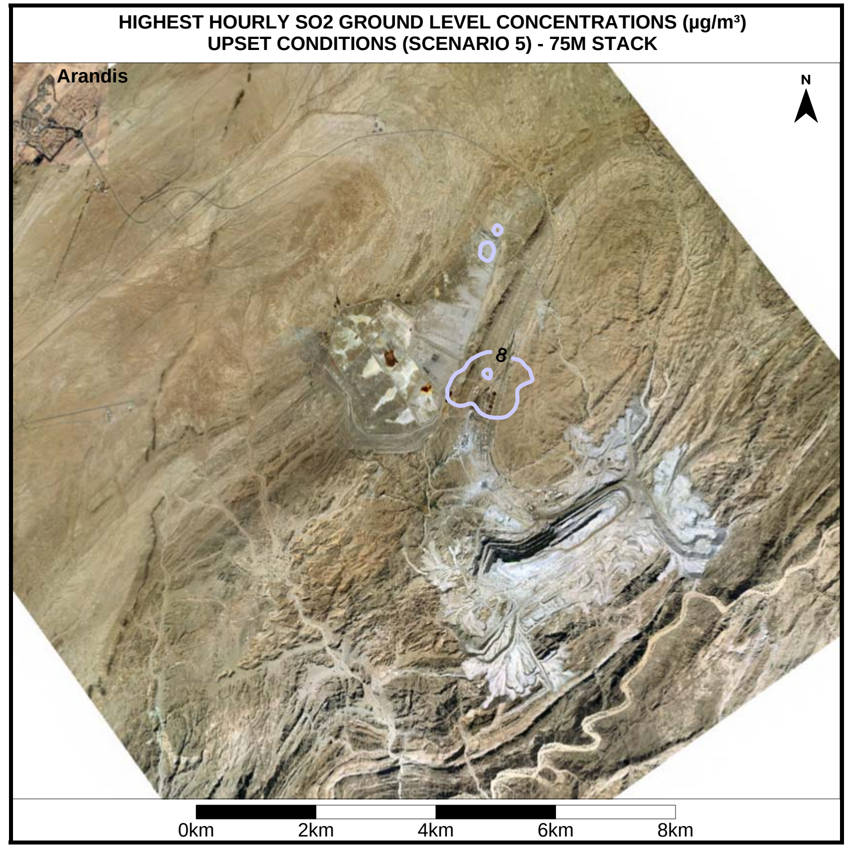


Figure 6-15: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 5* (75 m stack height).

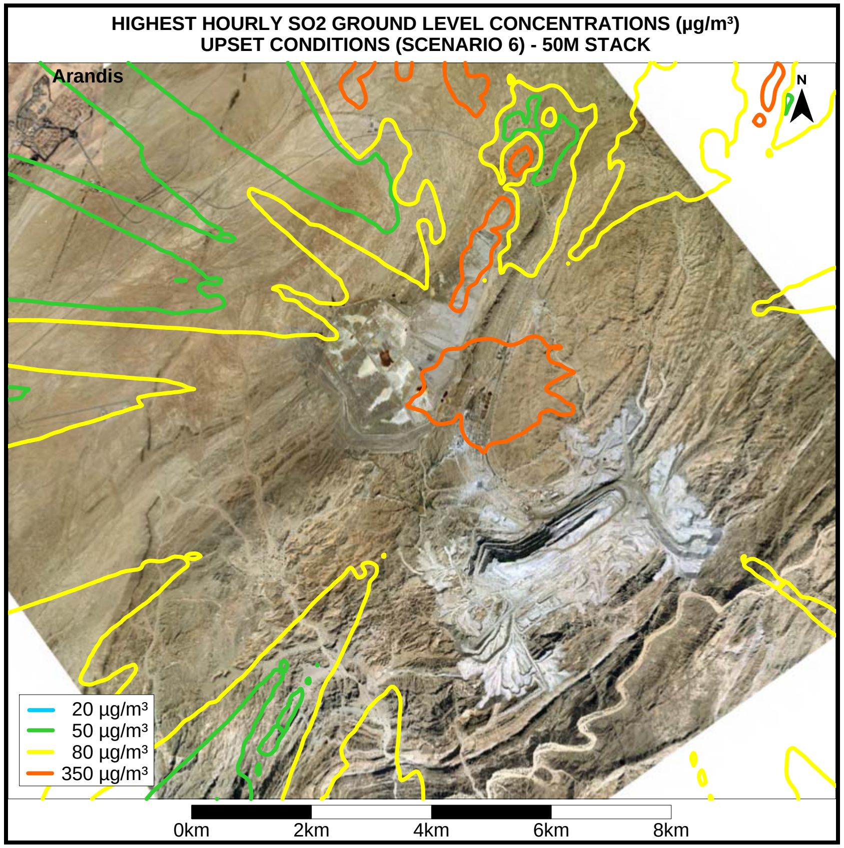


Figure 6-16: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 6* (50 m stack height).

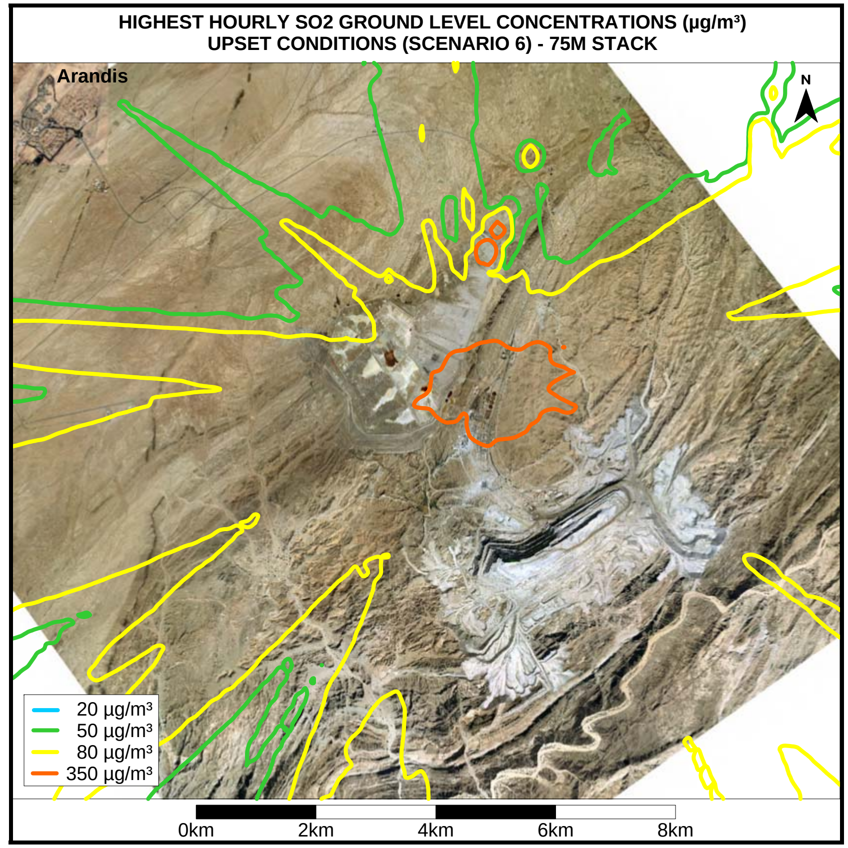


Figure 6-17: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 6* (75 m stack height).

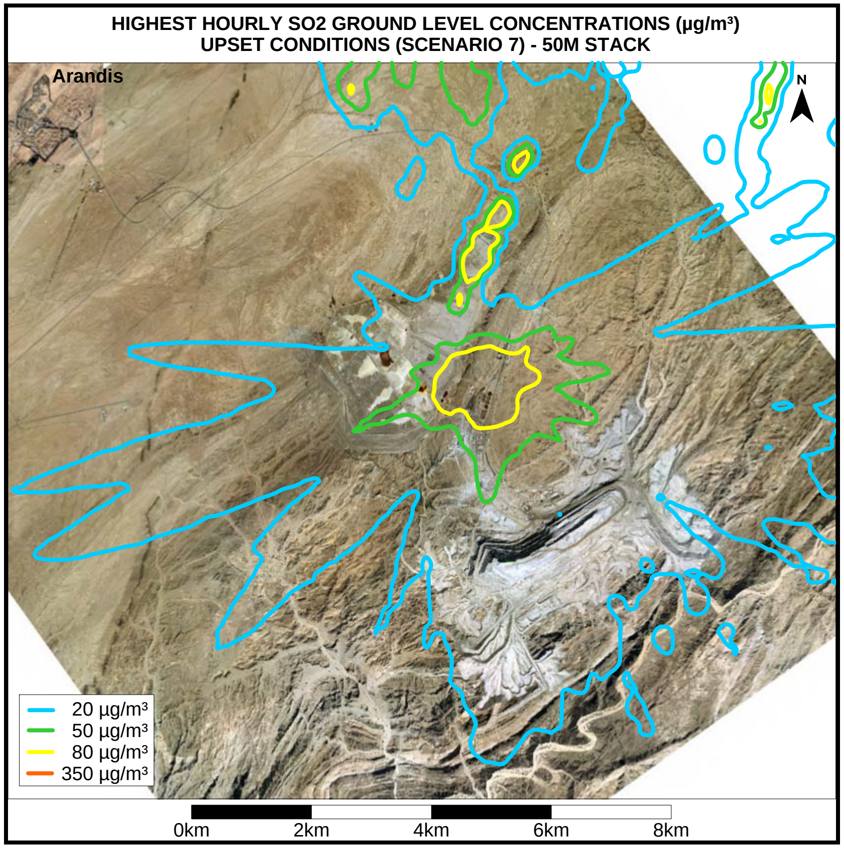


Figure 6-18: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 7* (50 m stack height).

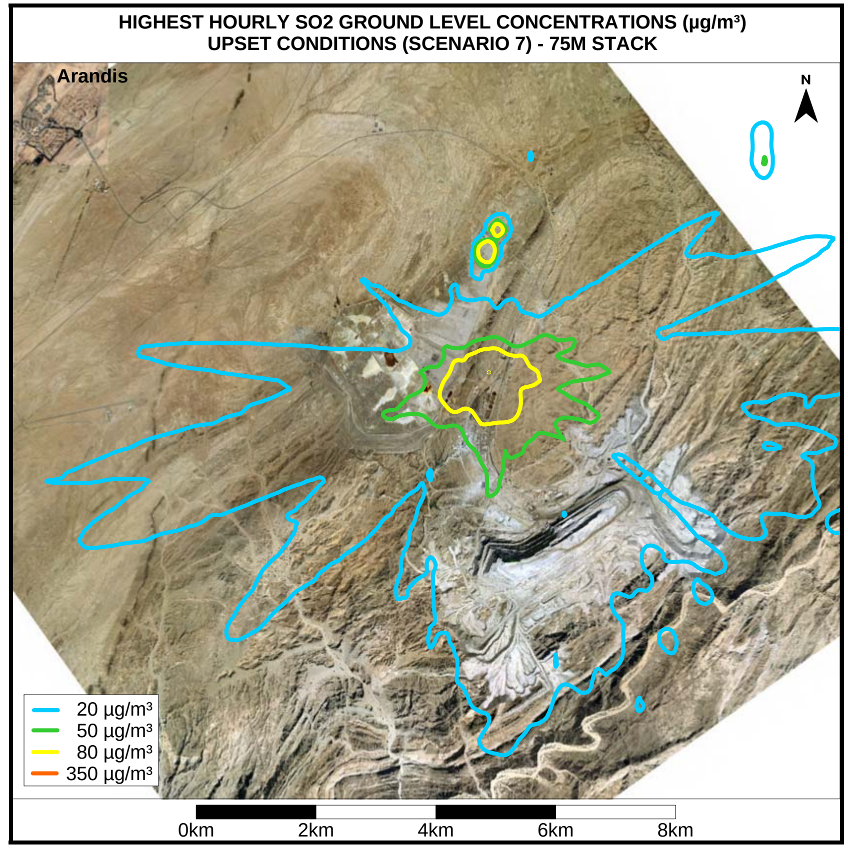


Figure 6-19: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 7* (75 m stack height).

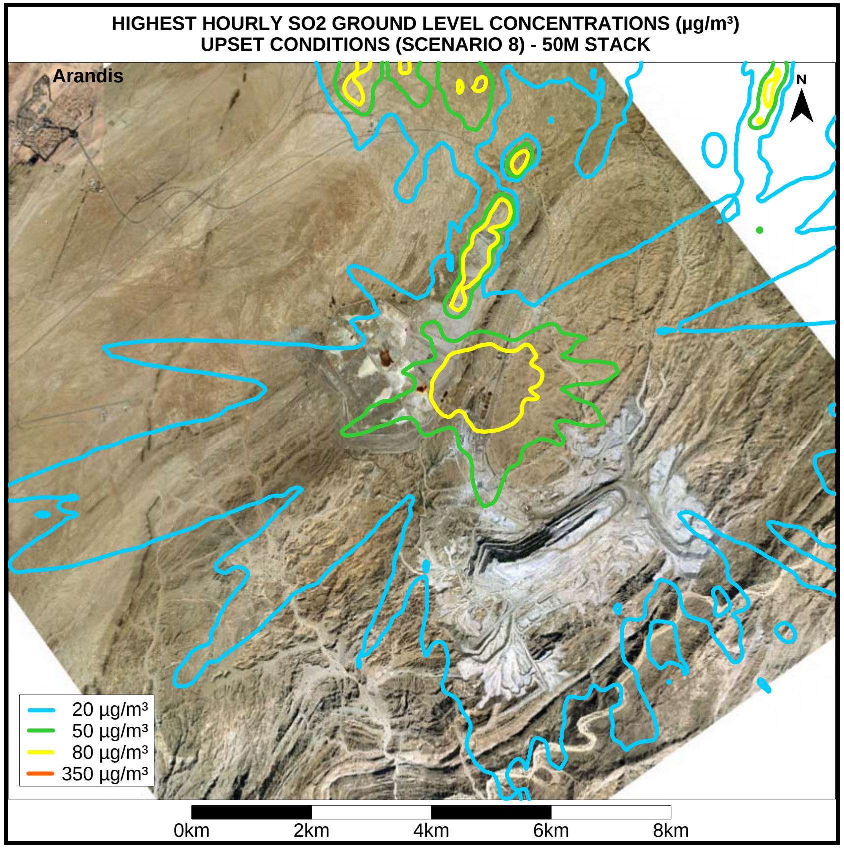


Figure 6-20: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 8* (50 m stack height).

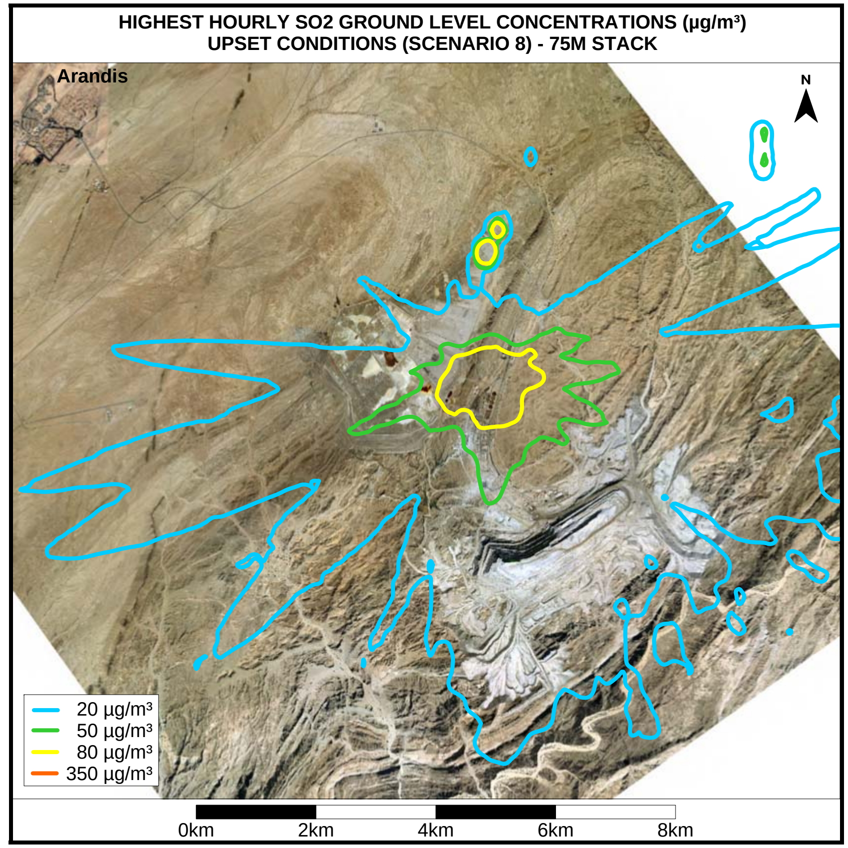


Figure 6-21: Highest hourly SO_2 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 8* (75 m stack height).

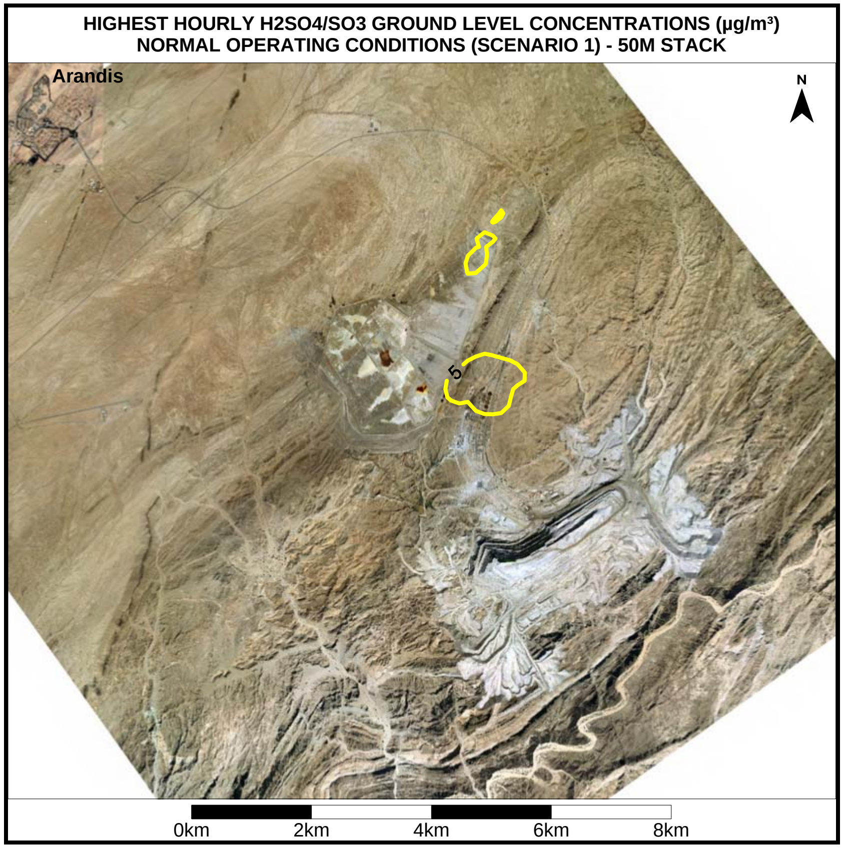


Figure 6-22: Highest hourly SO_3/H_2SO_4 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (50 m stack height).

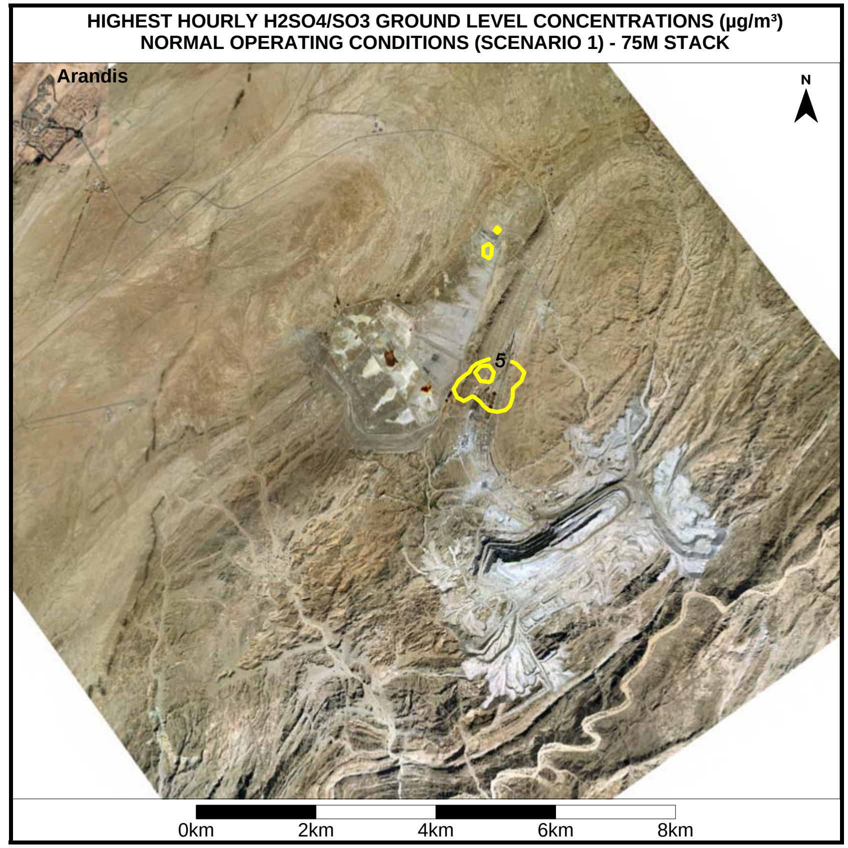


Figure 6-23: Highest hourly SO_3/H_2SO_4 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (75 m stack height).

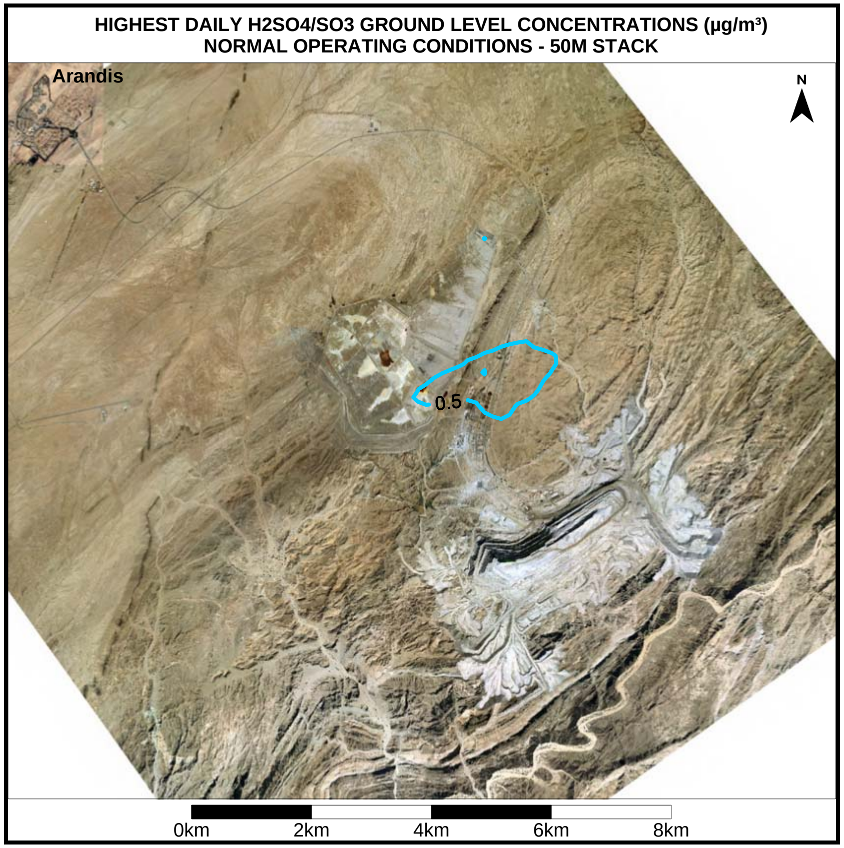


Figure 6-24: Highest daily SO_3/H_2SO_4 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (50 m stack height).

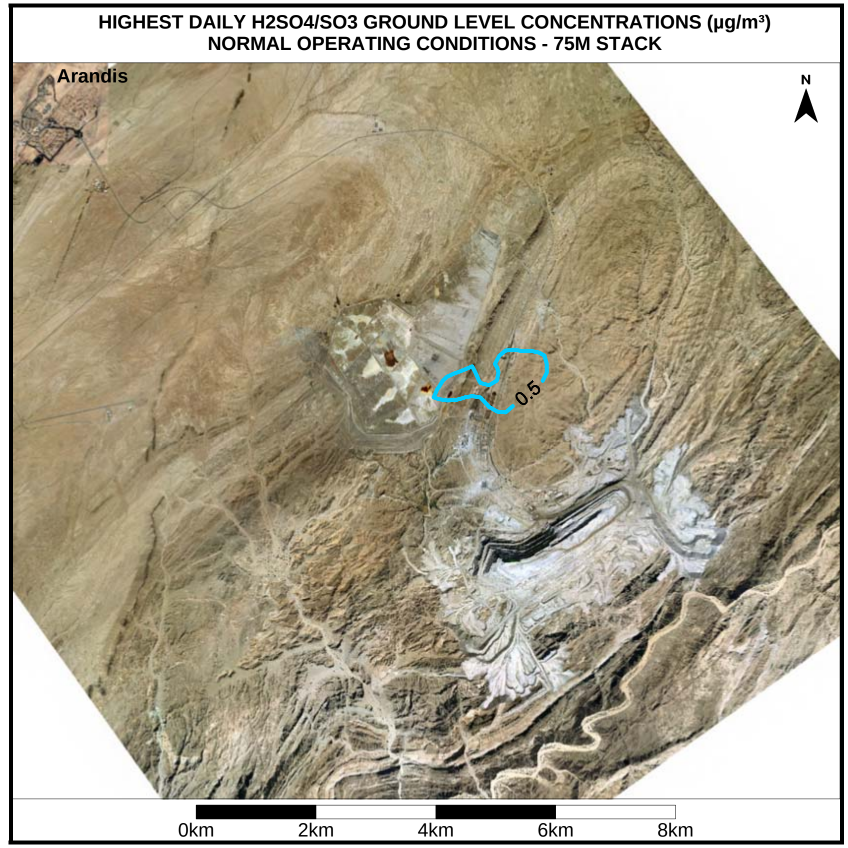


Figure 6-25: Highest daily SO_3/H_2SO_4 ground level concentrations due to normal operating conditions at the proposed Acid Plant – *Scenario 1* (75 m stack height).

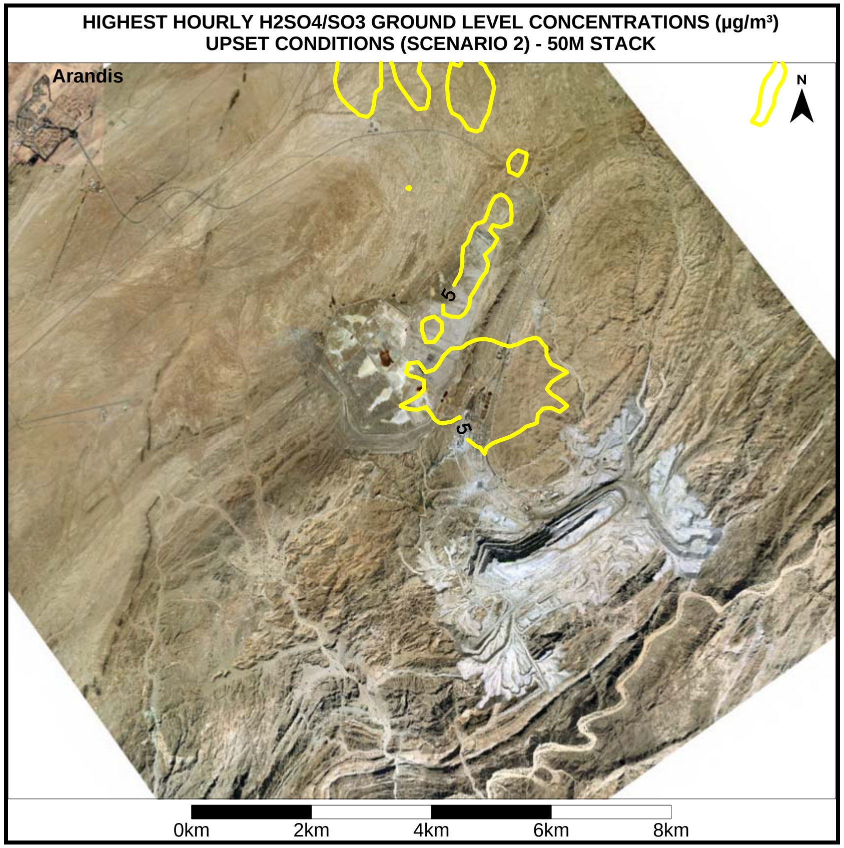


Figure 6-26: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 2* (50 m stack height).

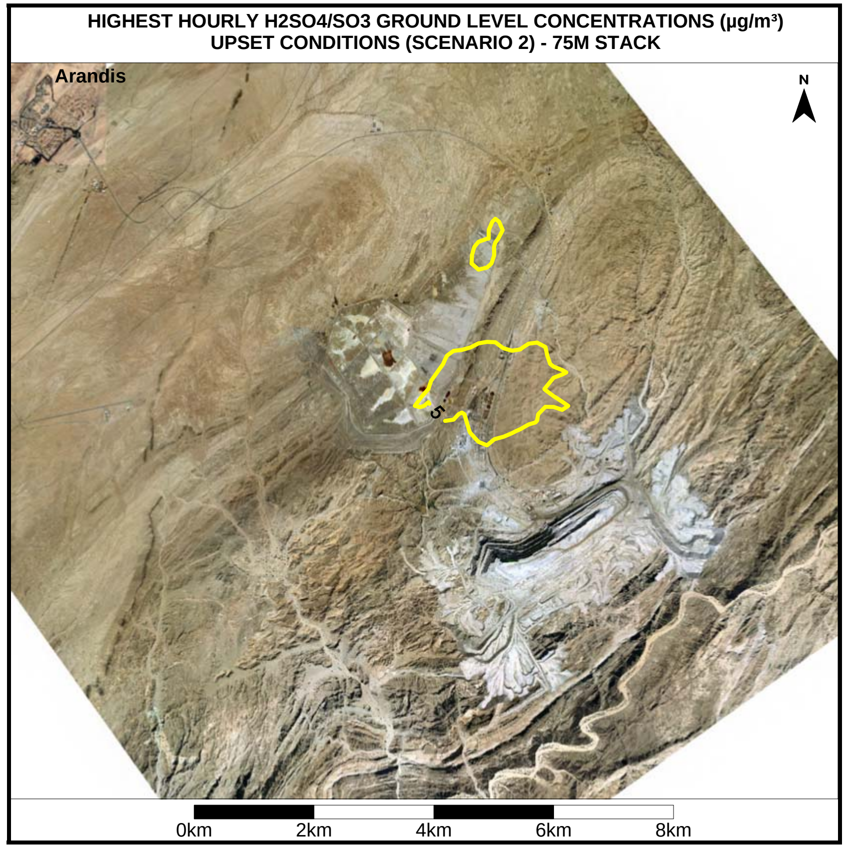


Figure 6-27: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 2* (75 m stack height).

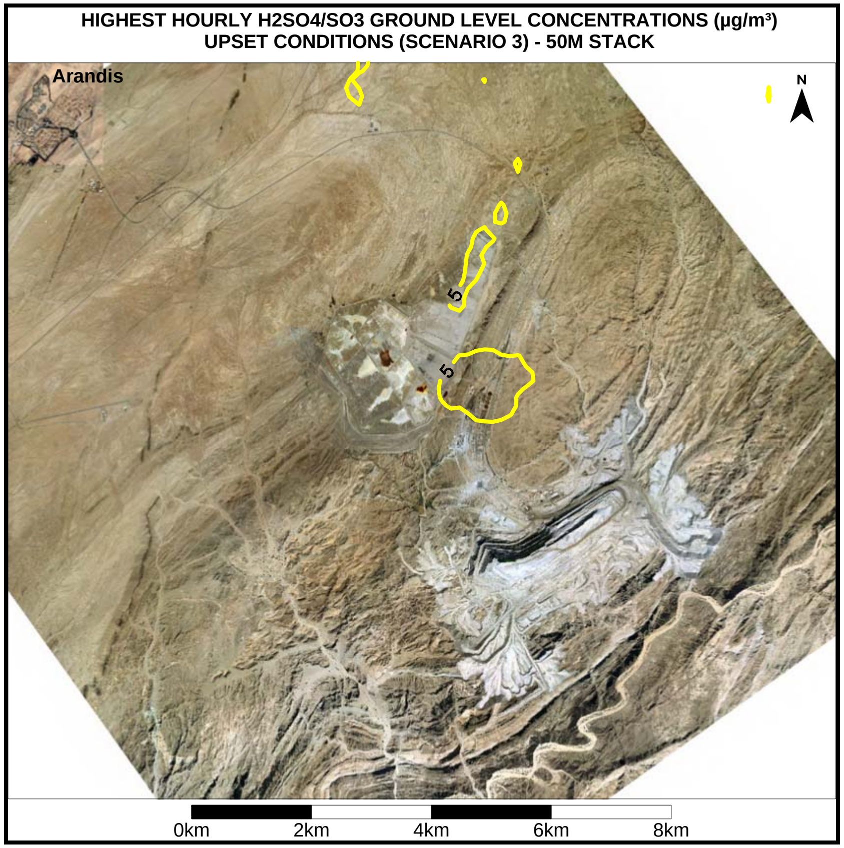


Figure 6-28: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 3* (50 m stack height).

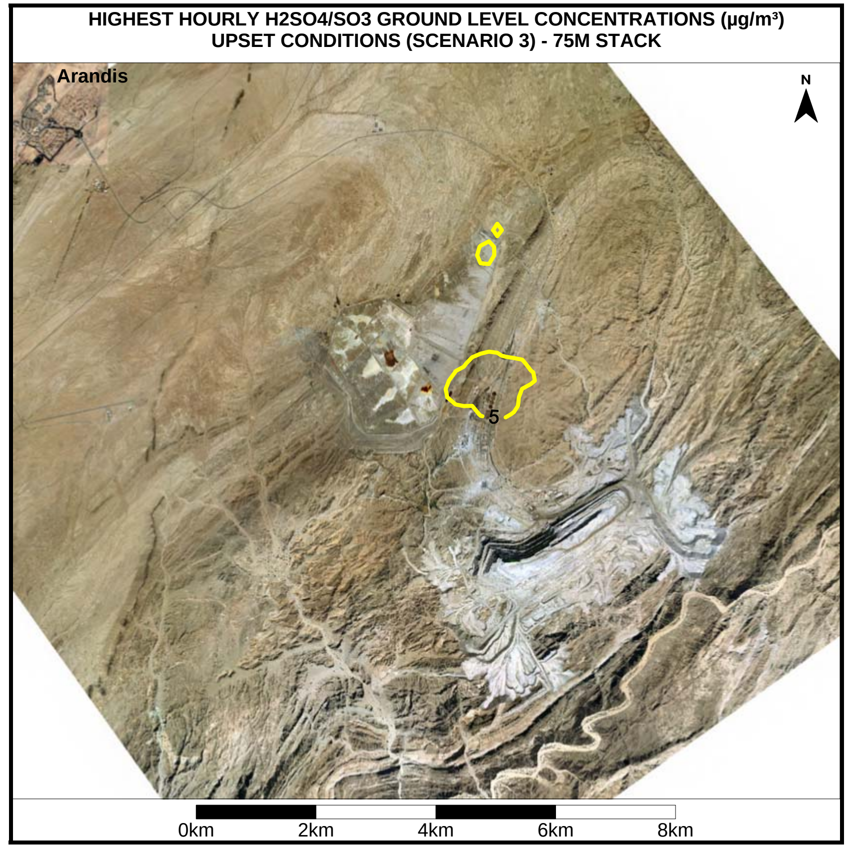


Figure 6-29: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 3* (75 m stack height).

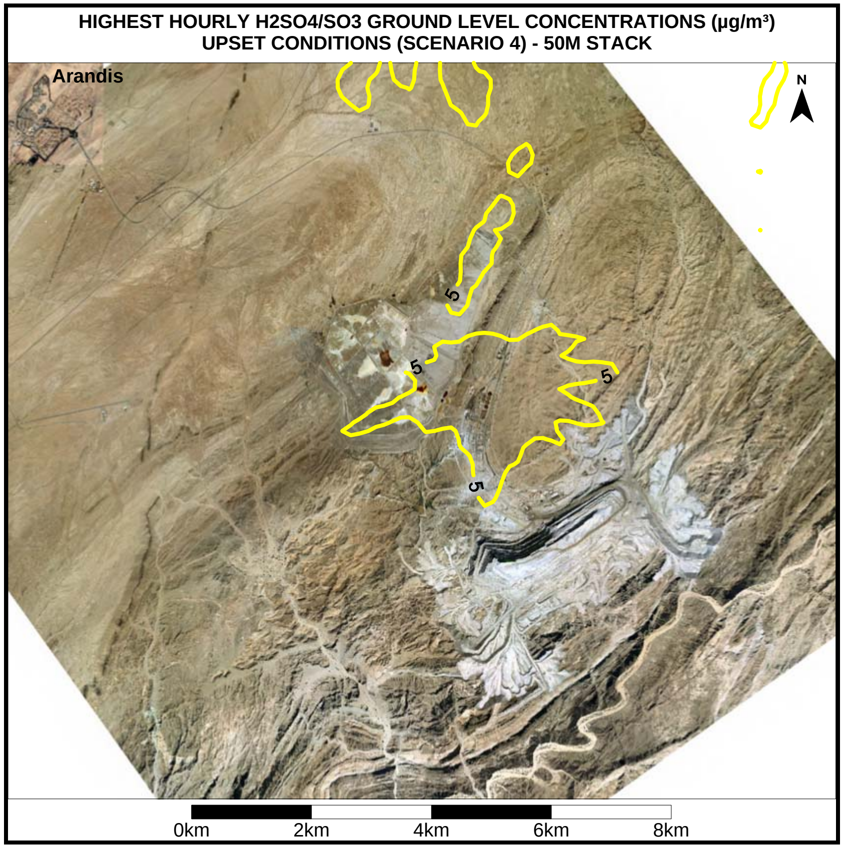


Figure 6-30: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 4* (50 m stack height).

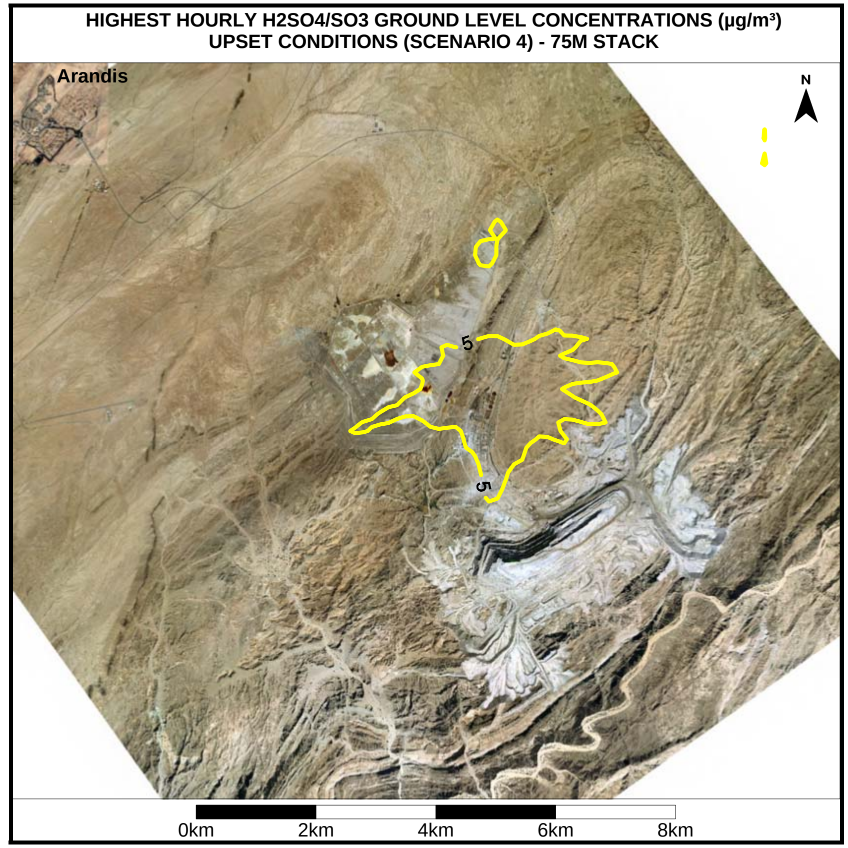


Figure 6-31: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 4* (75 m stack height).

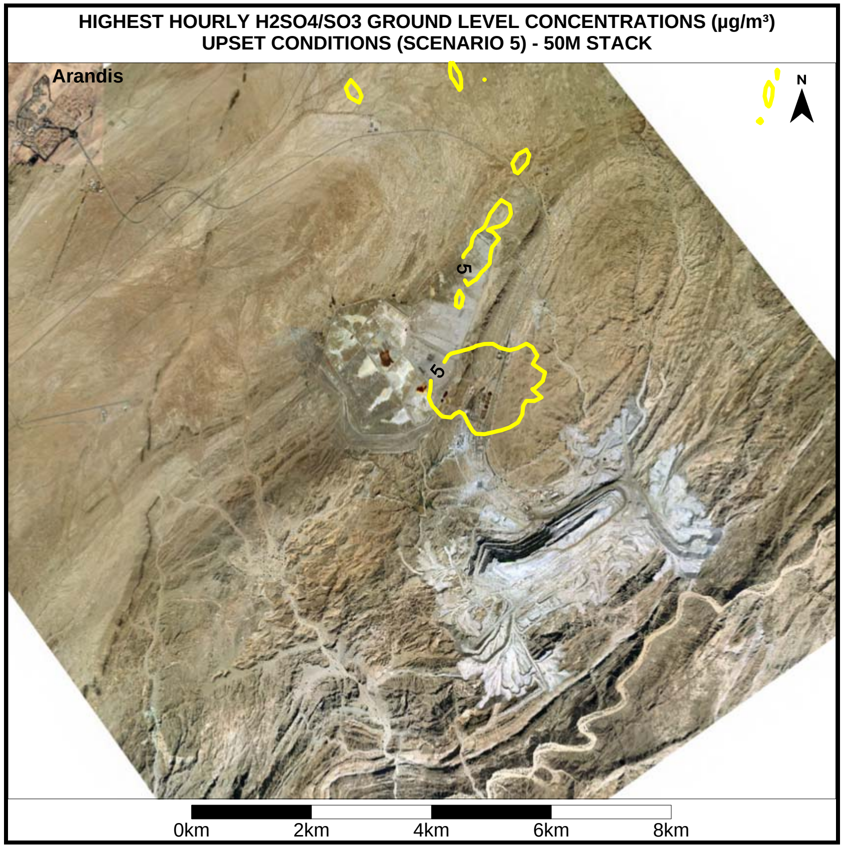


Figure 6-32: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 5* (50 m stack height).

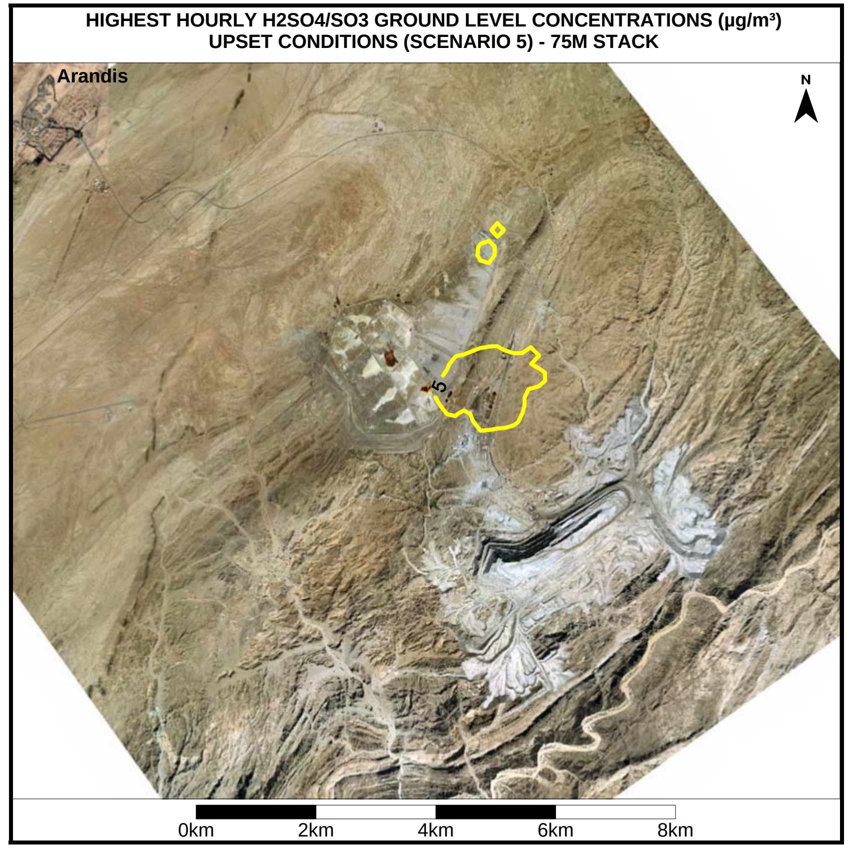


Figure 6-33: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 5* (75 m stack height).

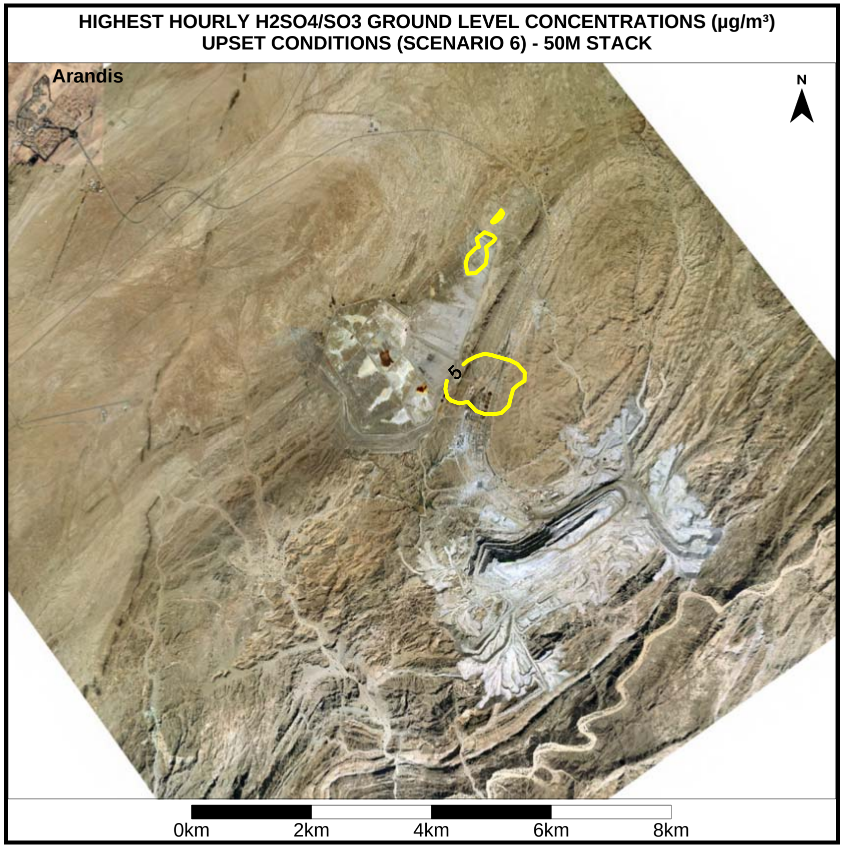


Figure 6-34: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 6* (50 m stack height).

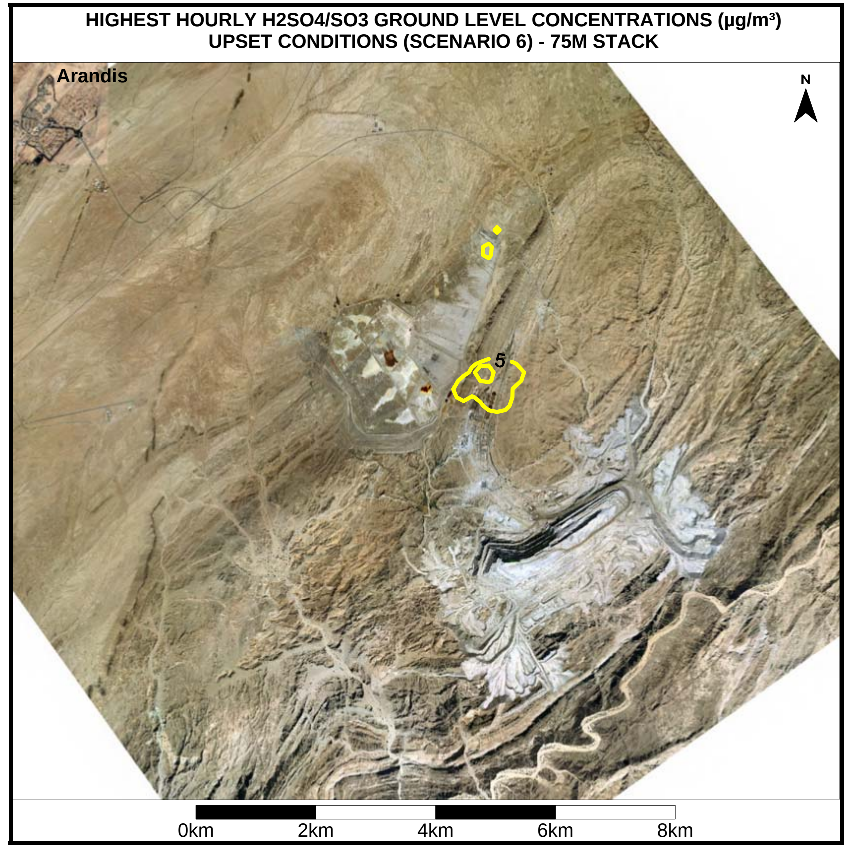


Figure 6-35: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 6* (75 m stack height).

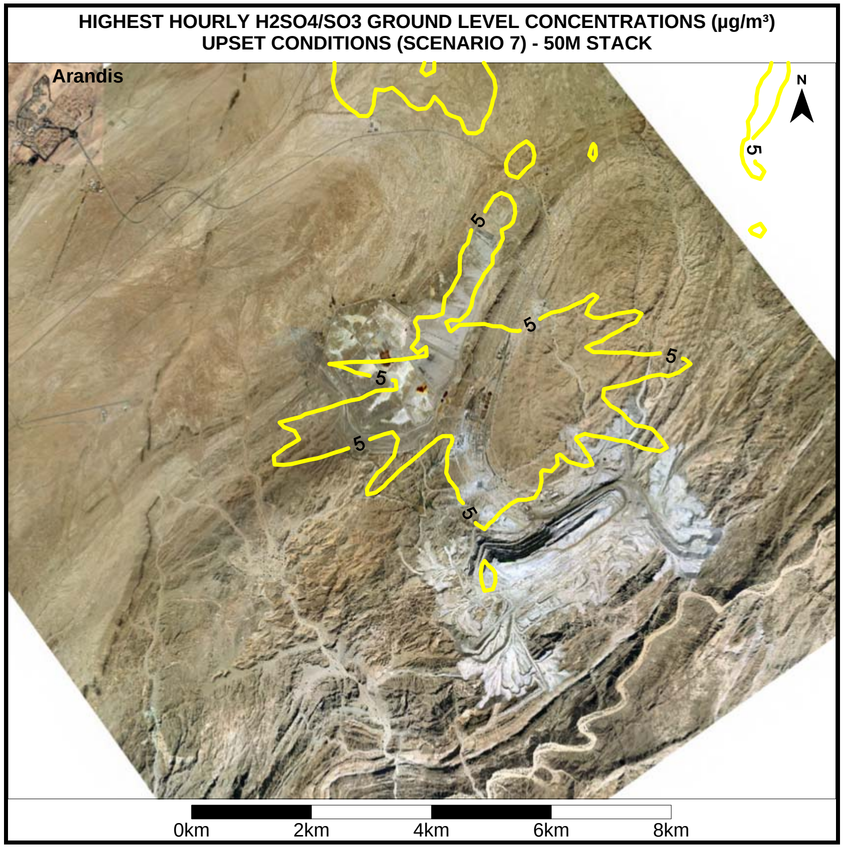


Figure 6-36: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 7* (50 m stack height).

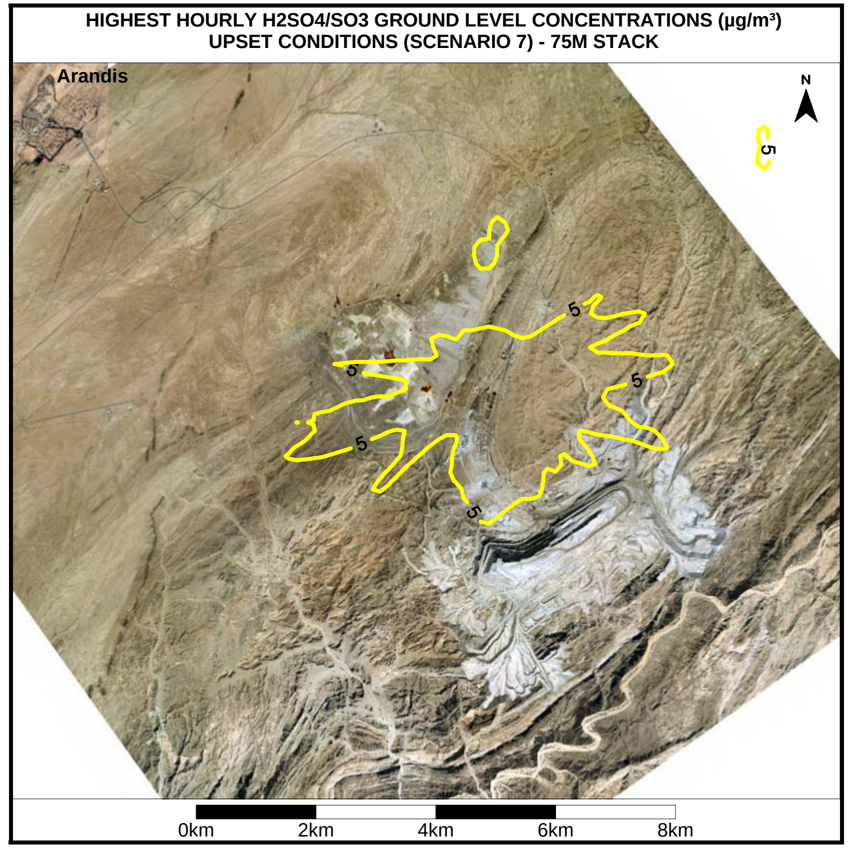


Figure 6-37: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 7* (75 m stack height).

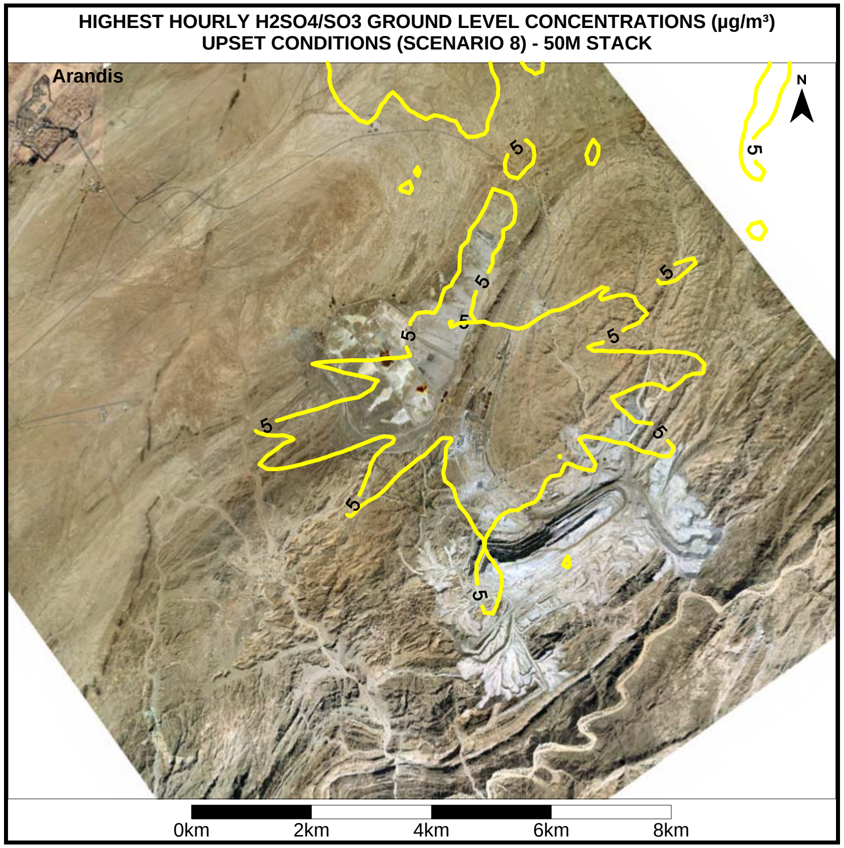


Figure 6-38: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 8* (50 m stack height).

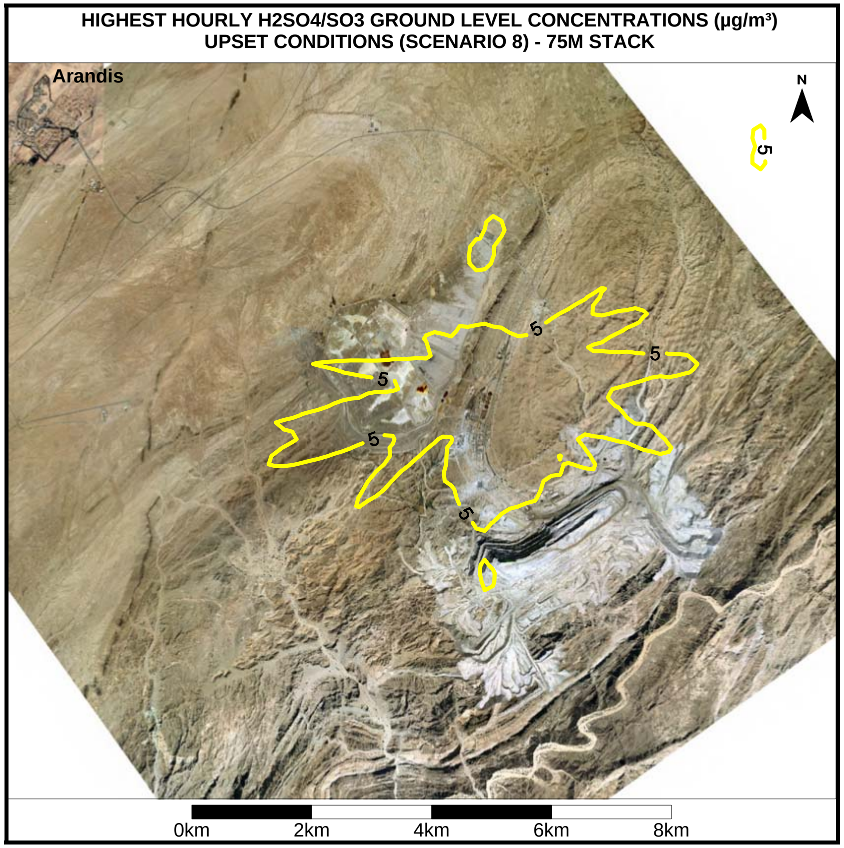


Figure 6-39: Highest hourly SO_3/H_2SO_4 ground level concentrations due to upset operating conditions at the proposed Acid Plant – *Scenario 8* (75 m stack height).

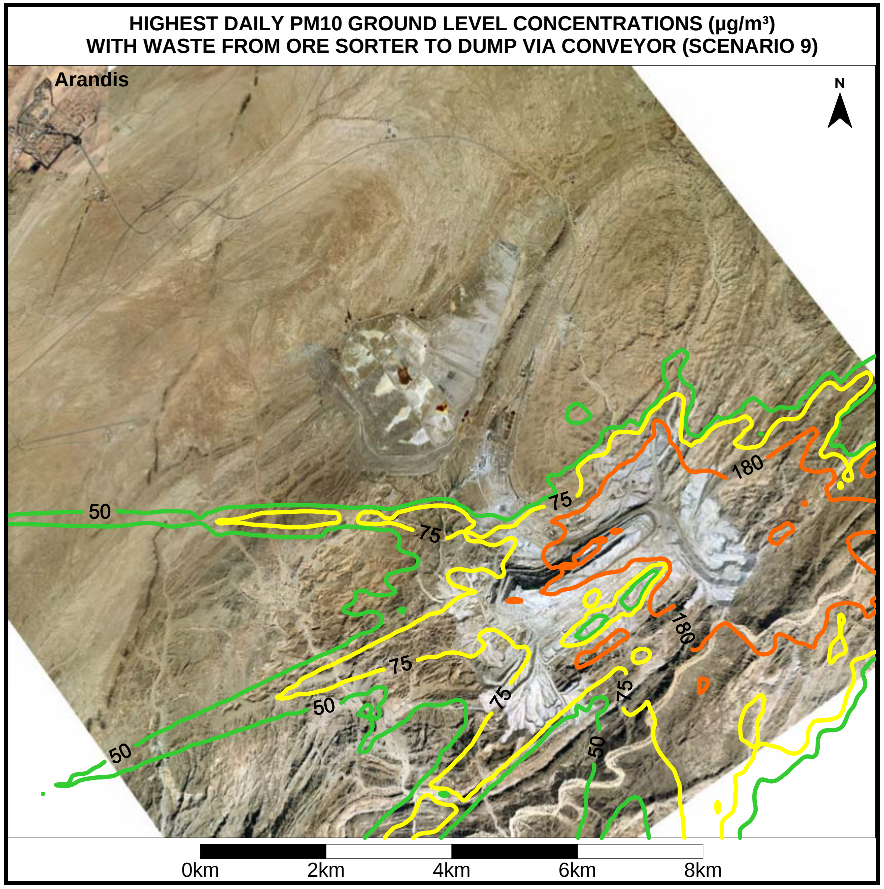


Figure 6-40: Highest daily PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 9*.

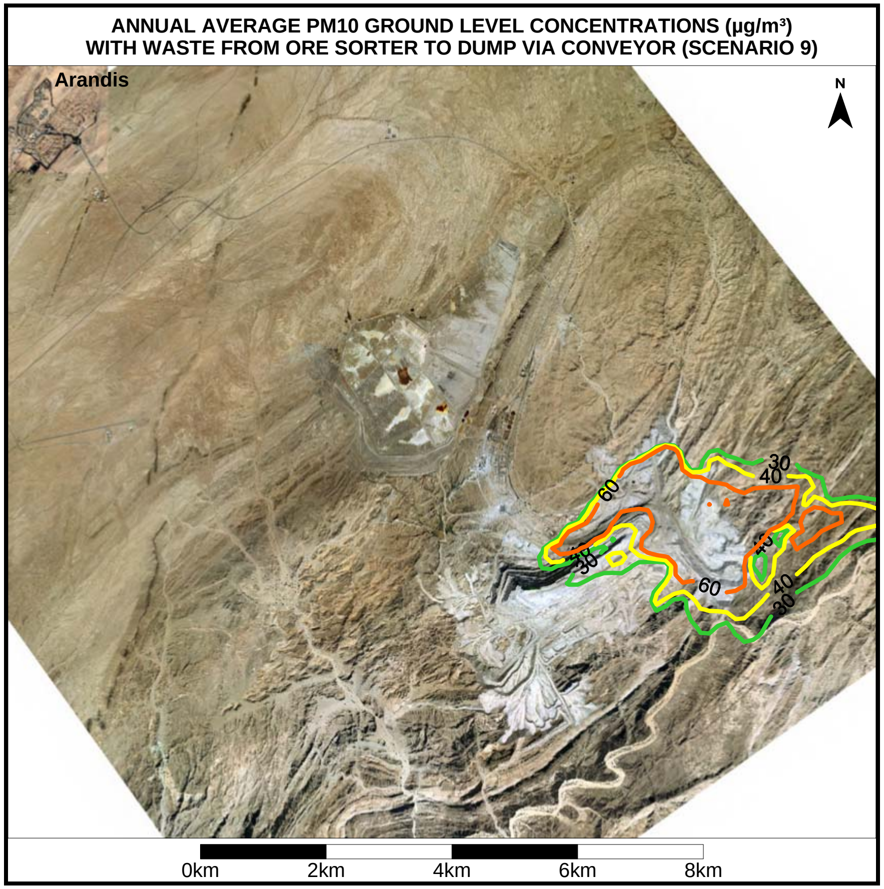


Figure 6-41: Annual average PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 9*.

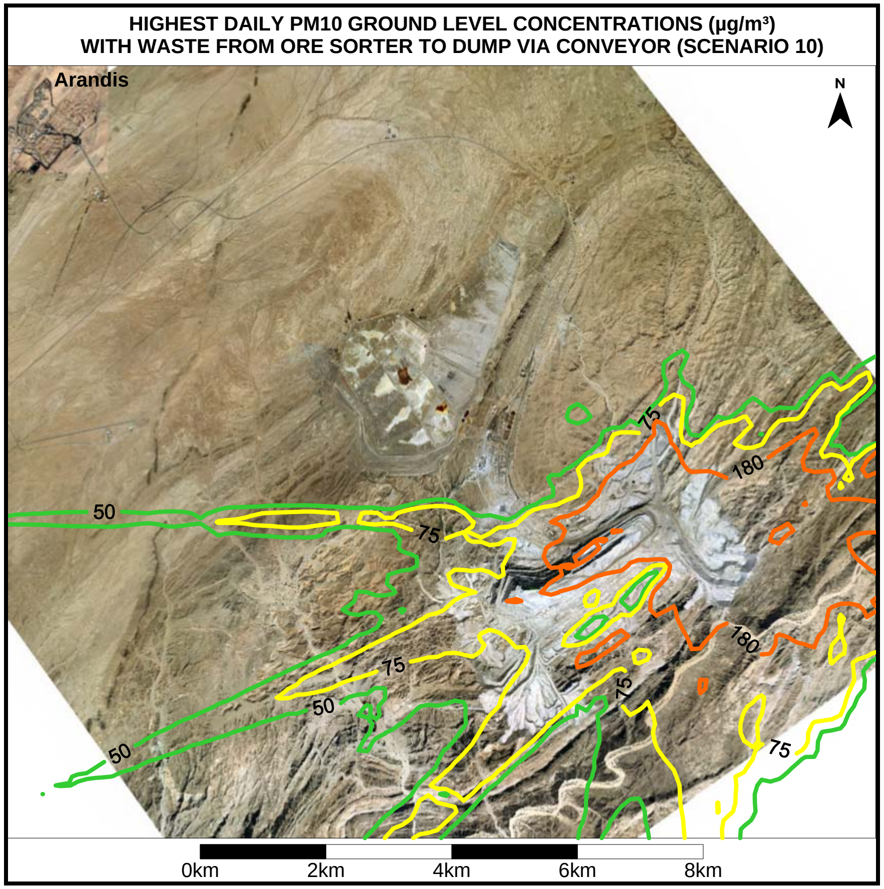


Figure 6-42: Highest daily PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 10*.

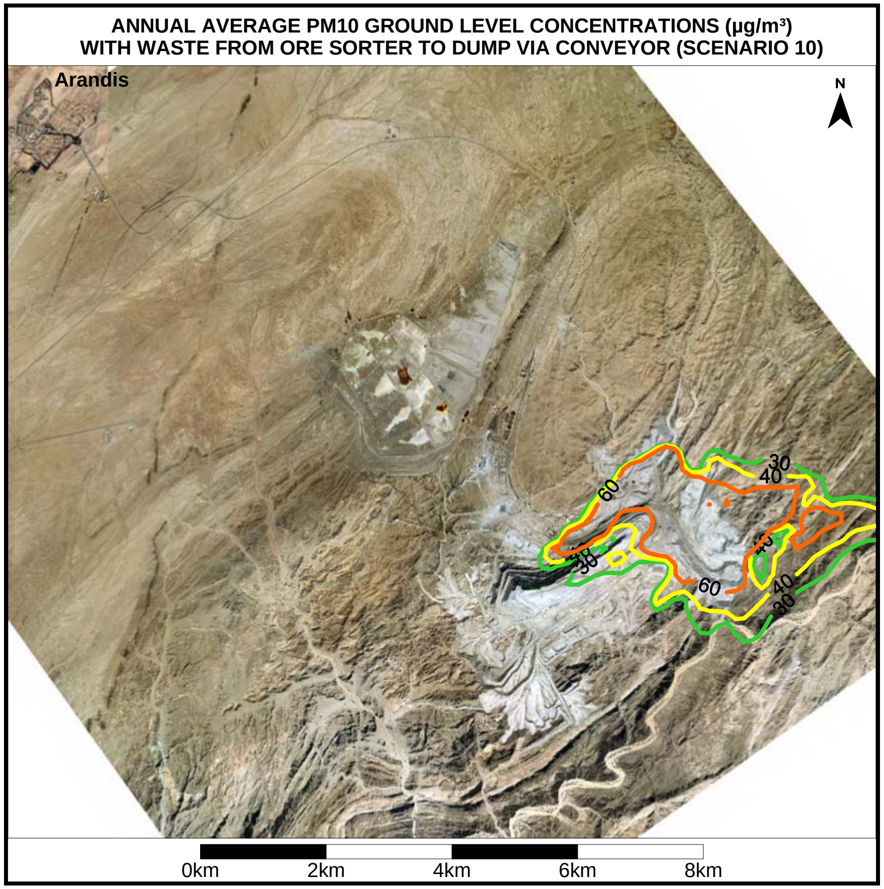
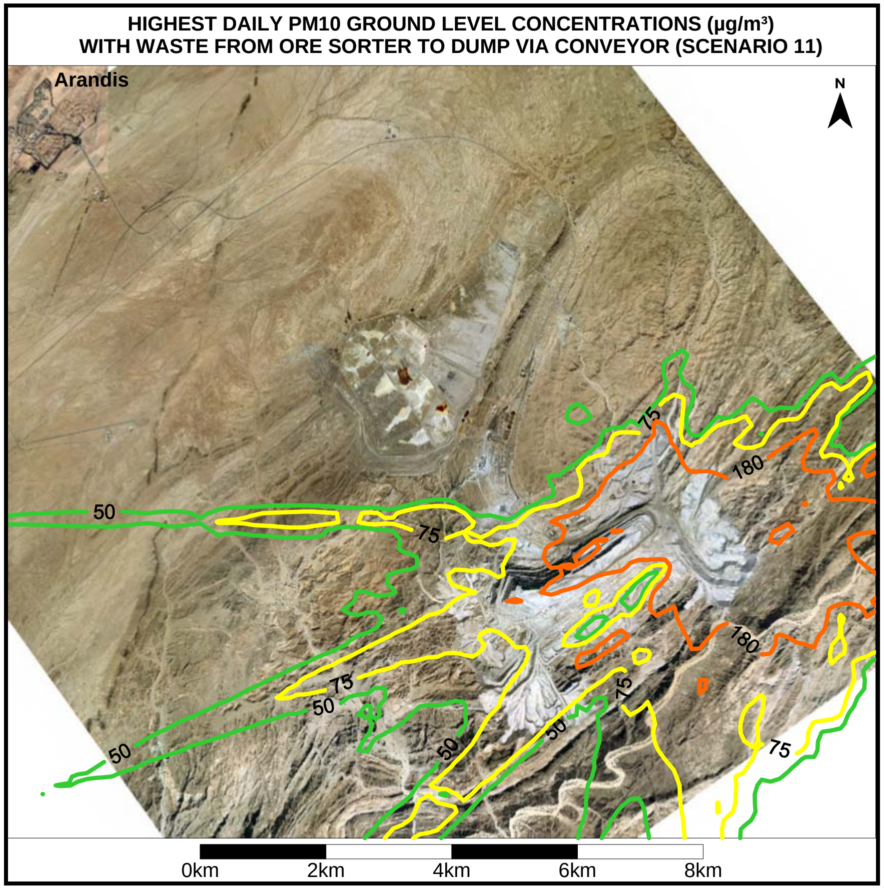


Figure 6-43: Annual average PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 10*.



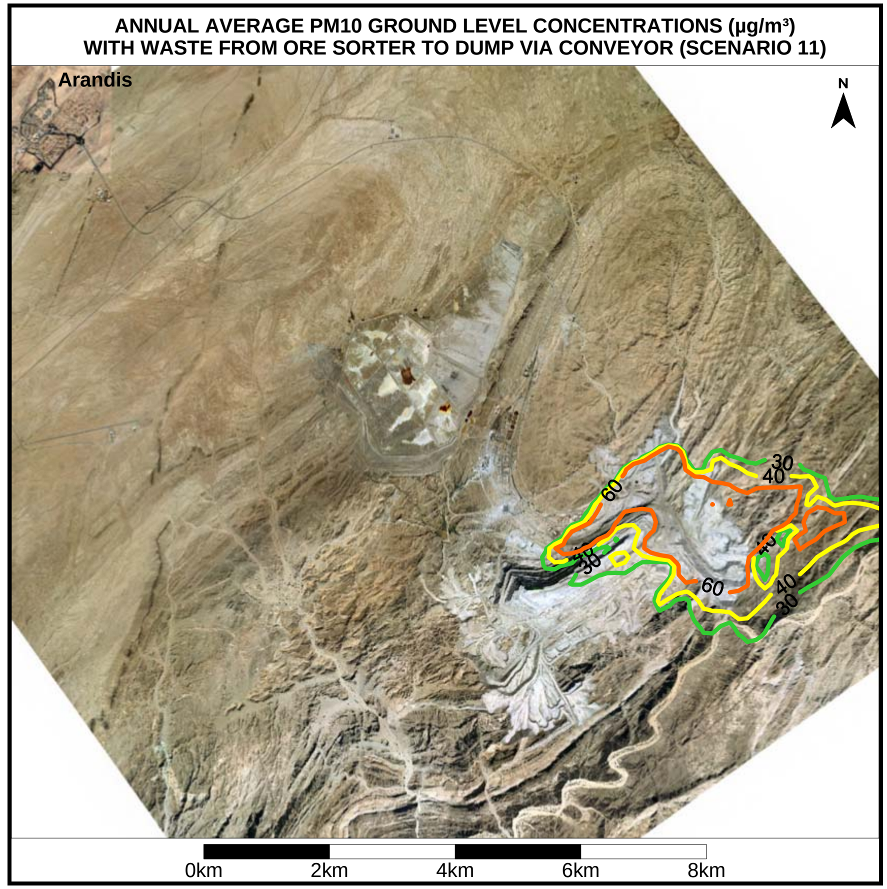


Figure 6-44: Highest daily PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 11.*

Figure 6-45: Annual average PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 11*.

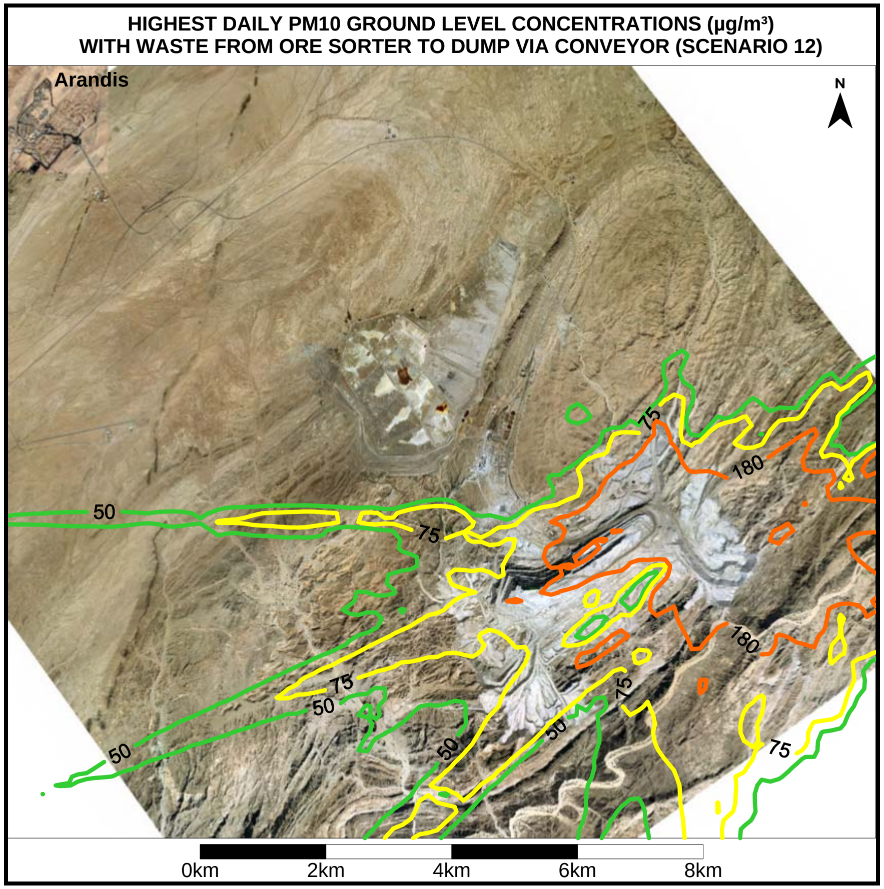


Figure 6-46: Highest daily PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 12*.

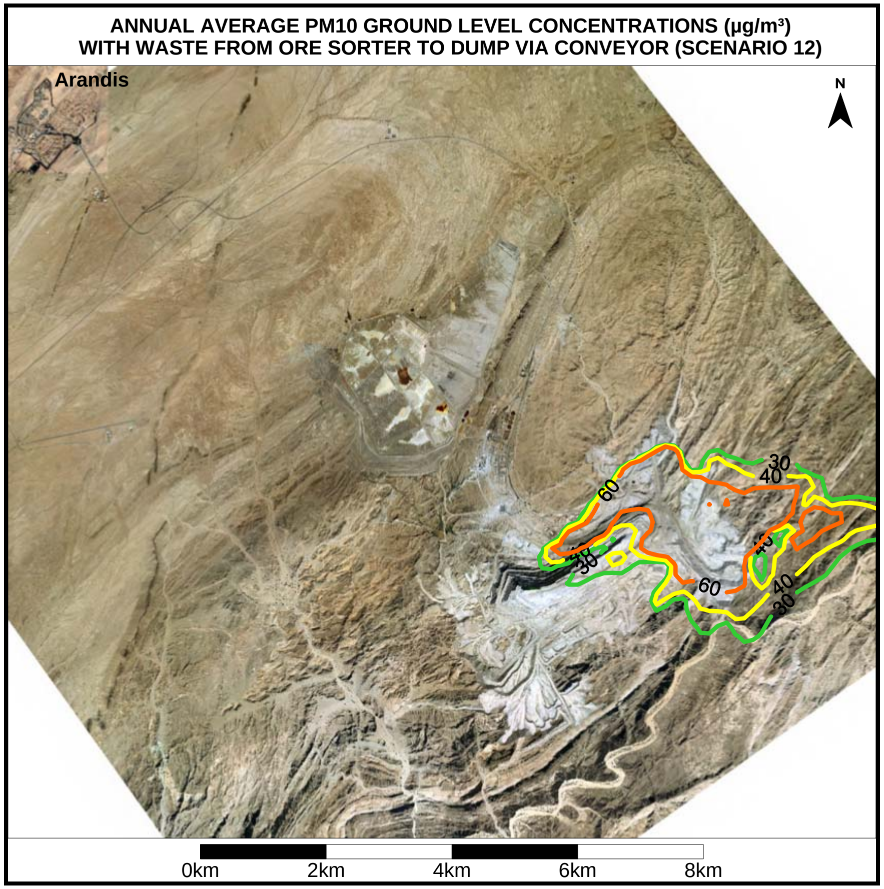


Figure 6-47: Annual average PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 12*.

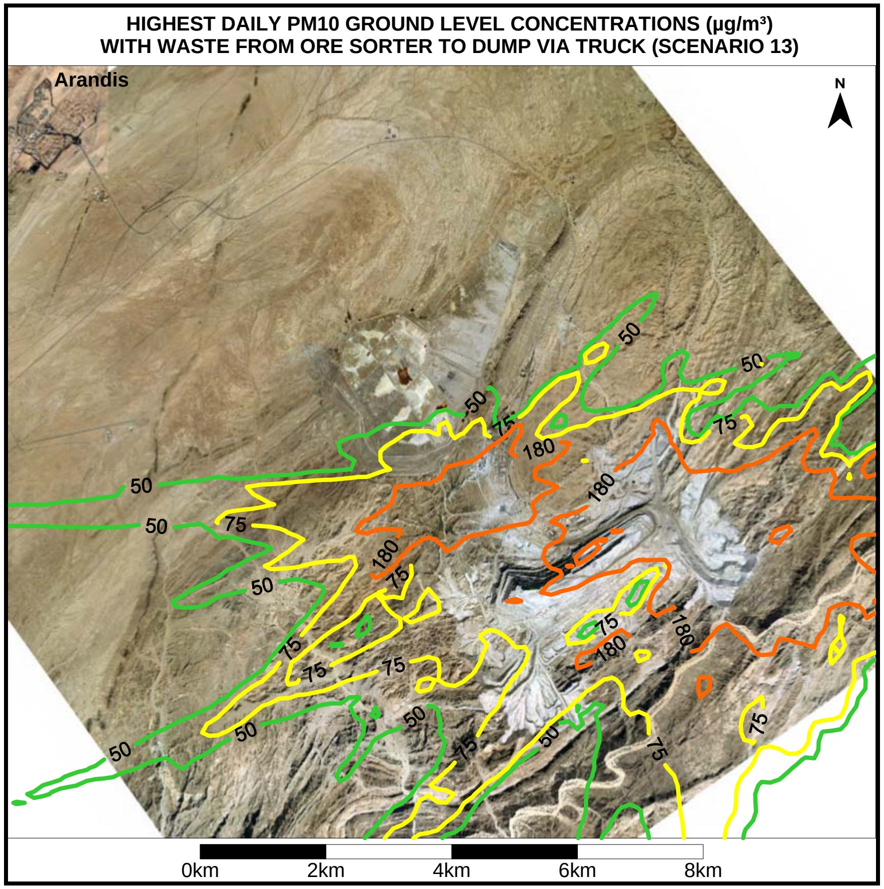


Figure 6-48: Highest daily PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via truck – *Scenario 13*.

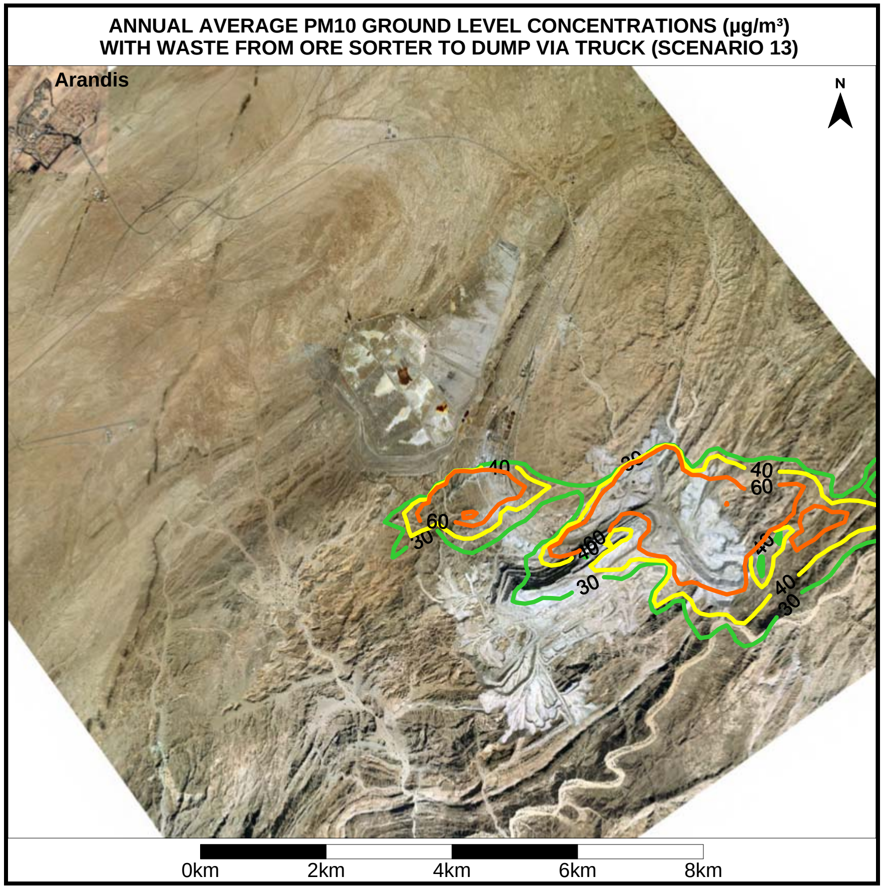


Figure 6-49: Annual average PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via truck – *Scenario 13*.

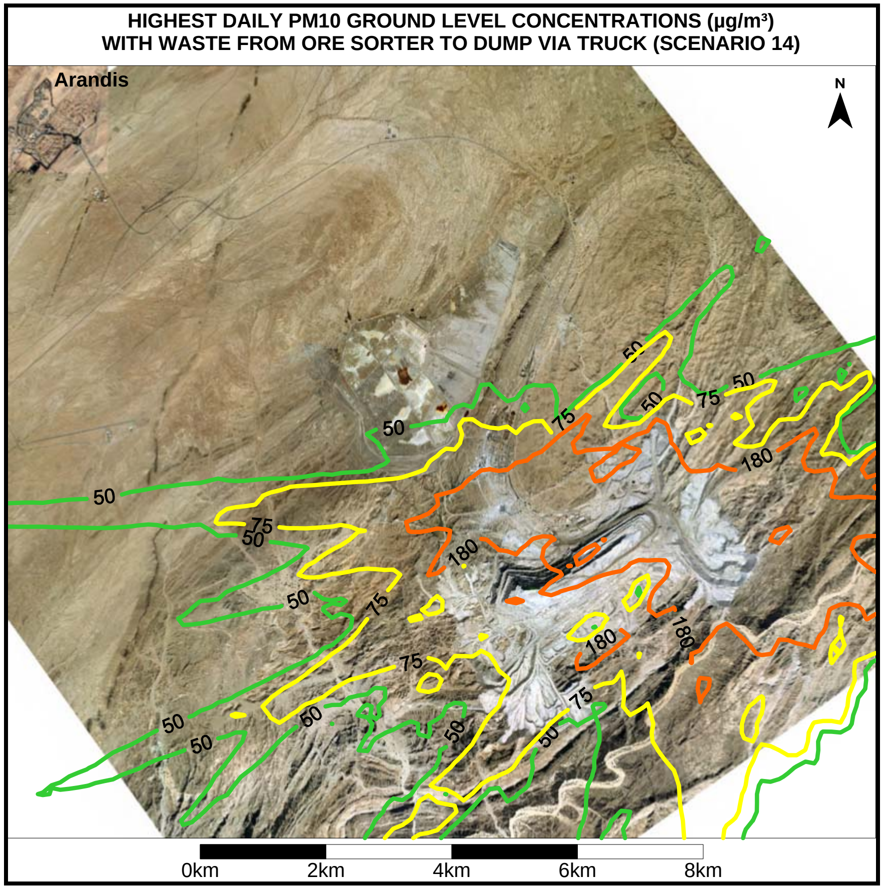


Figure 6-50: Highest daily PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via truck – *Scenario 14*.

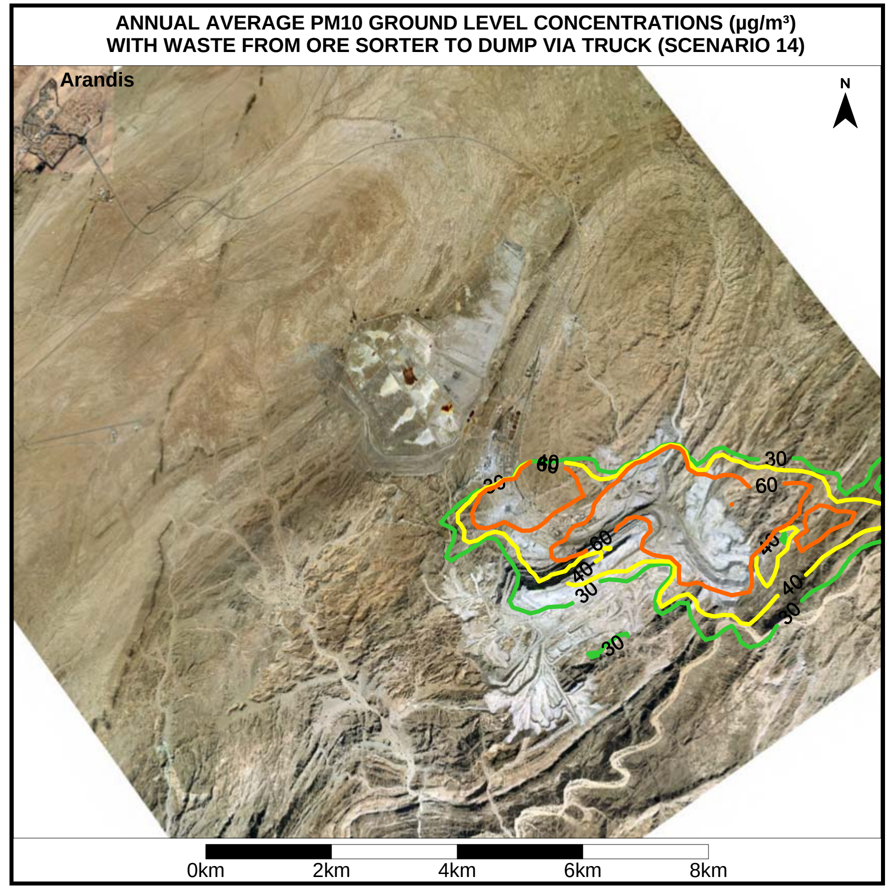


Figure 6-51: Annual average PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via truck – *Scenario 14*.

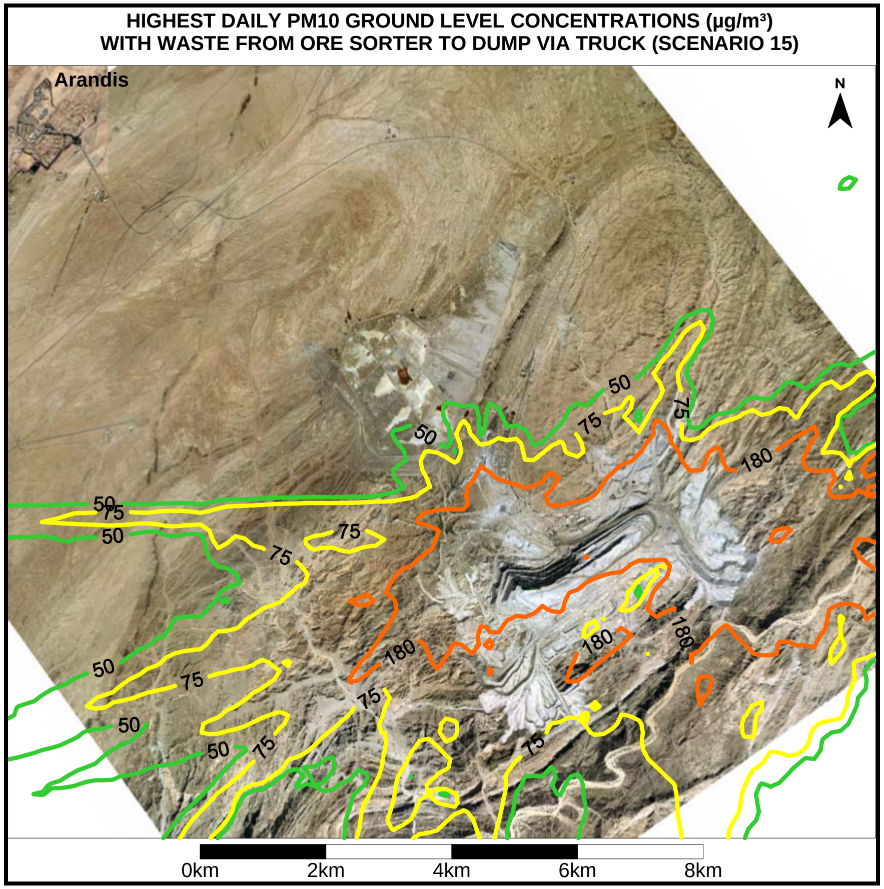


Figure 6-52: Highest daily PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via truck – *Scenario 15*.

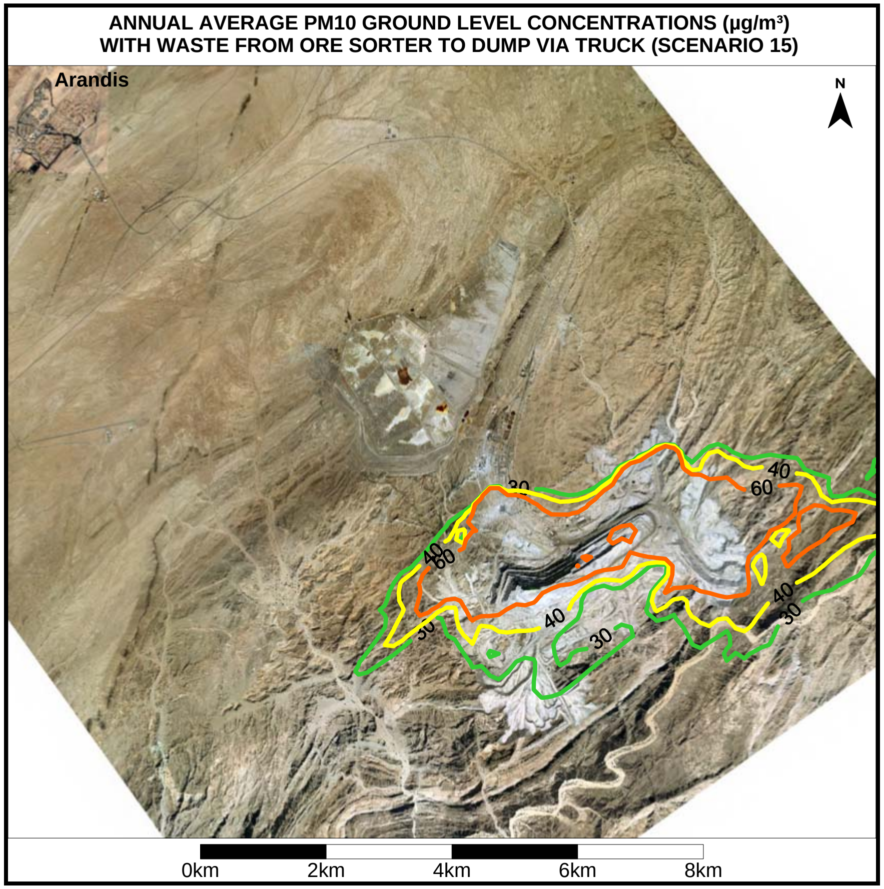


Figure 6-53: Annual average PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via truck – *Scenario 15*.

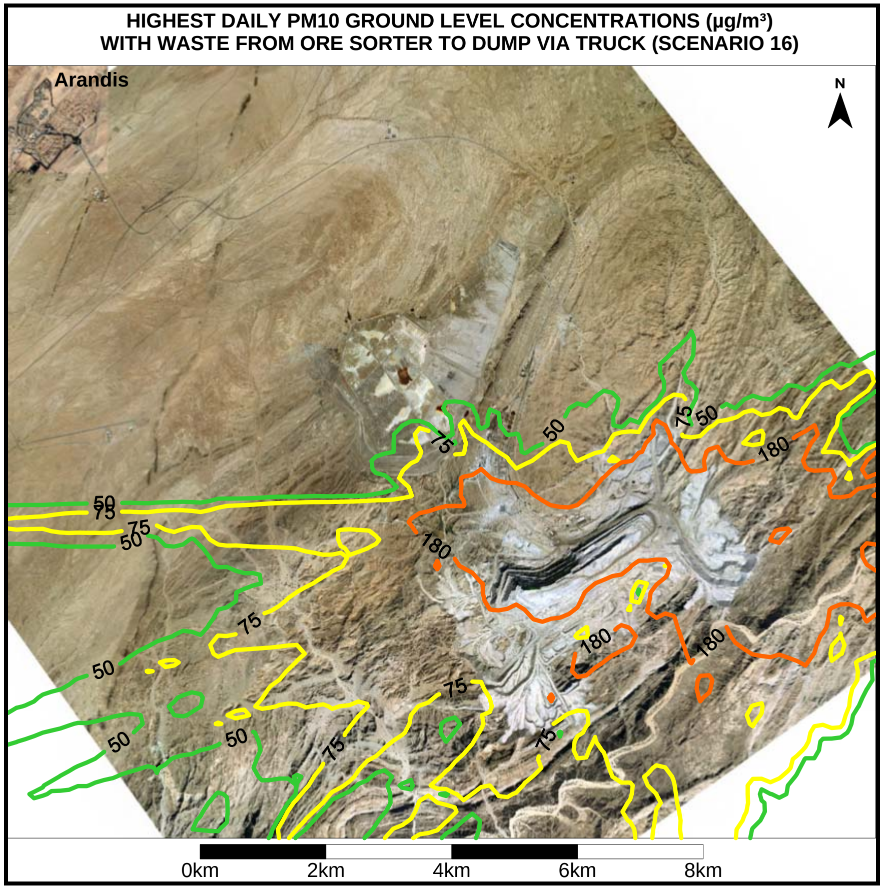


Figure 6-54: Highest daily PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via truck – *Scenario 16*.

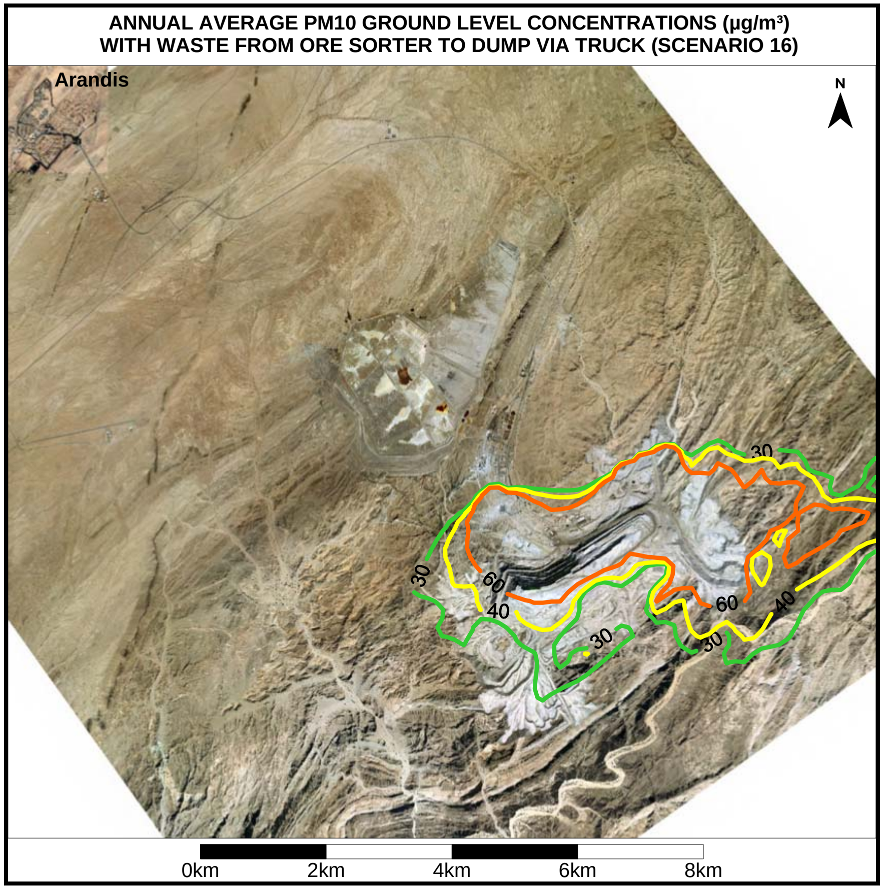


Figure 6-55: Annual average PM10 ground level concentrations due to normal operating conditions and transporting waste from Ore Sorter plant via truck – *Scenario 16*.

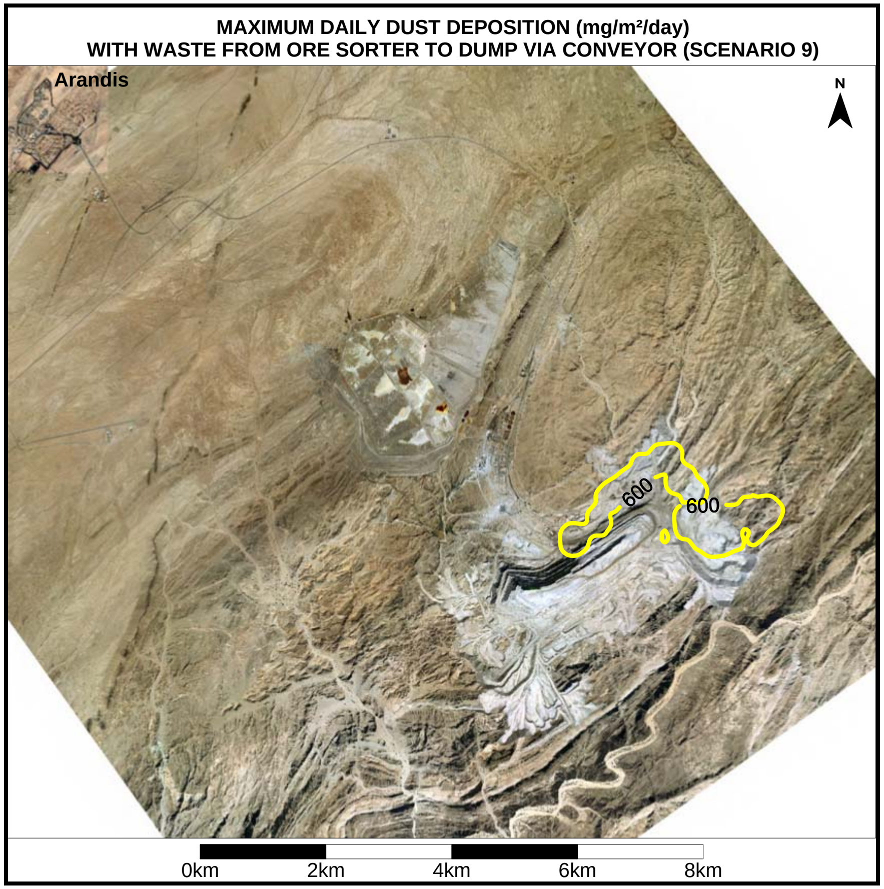


Figure 6-56: Maximum daily dust deposition due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 9*.

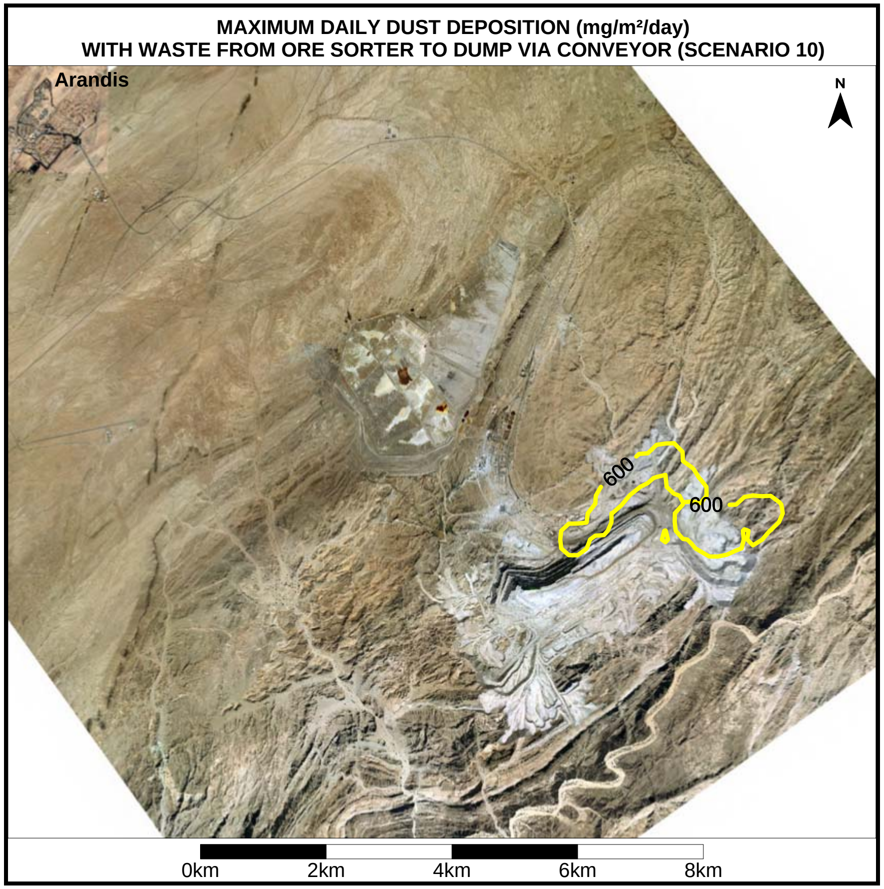


Figure 6-57: Maximum daily dust deposition due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 10*.

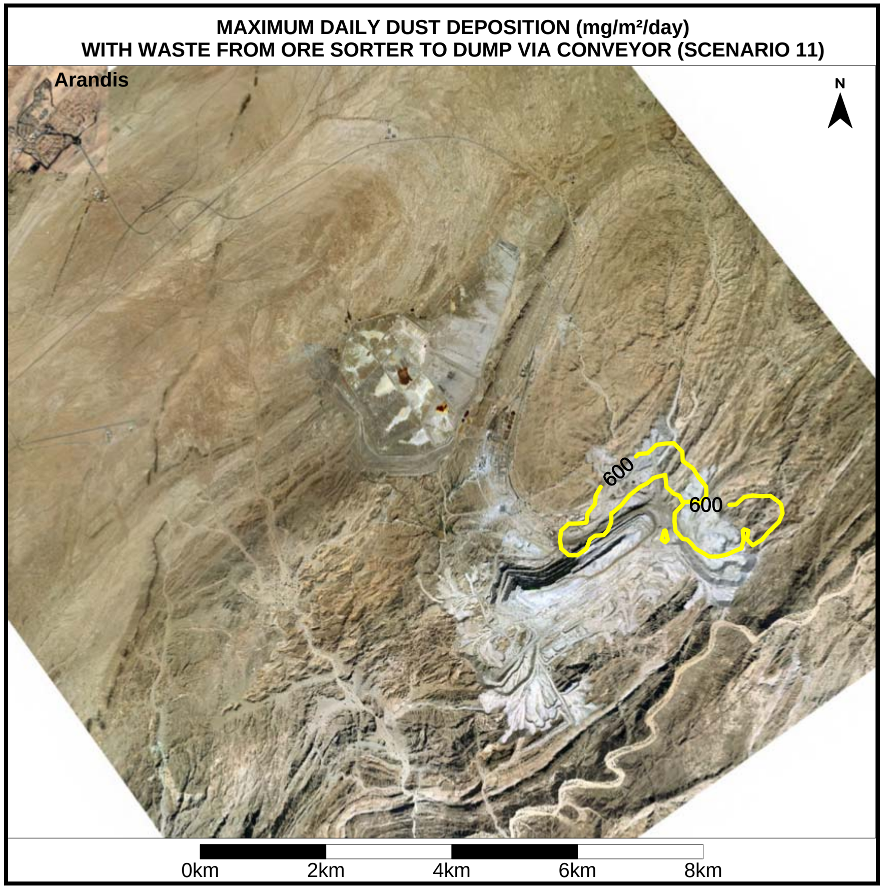


Figure 6-58: Maximum daily dust deposition due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 11*.

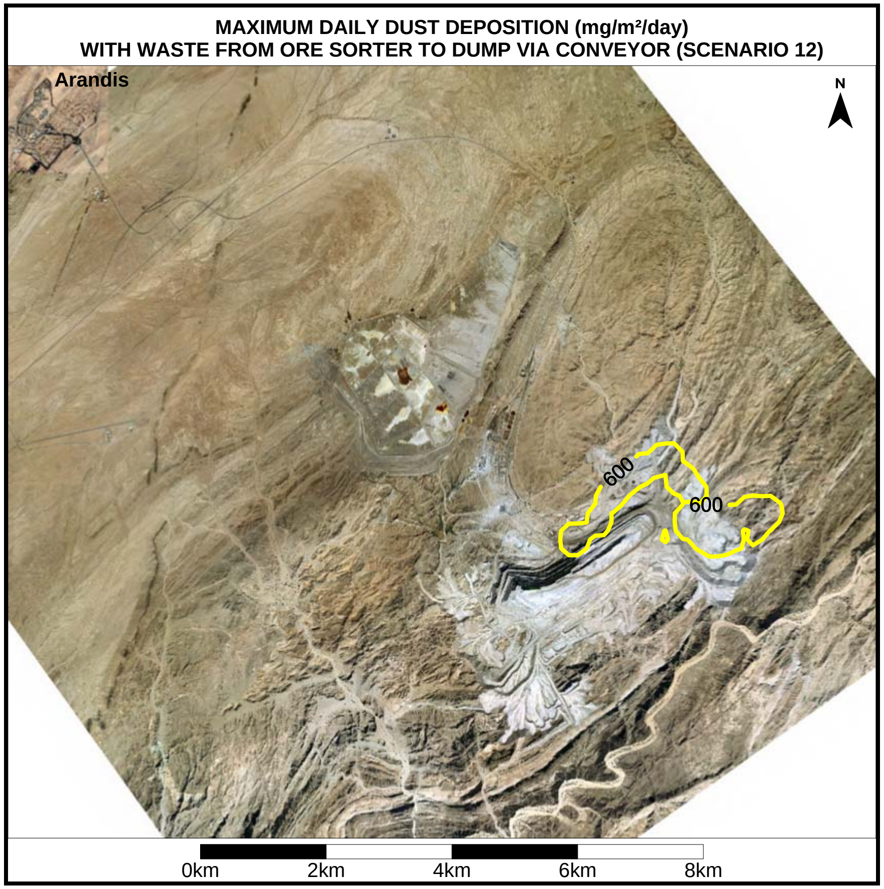


Figure 6-59: Maximum daily dust deposition due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 12*.

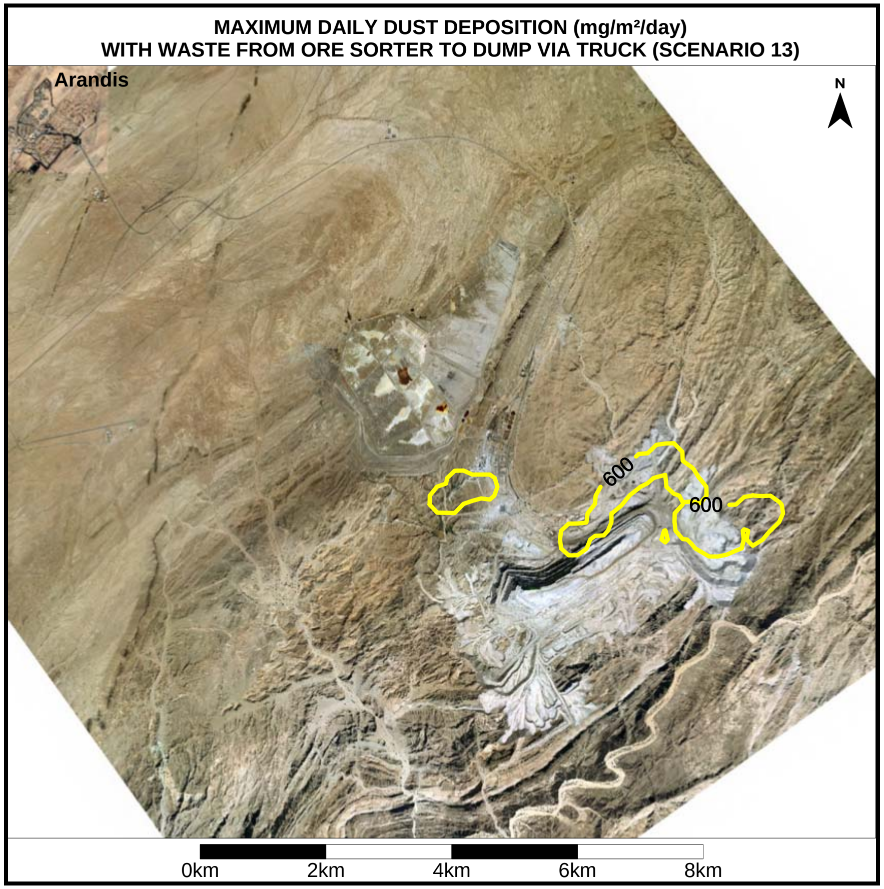


Figure 6-60: Maximum daily dust deposition due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 13*.

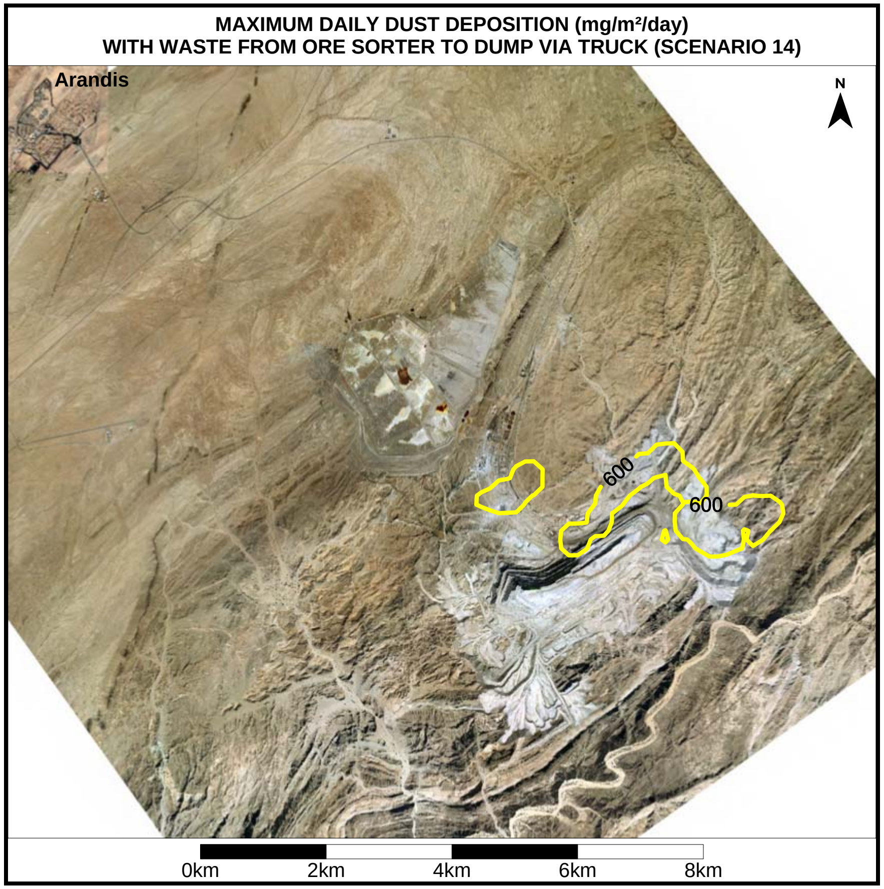


Figure 6-61: Maximum daily dust deposition due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 14*.

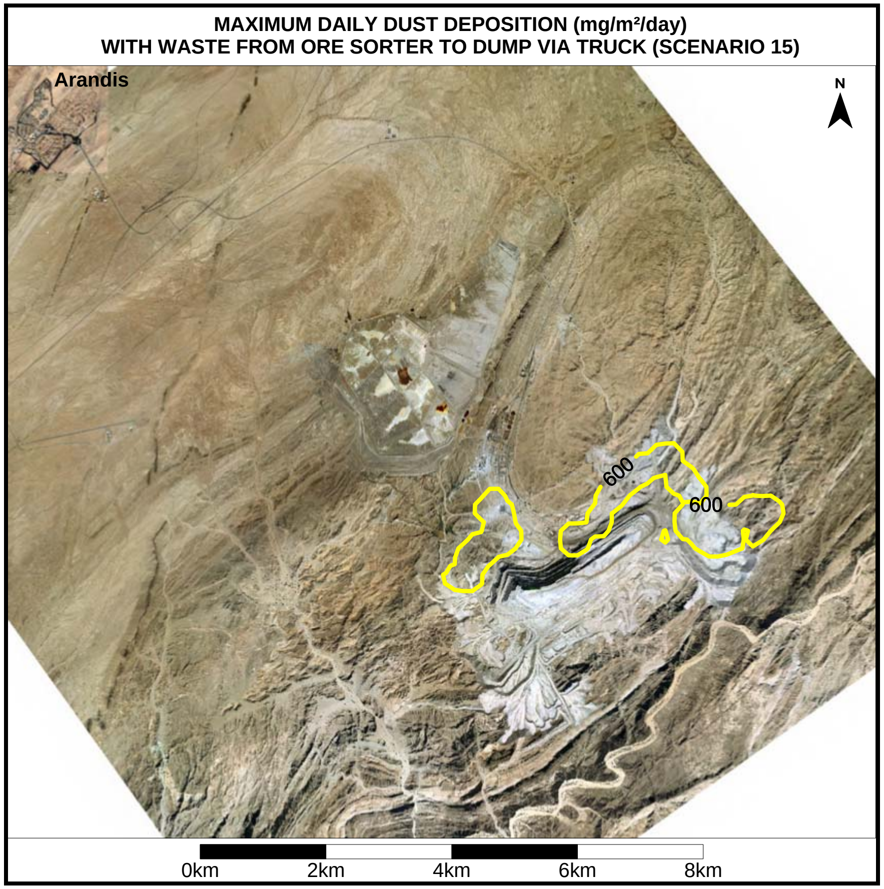


Figure 6-62: Maximum daily dust deposition due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 15*.

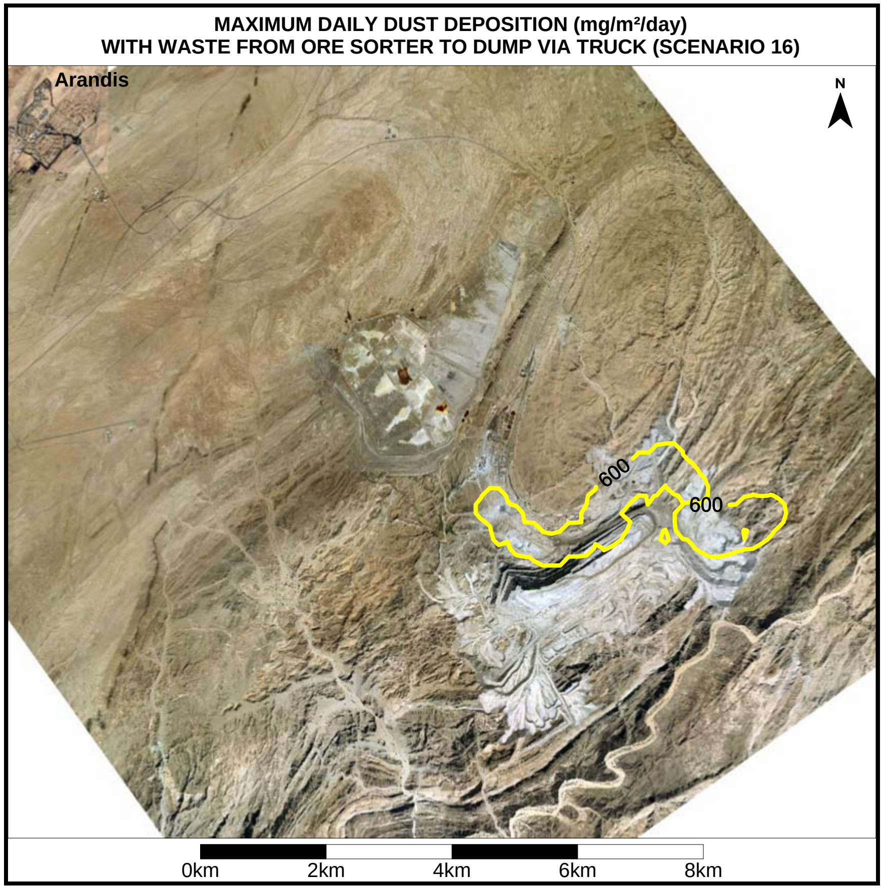


Figure 6-63: Maximum daily dust deposition due to normal operating conditions and transporting waste from Ore Sorter plant via conveyor – *Scenario 16*.

6.2 Compliance with Ambient Air Quality Criteria

In assessing “compliance” with air quality limits it is important to note the following:

- Variations in where air quality limits are applicable. The EC (and UK) stipulate that air quality limits are applicable in areas where there is a reasonable expectation that public exposures will occur over the averaging period of the limit. In the US, the approach is frequently adopted of applying air quality limits within all areas to which the public has access (i.e. everywhere not fenced off or otherwise controlled for public access). In South Africa there is still considerable debate regarding the practical implementation of the air quality standards included in the schedule to the Air Quality Act. The Act does however define “ambient air” as excluding air regulated by the Occupational Health and Safety Act of 1993. This implies that air quality limits may be required to be met beyond the fencelines of industries.

- The SA standards included in the schedule to the Air Quality Act are incomplete when compared to legal limits issued by other countries. Air quality standards typically comprise: thresholds, averaging periods, monitoring protocols, timeframes for achieving compliance and typically also permissible frequencies of exceedance. (Thresholds are generally set based on health risk criteria, with permissible frequencies and timeframes taking into account the existing air pollutant concentrations and controls required for reducing air pollution to within the defined thresholds. The practice adopted in Europe is to allow increasingly more limited permissible frequencies of exceedance, thus encouraging the progressive reduction of air pollution levels to meeting limit values.)

NOTE: Given the above uncertainties a conservative approach was adopted in assessing compliance of pollutants with SA air quality standard and with single exceedances of thresholds beyond the “fenceline” of the Rössing Uranium Mine being taken as constituting “non-compliance”. In order however to demonstrate areas of “non-compliance” should permissible frequencies be issued at a latter date reference is made to the EC air quality limits.

The concentrations simulated are depicted in Table 6-2. These concentrations reflect emissions from all sources due to the expansion (Phase 1) at Rössing Uranium Mine. Impacts were assessed at the mine boundary and at the nearest sensitive receptor (in terms of human settlement) of Arandis. Concentrations were referenced against the current SA standards, the proposed South African standards (SANS limits), the WHO guidelines and the EC limits as a fraction. Thus where this value is greater than one an exceedance of the relevant guideline in indicated.

6.2.1 Sulphur Dioxide (SO_2)

All predicted SO_2 ground level concentrations at the mine boundary and at Arandis, are in line with or below the relevant standards/guidelines for all averaging periods (for all scenarios).

The Occupational Safety and Health Administration (OSHA) has set a limit of 2 ppm (5 720 µg/m³) over an 8-hour work day, 40-hour workweek. Highest predicted on site daily SO_2 ground level concentrations due to normal operations of the Acid Plant are 47 µg/m³ (for a 50m stack height) and 29 µg/m³ (for a 75 m stack height). The predicted concentrations due to the proposed acid plant are therefore well below the occupational limits provided by the OSHA.

6.2.2 Sulphur Trioxide/ Acid Mist (SO_3/H_2SO_4)

The California Office of Environmental Health Hazard Assessment (OEHHA) provides an hourly effect screening level for sulphuric acid of 120 µg/m³. The hourly predicted ground level concentrations at the mine boundary and at Arandis are well below the screening level for all scenarios.

A daily occupational Time Weight Average (TWA) Threshold Limit Value (TLV) of 1 000 µg/m³ is available. Highest predicted on site daily H_2SO_4 ground level concentrations due to normal operations of the acid plant are 1.6 µg/m³ (for a 50m stack height) and 1.1 µg/m³ (for a 75 m stack height). The predicted concentrations due to the proposed acid plant are therefore well below the occupational limits.

6.2.3 Carbon Monoxide (CO)

Highest hourly predicted CO ground level concentrations due to blasting activities are well within all relevant guidelines/standards.

6.2.4 Hydrogen Sulphide (H_2S)

The predicted H_2S ground level concentrations due to blasting activities are well within effect screening levels for all averaging periods.

6.2.5 Inhalable Particulate Matter (PM10)

Incremental – due to expansion Phase 1 only

The highest daily predicted PM10 ground level concentrations at the mine boundary (for all scenarios) is in line with the current South African standard, but exceeds the proposed South African guideline, EC limit as well as the WHO guideline. The operations that contribute to these exceedances are the vehicle entrainment activities on the unpaved haul road from SK4 pit to the waste dump and to the crusher. Although increased particulate impacts occur due to the truck transportation of the ore sorter waste, these increases in concentration occur on-site and do not contribute to the highest ground level concentrations at the plant boundary. The EC daily PM10 limit allows for 35 exceedances of the 50 µg/m³ concentration level in a calendar year. The frequency of exceedance for the proposed operations is predicted to be 35 days for the simulated year of 2006 (Figure 6-64).

The Ore Sorter Plant is predicted to have a highest daily PM10 ground level concentration of 30 µg/m³ on site. Occupational Health Standards, as adopted by Rio Tinto, request that ground level concentrations should be below 10 000 µg/m³. The predicted ground level concentrations due to activities at the Ore Sorter Plant only are well within these standards.

Cumulative Impacts

The annual average PM10 ground level concentrations due to the expansion (Phase 1) are predicted to increase by 90 µg/m³ (at Pit Field Staff), 50 µg/m³ to 800 µg/m³ (at Reduction Staff), 0.9 µg/m³ to 10 µg/m³ (at Recovery Staff), 0.8 µg/m³ to 8 µg/m³ (at Extraction Staff) and 1.5 µg/m³ to 6 µg/m³ (at Tailings Dam). There is thus a potential for non-compliance of the occupational standard for PM10 at the Reduction Staff for *Scenario 14* (Table 6-4).

6.2.6 Dust Deposition

Incremental – due to expansion Phase 1 only

The predicted dust deposition due to proposed operations is well below the proposed South African Residential Target Level (600 mg/m²/day) at the mine boundary and at Arandis for all scenarios (Table 6-3).

Cumulative Impacts

The predicted dust fallout at the fallout plates on site is predicted to increase by 15 mg/m²/day to 100 mg/m²/day due to the expansion (Phase 1) (Table 6-4).

Table 6-2: Predicted incremental ground level concentrations due to all operations for mining of the SK4 ore body and proposed Acid Plant and Ore Sorter Plant.

Pollutant	Averaging Period	Standard/ Guideline	Max at Mine Boundary		Max at Arandis	
			Max Conc.	Fraction	Max Conc.	Fraction
***Scenario 1* – normal operations at the proposed Acid Plant (50m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	70	0.2	9	0.03
	Highest daily	125[(a)(b)(c)(d)]	8	0.06	0.65	0.005
	Annual average	50[(a)(b)(c)(d)]	0.35	0.007	0.0023	0.00005
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	3	0.03	0.42	0.0035
***Scenario 1* – normal operations at the proposed Acid Plant (75m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	19	0.05	7.8	0.02
	Highest daily	125[(a)(b)(c)(d)]	1.5	0.012	0.5	0.004
	Annual average	50[(a)(b)(c)(d)]	0.29	0.006	0.002	0.00004

Pollutant	Averaging Period	Standard/ Guideline	Max at Mine Boundary		Max at Arandis	
			Max Conc.	Fraction	Max Conc.	Fraction
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	0.8	0.007	0.32	0.003
***Scenario 2* –upset operations at the proposed Acid Plant (50m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	350	1.0	44	0.13
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	7	0.06	0.8	0.007
***Scenario 2* – upset operations at the proposed Acid Plant (75m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	100	0.29	30	0.09
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	1.8	0.02	0.58	0.005
***Scenario 3* – upset operations at the proposed Acid Plant (50m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	120	0.34	14	0.04
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	5	0.04	0.5	0.004
***Scenario 3* – upset operations at the proposed Acid Plant (75m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	30	0.09	10	0.03
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	1.1	0.009	0.37	0.003
***Scenario 4* – upset operations at the proposed Acid Plant (50m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	20	0.06	2.5	0.007
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	7	0.06	1	0.008
***Scenario 4* – normal operations at the proposed Acid Plant (75m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	5	0.014	1.9	0.005
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	2.1	0.02	0.8	0.007
***Scenario 5* – upset operations at the proposed Acid Plant (50m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	6	0.02	0.8	0.002
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	5	0.04	0.7	0.006
***Scenario 5* – upset operations at the proposed Acid Plant (75m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	1.7	0.005	0.6	0.002
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	1.4	0.01	0.55	0.005
***Scenario 6* – upset operations at the proposed Acid Plant (50m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	350	1.0	57	0.16
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	3	0.03	0.42	0.004
***Scenario 6* – upset operations at the proposed Acid Plant (75m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	120	0.34	45	0.13
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	0.8	0.007	0.32	0.003
***Scenario 7* – upset operations at the proposed Acid Plant (50m stack)**						
SO_2	Highest Hourly	350[(a)(b)]	80	0.23	10	0.03
SO_3/ H_2SO_4	Highest Hourly	120[(e)]	10	0.08	1.4	0.01

Pollutant	Averaging Period	Standard/ Guideline	Max at Mine Boundary		Max at Arandis	
			Max Conc.	Fraction	Max Conc.	Fraction
***Scenario 7* – upset operations at the proposed Acid Plant (75m stack)**						
SO_2	Highest Hourly	350(a)(b)	20	0.06	7.5	0.02
SO_3/ H_2SO_4	Highest Hourly	120(e)	2.8	0.02	1.1	0.009
***Scenario 8* – upset operations at the proposed Acid Plant (50m stack)**						
SO_2	Highest Hourly	350(a)(b)	80	0.23	11	0.03
SO_3/ H_2SO_4	Highest Hourly	120(e)	10	0.08	1.5	0.01
***Scenario 8* – upset operations at the proposed Acid Plant (75m stack)**						
SO_2	Highest Hourly	350(a)(b)	21	0.06	8	0.02
SO_3/ H_2SO_4	Highest Hourly	120(e)	2.9	0.02	1.1	0.009
***Scenario 9* – normal operations with waste from the Ore Sorter Plant transported to dump via conveyor**						
PM10	Highest daily	180(d) 75(a) 50(b)(c)	180	1.0 **2.4** **3.6**	10	0.06 0.13 0.20
	Annual average	60(d) 40(a) 30(b) 20(c)	20	0.3 0.5 0.7 1.0	0.15	0.003 0.004 0.005 0.008
***Scenario 10* – normal operations with waste from the Ore Sorter Plant transported to dump via conveyor**						
PM10	Highest daily	180(d) 75(a) 50(b)(c)	180	1.0 **2.4** **3.6**	10	0.06 0.13 0.20
	Annual average	60(d) 40(a) 30(b) 20(c)	20	0.3 0.5 0.7 1.0	0.15	0.003 0.004 0.005 0.008
***Scenario 11* – normal operations with waste from the Ore Sorter Plant transported to dump via conveyor**						
PM10	Highest daily	180(d) 75(a) 50(b)(c)	180	1.0 **2.4** **3.6**	10	0.06 0.13 0.20
	Annual average	60(d) 40(a) 30(b) 20(c)	20	0.3 0.5 0.7 1.0	0.15	0.003 0.004 0.005 0.008
***Scenario 12* – normal operations with waste from the Ore Sorter Plant transported to dump via conveyor**						
PM10	Highest daily	180(d) 75(a) 50(b)(c)	180	1.0 **2.4** **3.6**	10	0.06 0.13 0.20
	Annual average	60(d) 40(a) 30(b)	20	0.3 0.5 0.7	0.15	0.003 0.004 0.005

Pollutant	Averaging Period	Standard/ Guideline	Max at Mine Boundary		Max at Arandis	
			Max Conc.	Fraction	Max Conc.	Fraction
		20(c)		1.0		0.008
***Scenario 13* – normal operations with waste from the Ore Sorter Plant transported to dump via truck**						
PM10	Highest daily	180(d)	180	1.0	12	0.07
		75(a)		**2.4**		0.16
		50(b)(c)		**3.6**		0.24
	Annual average	60(d)	20	0.3	0.24	0.004
		40(a)		0.5		0.006
		30(b)		0.7		0.008
		20(c)		1.0		0.012
***Scenario 14* – normal operations with waste from the Ore Sorter Plant transported to dump via truck**						
PM10	Highest daily	180(d)	180	1.0	12	0.07
		75(a)		**2.4**		0.16
		50(b)(c)		**3.6**		0.24
	Annual average	60(d)	20	0.3	0.24	0.004
		40(a)		0.5		0.006
		30(b)		0.7		0.008
		20(c)		1.0		0.012
***Scenario 15* – normal operations with waste from the Ore Sorter Plant transported to dump via truck**						
PM10	Highest daily	180(d)	180	1.0	13	0.07
		75(a)		**2.4**		0.17
		50(b)(c)		**3.6**		0.26
	Annual average	60(d)	20	0.3	0.25	0.004
		40(a)		0.5		0.006
		30(b)		0.7		0.008
		20(c)		1.0		0.013
***Scenario 16* – normal operations with waste from the Ore Sorter Plant transported to dump via truck**						
PM10	Highest daily	180(d)	180	1.0	15	0.08
		75(a)		**2.4**		0.20
		50(b)(c)		**3.6**		0.30
	Annual average	60(d)	20	0.3	0.26	0.004
		40(a)		0.5		0.007
		30(b)		0.7		0.009
		20(c)		1.0		0.013
Blasting Activities						
CO	Highest hourly	40 000(d)	0.01	<0.001	<0.01	<0.001
		30 000(a)		<0.001		<0.001
H_2S	Highest hourly	425(e)	0.028	<0.001	<0.028	<0.001
	Highest daily	150(e)	0.0022	<0.001	<0.0022	<0.001
	Annual average	2(e)	0.0003	<0.001	<0.0003	<0.001

Notes:

(a) The proposed South African Standards (SANS limits)
(b) The EC limits
(c) The WHO guidelines
(d) The current SA standards
(e) Effect screening level

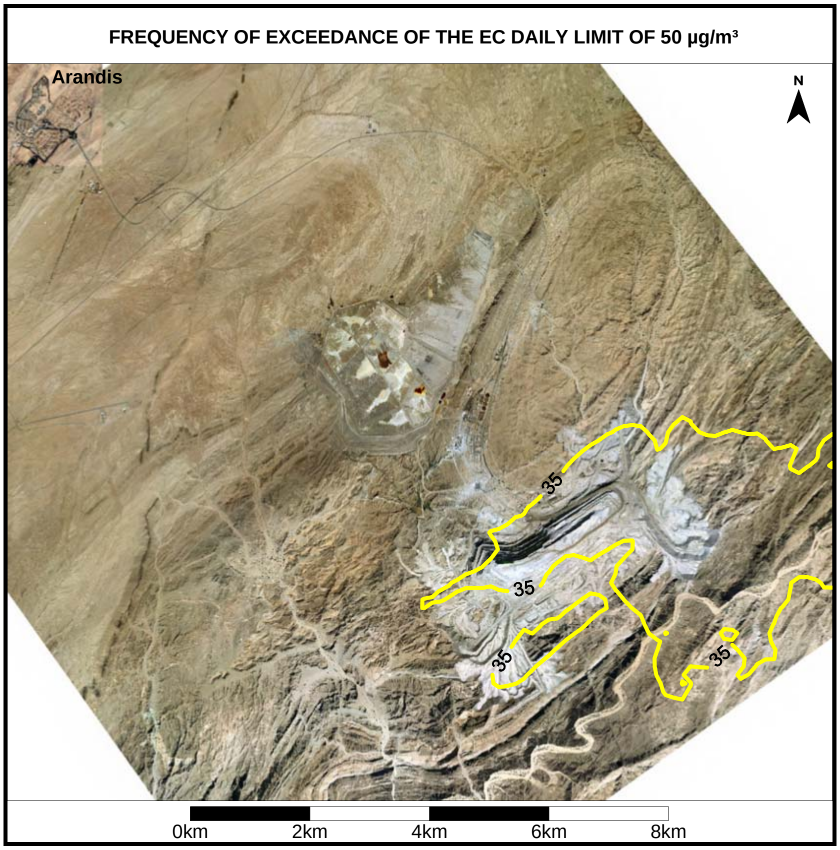


Figure 6-64: Maximum frequency of exceedance of the EC limit (50 µg/m³) for predicted PM10 ground level concentrations (*Scenario 9*).

Table 6-3: Predicted incremental dust fallout due to operations to extract the SK4 ore body and the proposed operation of the Ore Sorter Plant.

Pollutant	Averaging period	Standard/ Guideline	Max at Mine Boundary		Arandis	
			Max Dep	Fraction	Max Dep	Fraction
***Scenario 9* – normal operations with waste from the Ore Sorter Plant transported to dump via conveyor**						
TSP (mg/m²/day)	Daily Maximum	600[a] 1 200[b]	60	0.1 0.05	1	0.002 0.0008
***Scenario 10* – normal operations with waste from the Ore Sorter Plant transported to dump via conveyor**						
TSP (mg/m²/day)	Daily Maximum	600[a] 1 200[b]	60	0.1 0.05	1	0.002 0.0008
***Scenario 11* – normal operations with waste from the Ore Sorter Plant transported to dump via conveyor**						
TSP (mg/m²/day)	Daily Maximum	600[a] 1 200[b]	60	0.1 0.05	1	0.002 0.0008
***Scenario 12* – normal operations with waste from the Ore Sorter Plant transported to dump via conveyor**						
TSP	Daily	600[a]	60	0.1	1	0.002

Pollutant	Averaging period	Standard/ Guideline	Max at Mine Boundary		Arandis	
			Max Dep	Fraction	Max Dep	Fraction
(mg/m²/day)	Maximum	1 200[(b)]		0.05		0.0008
***Scenario 13* – normal operations with waste from the Ore Sorter Plant transported to dump via truck**						
TSP (mg/m²/day)	Daily Maximum	600[(a)] 1 200[(b)]	60	0.1 0.05	1	0.002 0.0008
***Scenario 14* – normal operations with waste from the Ore Sorter Plant transported to dump via truck**						
TSP (mg/m²/day)	Daily Maximum	600[(a)] 1 200[(b)]	60	0.1 0.05	1	0.002 0.0008
***Scenario 15* – normal operations with waste from the Ore Sorter Plant transported to dump via truck**						
TSP (mg/m²/day)	Daily Maximum	600[(a)] 1 200[(b)]	90	0.15 0.08	1	0.002 0.0008
***Scenario 16* – normal operations with waste from the Ore Sorter Plant transported to dump via truck**						
TSP (mg/m²/day)	Daily Maximum	600[(a)] 1 200[(b)]	120	0.2 0.1	1.5	0.003 0.001

Notes:

(a) The proposed South African residential action level
(b) The proposed South African industrial action level

Table 6-4: Cumulative PM10 ground level concentrations and dust deposition due to all activities (current and proposed – expansion Phase 1) at various monitoring sites at Rössing Uranium Mine[(a)(b)].

Scenario	PM10 ground level concentrations (µg/m³)					Dust deposition (mg/m²/day)
	Pit Field Staff (310 µg/m³)	Reduction Staff (320 µg/m³)	Recovery Staff (190 µg/m³)	Extraction Staff (240 µg/m³)	Tailings Dam Equipment Operators (130 µg/m³)	Fallout plates (13 950 mg/m²/day)
9	400	370	191	241	132	13 965
10	400	370	191	241	132	13 965
11	400	370	191	241	132	13 965
12	400	370	191	241	132	13 965
13	400	480	200	248	136	14 050
14	400	1 120	195	244	134	13 970
15	400	520	193	243	134	13 970
16	400	820	193	243	134	13 980

Note:

(a) Measure dust fallout and PM10 concentrations are given in brackets
(b) Measured annual average data was obtained for the period 2006 for PM10 concentrations and the highest dust deposition for the period October 2006 to October 2007.

7. AIR QUALITY MANAGEMENT MEASURES FOR RÖSSING URANIUM MINE: EXPANSION (PHASE 1)

An air quality impact assessment was conducted for the proposed expansion (Phase 1) at Rössing Uranium Mine in Namibia. The main objective of this study was to determine the significance of the predicted impacts from the proposed operations on the surrounding environment and on human health.

Dispersion simulations were undertaken for various scenarios, including:

- *Scenario 1:* Routine operations at the Acid Plant
- *Scenario 2:* Upset operating conditions at the Acid Plant – **Poor Start Up**: Temperature of pass 1 is above strike temperature and temperatures of passes 2 and/or 3 of the converter are below striking temperature. Pass 4 also below strike temperature.
- *Scenario 3:* Upset operating conditions at the Acid Plant – **Controlled Start Up**: All converter passes are at striking temperature (2-4 hours).
- *Scenario 4:* Upset operating conditions at the Acid Plant – **Boiler or other steaming equipment failure:** Normally a tube failure with lots of water entering the gas stream (15 minutes).
- *Scenario 5:* Upset operating conditions at the Acid Plant – **Interruption of acid flow to Acid Towers** (2-5 minutes).
- *Scenario 6:* Upset operating conditions at the Acid Plant – **Poor control of converter temperatures** (2-4 hours).
- *Scenario 7:* Upset operating conditions at the Acid Plant – **Poor control of acid concentrators** (1 hour).
- *Scenario 8:* Upset operating conditions at the Acid Plant – **Poor control of acid temperatures.**
- *Scenario 9:* Waste from the Ore Sorter plant is transported to waste storage area Option 1 via conveyor belt.
- *Scenario 10:* Waste from the Ore Sorter plant is transported to waste storage area Option 2 via conveyor belt.

- *Scenario 11:* Waste from the Ore Sorter plant is transported to waste storage area Option 3 via conveyor belt.

- *Scenario 12:* Waste from the Ore Sorter plant is transported to waste storage area Option 4 via conveyor belt.

- *Scenario 13:* Waste from the Ore Sorter plant is transported to waste storage area Option 1 via trucks.

- *Scenario 14:* Waste from the Ore Sorter plant is transported to waste storage area Option 2 via trucks.

- *Scenario 15:* Waste from the Ore Sorter plant is transported to waste storage area Option 3 via trucks.

- *Scenario 16:* Waste from the Ore Sorter plant is transported to waste storage area Option 4 via trucks.

7.1 Site Specific Management Objectives

The main objective of Air Quality Management measures for the proposed expansion (Phase 1) at Rössing Uranium Mine is to ensure that all operations at the mine and processing plant will be within compliance with the Namibian legal requirements and international best practice (i.e. EC limits and WHO guidelines). In order to define site specific management objectives, the main sources of pollution needed to be identified.

The main pollutants of concern identified during the impact assessment were particulates (PM10 and TSP), sulphur dioxide (SO_2) and sulphuric acid mist (SO_3).

The sources of particulate emission during operations were identified as vehicle entrainment, materials handling, drilling and blasting, conveyor transfer points and point sources from the Ore Sorter Plant. SO_2 and SO_3/H_2SO_4 emissions were identified from the Acid Plant.

7.1.1 Identification of Suitable Pollution Abatement Measures

7.1.1.1 Construction Phase

Dust control measures which may be implemented during the construction phase are outlined in Table 7-1. Control techniques for fugitive dust sources generally involve watering, chemical stabilization, and the reduction of surface wind speed though the use of windbreaks and source enclosures.

Table 7-1: Dust control measures implementable during construction activities

Construction Activity	Recommended Control Measure(s)
Truck transport and road dust entrainment	Where possible and for high risk sites, pave all major haul routes. Paving is highly effective but is expensive and unsuitable for surfaces used by very heavy vehicles or subject to spillage of material in transport. In addition, dust control measures will usually still be required on the paved surfaces. The use of gravel or slag can be moderately effective, but repeated additions will usually be required.
	Set speed limits of 35 km/hr or less for site traffic on paved roads and 10-15 km/hr on unpaved surfaces. Speed controls on vehicles have an approximately linear effect on dust emissions. Thus by reducing the speed from 30 km/hr to 15 km/hr dust emissions can be reduced by 50%.
	Wet suppression of unpaved areas should be applied during dry windy periods, using a water cart and/or fixed sprinklers.
	Chemical suppression can also be used in conjuction with wet suppression. This involves the use of chemical additives in the water, which help to form a crust on the surface and bind the dust particles together. Chemical stabilisation reduces watering requirements, but any savings can be offset by the cost of the additives. Repeat treatments are usually required at intervals of 1-4 weeks. The method is best suited to permanent site roads and usually not cost-effective on temporary roads, which are common in mines and construction sites.
	Inspect haul roads for integrity and repair if required.
	Provide hard-standing areas for vehicles and regularly inspect and clean these areas.
	Reduce mud/dirt carry-out onto paved roads.
	Reduce unnecessary traffic.
	Cover loads with tarpaulins to prevent dust re-entrainment from trucks.
	Limit load size to reduce spillage.
	Minimise travel distances through appropriate site layout and design.
	Use wheel and truck wash facilities at site exits.
Excavation and earthworks	Re-vegetate dry, exposed areas to stabalise surfaces. Only remove secure covers in small areas and not all at once. All activities must be damped down, especially during dry weather.
Stockpiles and storage mounds	Limit the height and slope of the stockpiles to reduce wind entrainment. For example, a flat shallow stockpile will be subject to less wind turbulence than one with a tall conical shape.
	Keep stockpiles or mounds away from the site boundary, sensitive receptors and watercourses. If necessary, take into account the predominant wind direction to reduce the likelihood of affecting sensitive receptors.
	Make sure the stockpiles are maintained for the shortest possible time.

Construction Activity	Recommended Control Measure(s)
	Seed, re-vegetate or turf long term stockpiles to stabalise surfaces or use surface binding agents.
	Where possible, enclose stockpiles or keep them securely sheeted.
	Erect fences of similar height and size to the stockpile to act as wind barriers and keep these clean using wet methods. Porous fences or hedges often make the most suitable shelter.
	Store fine material (under 3 mm in size) inside buildings or enclosures.
	Minimise drop heights to control the fall of materials.

7.1.1.2 Operational Phase

Acid Plant

Feasible mitigation measures identified for upset conditions at the Acid Plant are given in Table 7-2.

Table 7-2: Various mitigation measures for upset conditions at the Acid Plant.

Condition	Mitigation
Poor Start up: Temperature of pass 1 is above strike temperature and Temperatures of passes 2 and/or 3 of the converter are below striking temperature. Pass 4 also below strike temperature.	These conditions can be controlled by pre-heating the converter and ensuring that striking temperature has been achieved before Sulphur is introduced into the plant. These conditions should only be present after a cold start up or when the plant was off line for more than 16 hours
Controlled Start up: All converter passes are at striking temperatures	This is typical of a start up after an 8 hour shut. Plant is run at reduced capacities until all converter passes are at striking temperature. These results can also be achieved with a well planned start up from cold.
Boiler or other steaming equipment failure: Normally a tube failure with lots of water entering the gas stream	These conditions will be detected through proper instrumentation and the total plant will be shut as quickly as possible to affect repairs
Interruption of acid flow to Acid Towers:	The main blower will be interlocked to the acid flow/pressure/temp/Amps of pumps and will shut down the plant immediately when any of these parameters go out of range. During run down of blower gas flow will very quickly reduce from maximum to zero
Poor control of Converter temperatures	A well maintained SO_2 analyser on the stack will provide information that the SO_2 limits have been exceeded. A number of actions can be taken to rectify problem.

Condition	Mitigation
Poor control of Acid Concentrations	Back up acid analysers can be installed to ensure accurate measurement of acid concentrations. Stack visibility will increase and controls can be put in place to shut the plant if a visible stack condition continue for more than 20 minutes
Poor control of Acid Temperatures	Thermocouples are installed in the acid system to monitor temperatures. Stack visibility will increase and controls can be put in place to shut the plant if a visible stack condition continue for more than 20 minutes

Vehicle Entrainment on Haul Roads

Vehicle entrained dust from unpaved road surfaces is predicted to result in significant ground level concentration impacts during the operational phase.

Three types of measures may be taken to reduce emissions from unpaved roads: (a) measures aimed at reducing the extent of unpaved roads, e.g. paving, (b) traffic control measures aimed at reducing the entrainment of material by restricting traffic volumes and reducing vehicle speeds, and (c) measures aimed at binding the surface material or enhancing moisture retention, such as wet suppression and chemical stabilization (EPA, 1987; Cowherd *et al.*, 1988). Control efficiencies of up to 90% can be obtained from chemical stabilisation if surfaces are regularly treated and maintained. Various control measures for paved/treated road surfaces is given in Table 7-3.

Table 7-3: Control efficiencies for control measures for paved and treated roads.

Paved Road Control Measures	Estimated PM10 Control Efficiency	Reference
General road cleaning	35%[(a)]	Cowherd *et al*. 1988
Vacuum sweeping	0% - 58% 30% - 60%[(b)] 46%[(c)] 34%[(d)]	Cowherd and Kinsey 1986 Calvert *et al.* 1984 Eckle and Trozzo 1984 Cowherd *et al.* 1988
'Improved' vacuum sweeping	37%[(d)]	Cowherd *et al.* 1988
Broom sweeping	25% to 30%[(e)]	Cowherd *et al.* 1988, EPA 1992
Water flushing	69-0.231 V [(f)(g)]	Cowherd and Kinsey 1986
Water flushing followed by sweeping	96-0.263V [(f)(g)]	Cowherd and Kinsey 1986

Notes:

a) Represents the upper bound on efficiencies obtained in practice since no re-deposition after cleaning was considered in the estimation of the control efficiency.
b) Refers to control efficiency provided by efficiency designed and well maintained vacuum sweepers.
c) Control efficiency for particulates with an aerodynamic diameter of less than 30 µm (PM30).
d) Estimated based on measured initial and residual < 63 µm loadings on urban paved roads.
e) Maximum (initial) instantaneous control efficiencies with the efficiency decreasing after cleanup.

f) Water applied at 2.173 litres per m^2.
g) V = number of vehicle passes since application.

Ore Sorter Plant

The filter bags at the various baghouses at the Ore Sorter Plant will need to be regularly maintained in order to reduce particulate emissions efficiently.

Wind Erosion

Although the expansion project does not add additional wind erosion sources, the current emissions from wind erosion is potentially significant. The largest impacting source would be wind erosion from the tailings dam. These storage areas are engineered to optimise the amount of tailings stored, while avoiding potential environmental impacts. Because many tailings are finely grained, they can easily be eroded when dry and storage areas become dust. With no controls on the slopes and on the surfaces of the tailings dam, high impacts would be experienced.

Vegetal cover retards erosion by binding the residue with a root network, by sheltering the residue surface and by trapping material already eroded. Vegetation is also considered the most effective control measure in terms of its ability to also control water erosion. The long-term effectiveness of suitable vegetation selected for the site will be dependent on (a) the nature of the cover, and (b) the availability of aftercare. It should be noted that vegetation is defined for this purpose as the "establishment of self sustaining vegetation cover". Erosion losses from grassed slopes measured by Blight (1989) was found to be in the order of 100 t/ha/year compared to uncontrolled slopes from which losses of up to 500 t/ha/year were recorded. Rock cladding or armouring of the sides of tailings dams has been shown in various international studies to be effective in various instances in reducing wind erosion of slopes. Cases in which rock cladding has been found to be effective in this regard generally involve rock covers of greater than 0.5 m in depth (Ritcey, 1989; Jewell and Newson, 1997). Rock cladding on tailings dams has been found to be unlikely to protect the impoundment from water erosion in the event of an overtopping event, or even the long-term effects of rainfall. Experience has shown that the threshold wind velocity of local gold mine tailings impoundments generally accords with a wind speed of ~4.5 m/s (Mitzelle *et al*., 1995), which corresponds with a threshold friction velocity of ~0.24 m/s.

The following recommendations regarding wind blown dust sources are made:

- It is recommended that the walls of the tailings dam be covered (rock gladded) up to 1 m from the top throughout the life of mine. Rock cladding has the potential for effective dust suppression and will result in the reduction of wind blown dust.

- In addition screens should be installed on the crest of the tailings dam walls mainly to act as wind breaks.

Materials Handling Operations

Materials handling operations were identified as potentially sources of emissions due to the proposed activities at the mine.

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%.

The control efficiency of pure water suppression can be estimated based on the US-EPA emission factor which relates material moisture content to control efficiency. This relationship is illustrated in Figure 7-1. From the relationship between moisture content and dust control efficiency it is apparent that by doubling the moisture content of the material an emission reduction of 62% could be achieved. Thus chemicals mixed into the water will not just save on water consumption but also improve the control efficiency of the application even further.

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 have been noted by various studies to improve the efficiency of water suppression systems and belt-to-belt transfer points.

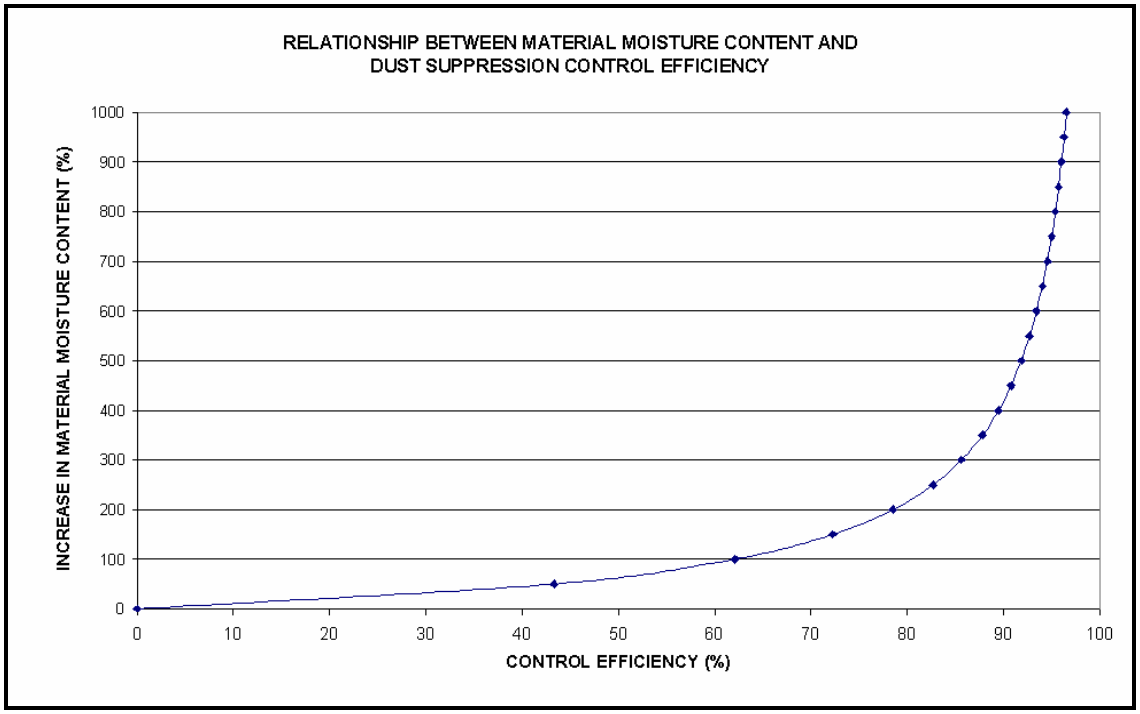


Figure 7-1: Relationship between the moisture content of the material handled and the dust control efficiency (calculated based on the US-EPA predictive emission factor equation for continuous and batch drop operations).

Open pit operations

All materials handling operations will reduce dust generation by 62% by merely doubling the moisture content of the material handled. In addition, the Australian NPi in their Emission Estimation Technique Manual for Mining stipulates a 50% reduction of TSP emissions due to pit retention, and 5% for PM10 emissions. This is based on the increase in volume (the deeper the pit becomes) and thus resulting in better dispersion potential for specifically PM10 emissions before reaching the surface. Similarly for TSP, the potential for deposition on the surface becomes smaller for more dust would settle within the pit.

7.1.1.3 Closure and Post-closure Phase

The control measures during the construction phase will apply to the closure and post-closure phase.

7.2 Monitoring Requirements

Performance Indicators

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

Performance indicators are usually selected to reflect both the source of the emission directly and the impact on the receiving environment. Ensuring that no visible evidence of wind erosion exists represents an example of a source-based indicator, whereas maintaining off-site dustfall levels to below a certain threshold represents an impact- or receptor-based performance indicator. Source-based performance indicators have been included in regulations abroad. The Queensland Environmental Management Overview Strategy (QDPI, 1988), for example, states that erosion rates must not be higher than 40 t/hectare/year and that the depths of drills and gullies be limited to less than 30 cm. The ambient air quality guidelines and standards given for respirable and inhalable particulate concentrations by various countries, including Botswana, represent receptor-based objectives.

Specification of Source Based Performance Indicators

- Source based performance indicators for the tailings dam would include cover density to be 80% on the entire slope up to 1 m from crest, and dustfall immediately downwind to be <1,200 mg/m^2/day.
- For the unpaved access road it is recommended that dust fallout in the immediate vicinity of the road perimeter be less than 600 mg/m^2/day and for unpaved haul roads associated with on-site activities it should be less than1,200 mg/m^2/day.
- The absence of visible dust plume at all tipping points and outside the primary crusher would be the best indicator of effective control equipment in place. In addition the dustfall in the immediate vicinity of various sources should be less than 1,200 mg/m^2/day.
- From all activities associated with the Rössing Uranium Mine and Ore Sorting Plant, dustfall in close proximity to sensitive receptors (i.e. Arandis) should not exceed 600 mg/m^2/day.

Receptor based Performance Indicators

Based on the impacts predicted from the expansion operations (Phase 1) on the surrounding environment and the limitations associated with the data used, it is recommended that the current dust fallout monitoring network be continued and expanded.

Dust fallout monitoring network

A dust fallout network for Rössing Uranium Mine is available in the form of four dust fallout plates located southeast of the tailings dam. It is recommended that a dust fallout network, comprising of 6 single dust fallout buckets be established in addition to the dust fallout plates to provide management with an indication of what the increase in fugitive dust levels are once the expansion (Phase 1) commences (Figure 7-2). In addition, a dust fallout network can serve to meet various objectives, such as:

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

The monthly results from the six single dust fallout buckets should be presented as total daily dustfall over a month (28 to 32 days). Monitoring procedures and reporting protocol are provided in Table 7-4.

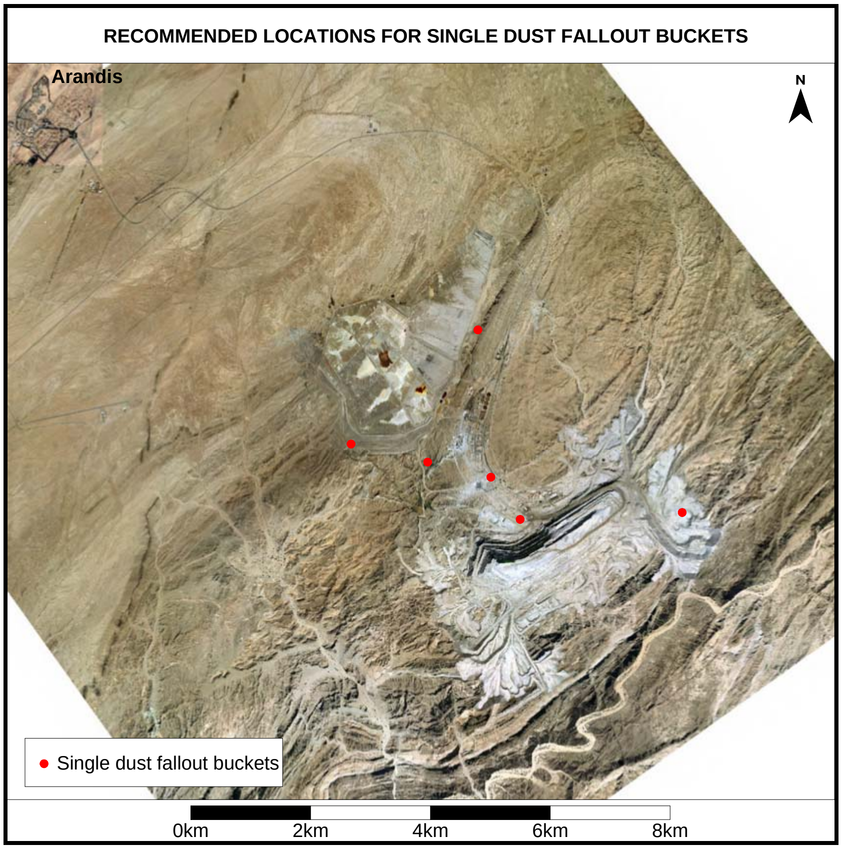


Figure 7-2: Proposed locations for single dust fallout buckets.

Table 7-4: Ambient air monitoring, performance assessment and reporting programme.

Monitoring Strategy Criteria	Dustfall Monitoring
Monitoring objectives	- Assessment of compliance with dustfall limits within the main impact zone of the operation. - Facilitate the measurement of progress against environmental targets within the main impact zone of the operation. - Temporal trend analysis to determine the potential for nuisance impacts within the main impact zone of the operation. - Tracking of progress due to pollution control measure implementation within the main impact zone of the operation. - Informing the public of the extent of localised dust nuisance impacts occurring in the vicinity of Rössing Mine operations.
Monitoring location(s)	Figure 7-2. Dustfall to be recorded by dustfall monitoring network comprising 6 single buckets.

Monitoring Strategy Criteria	Dustfall Monitoring
Sampling techniques	*Single Bucket Dust Fallout Monitors* Dust fallout sampling measures the fallout of windblown settleable dust. Single bucket fallout monitors to be deployed following the American Society for Testing and Materials standard method for collection and analysis of dustfall (ASTM D1739). This method employs a simple device consisting of a cylindrical container half-filled with de-ionised water exposed for one calendar month (30 days, ±3 days). The water is treated with an inorganic biocide to prevent algae growth in the buckets. The bucket stand comprises a ring that is raised above the rim of the bucket to prevent contamination from perching birds. Once returned to the laboratory, the content of the bucket are filtered and the residue dried before the insoluble dust is weighed.
Accuracy of sampling technique	Margin of accuracy given as ±200 mg/m^2/day.
Sampling frequency and duration	On-going, continuous monitoring to be implemented facilitating data collection over 1-month averaging period.
Commitment to QA/QC protocol	Comprehensive QA/QC protocol implemented.
Interim environmental targets (i.e. receptor-based performance indicator)	Maximum total daily dustfall (calculated from total monthly dustfall) of not greater than 600 mg/m^2/day for residential areas. Maximum annual average dustfall to be less than 1,200 mg/m^2/day on-site.
Frequency of reviewing environmental targets	Annually (or may be triggered by changes in air quality regulations).
Action to be taken if targets are not met	(i) Source contribution quantification. (ii) Review of current control measures for significant sources (implementation of contingency measures where applicable).
Procedure to be followed in reviewing environmental targets and other elements of the monitoring strategy (e.g. sampling technique, duration, procedure)	Procedure to be drafted in liaison with I&APs through the proposed community liaison forum. Points to be taken into account will include, for example: (i) trends in local and international ambient particulate guidelines and standards and/or compliance monitoring requirements, (ii) best practice with regard to monitoring methods, (iii) current trends in local air quality, i.e. is there an improvement or deterioration, (iv) future development plans within the airshed (etc.)
Progress reporting	At least twice annually to the necessary authorities and community forum.

7.3 Record-keeping, Environmental Reporting and Community Liaison

Periodic Inspections and Audits

Periodic inspections and external audits are essential for progress measurement, evaluation and reporting purposes. According to the Guidelines of the Chamber of Mines (1996), every decommissioned residue deposit should be inspected at yearly intervals by a suitably qualified person and any alteration or deterioration of conditions at the deposit reported to the responsible authority.

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 forms part of an APCS and should be initiated at Rössing Uranium Mine (if it is not in place already). Results from site inspections and off-site monitoring efforts should be combined to determine progress against source- and receptor-based performance indicators. Progress should be reported to all I&APs, 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.

Liaison Strategy for Communication with I&APs

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

Financial Provision (Budget)

The budget should provide a clear indication of the capital and annual maintenance costs associated with dust control measures and dust monitoring plans. It may be necessary to make assumptions about the duration of aftercare prior to obtaining closure. This assumption must be made explicit so that the financial plan can be assessed within this framework. Costs related to inspections, audits, environmental reporting and I&AP liaison should also be indicated where applicable. Provision should also be made for capital and running costs associated with dust control contingency measures and for security measures.

The financial plan should be audited by an independent consultant, with reviews conducted on an annual basis.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Dispersion simulations were undertaken for various scenarios, including:

- *Scenario 1:* Routine operations at the Acid Plant
- *Scenario 2:* Upset operating conditions at the Acid Plant – **Poor Start Up**: Temperature of pass 1 is above strike temperature and temperatures of passes 2 and/or 3 of the converter are below striking temperature. Pass 4 also below strike temperature.
- *Scenario 3:* Upset operating conditions at the Acid Plant – **Controlled Start Up**: All converter passes are at striking temperature (2-4 hours).
- *Scenario 4:* Upset operating conditions at the Acid Plant – **Boiler or other steaming equipment failure:** Normally a tube failure with lots of water entering the gas stream (15 minutes).
- *Scenario 5:* Upset operating conditions at the Acid Plant – **Interruption of acid flow to Acid Towers** (2-5 minutes).
- *Scenario 6:* Upset operating conditions at the Acid Plant – **Poor control of converter temperatures** (2-4 hours).
- *Scenario 7:* Upset operating conditions at the Acid Plant – **Poor control of acid concentrators** (1 hour).
- *Scenario 8:* Upset operating conditions at the Acid Plant – **Poor control of acid temperatures.**
- *Scenario 9:* Waste from the Ore Sorter plant is transported to waste storage area Option 1 via conveyor belt.
- *Scenario 10:* Waste from the Ore Sorter plant is transported to waste storage area Option 2 via conveyor belt.
- *Scenario 11:* Waste from the Ore Sorter plant is transported to waste storage area Option 3 via conveyor belt.

- *Scenario 12:* Waste from the Ore Sorter plant is transported to waste storage area Option 4 via conveyor belt.

- *Scenario 13:* Waste from the Ore Sorter plant is transported to waste storage area Option 1 via trucks.

- *Scenario 14:* Waste from the Ore Sorter plant is transported to waste storage area Option 2 via trucks.

- *Scenario 15:* Waste from the Ore Sorter plant is transported to waste storage area Option 3 via trucks.

- *Scenario 16:* Waste from the Ore Sorter plant is transported to waste storage area Option 4 via trucks.

The main findings from this investigation may be summarised as follows:

- All predicted SO_2 ground level concentrations at the mine boundary and at Arandis, were in line with or below the relevant standards/guidelines for all averaging periods (for all scenarios).

- The hourly predicted ground level concentrations at the mine boundary and at Arandis were well below the effect screening level (OEHHA) for all scenarios.

- Highest hourly predicted CO ground level concentrations due to blasting activities were within all relevant guidelines/standards.

- The predicted H_2S ground level concentrations due to blasting activities were within effect screening levels for all averaging periods.

- *Incremental PM10 Impacts* – The highest daily predicted PM10 ground level concentrations at the mine boundary (for all scenarios) was in line with the current South African standard, but exceeded the proposed South African guideline, EC limit and WHO guideline. The operations that contribute to these exceedances were the vehicle entrainment activities on the unpaved haul road from SK4 pit to the waste dump and to the crusher. The EC daily PM10 limit allows for 35 exceedances of the 50 µg/m³ concentration level in a calendar year. The frequency of exceedance for the proposed operations was predicted to be 35 days for the simulated year of 2006.

- *Cumulative PM10 Impacts* – The annual average PM10 ground level concentrations due to the expansion (Phase 1) were predicted to increase by 90 μg/m³ (at Pit Field Staff), 50 μg/m³ to 800 μg/m³ (at Reduction Staff), 0.9 μg/m³ to 10 μg/m³ (at Recovery Staff), 0.8 μg/m³ to 8 μg/m³ (at Extraction Staff) and 1.5 μg/m³ to 6 μg/m³ (at Tailings Dam).

- *Incremental Dust Deposition* – The predicted dust deposition due to proposed operations was well below the proposed South African Residential Target Level (600 mg/m²/day) at the mine boundary and at Arandis for all scenarios.

- *Cumulative Dust Deposition* – The predicted dust fallout at the fallout plates on site was predicted to increase by 15 mg/m²/day to 100 mg/m²/day due to the expansion (Phase 1).

8.2 Recommendations

- It is recommended that a dust fallout network should be established to monitor increases in dust fallout in the surrounding area due to the proposed expansion activities;

- It is recommended that the Air Quality Management Plan as stipulated in Section 7 of the report, be implemented during the operational phases of the expansion (Phase 1);

- In addition, it is recommended that stack monitoring be undertaken once the proposed Acid Plant is in operation in order to verify the emissions from the process.

9. REFERENCES

Blight G E (1989). Erosion Losses from the Surfaces of Gold-tailings Dams, *Journal of the the South African Institute of Mining and Metallurgy*, vol. 89 (1), 23-29.

Calvert, S., Brattin, H., Bhutra, S., and Ono, D. (1984). Improved Street Sweepers for Controlling Urban Inhalable Particulate Matter, EPA-600/7-84-021, US Environmental Protection Agency, Reseach Triangle Park, North Carolina.

CEPA/FPAC Working Group (1998). *National Ambient Air Quality Objectives for Particulate Matter. Part 1: Science Assessment Document*, A Report by the Canadian Environmental Protection Agency (CEPA) Federal-Provincial Advisory Committee (FPAC)on Air Quality Objectives and Guidelines.

Chamber of Mines of South Africa (1996). *Handbook of Guidelines for Environmental Protection. Volume 1/1979 Revised 1983 and 1995. The Engineering Design, Operation and Closure of Metalliferous, Diamond and Coal Residue Deposits*, March 1996.

Cowherd C, Muleski GE and Kinsey JS (1988). *Control of Open Fugitive Dust Sources*, EPA-450/3-88-008, US Environmental Protection Agency, Research Triangle Park, North Carolina.

Cowherd C and Kinsey J S (1986). Identification, Assessment and Control of Fugitive Particulate Emissions, EPA-600/8-86-023, US Environmental Protection Agency, Research Triangle Park, North Carolina.

Dockery D. W. and Pope C. A. (1994). Acute Respiratory Effects of Particulate Air Pollution*, Annual Review of Public Health,* 15, 107 - 132.

Eckle TF and Trozzo DL (1984). Verification of the Efficiency of a Road-Dust Emission-Reduction Program by Exposure Profile Measurement, Presented at an EPA/AISI Symposium on Iron and Steel Pollution Abatement, Cleveland, Ohio, October 1984.

EPA (1987). PM10 SIP Development Guideline, EPA-450/2-86-001, US Environmental Protection Agency, Research Triangle Park, North Carolina.

EPA (1992). *Fugitive Dust Background Document and Technical Information Document for Best Available Control Measures,* EPA-450/2-92-004, US Environmental Protection Agency, Research Triangle Park, North Carolina.

EPA (1998a). Compilation of Air Pollution Emission Factors for Aggregate Handling (AP-42), 6th Edition, Volume 1, as contained in the *AirCHIEF (AIR Clearinghouse for Inventories and Emission Factors) CD-ROM (compact disk read only memory)*, US Environmental Protection Agency, Research Triangle Park, North Carolina.

EPA (1998b). Compilation of Air Pollution Emission Factors for Western Surface Coal Mining (AP-42), 6th Edition, Volume 1, as contained in the *AirCHIEF (AIR Clearinghouse for Inventories and Emission Factors) CD-ROM (compact disk read only memory)*, US Environmental Protection Agency, Research Triangle Park, North Carolina.

EPA (2003). Compilation of Air Pollution Emission Factors for Paved Roads (AP-42), 6th Edition, Volume 1, as contained in the *AirCHIEF (AIR Clearinghouse for Inventories and Emission Factors) CD-ROM (compact disk read only memory)*, US Environmental Protection Agency, Research Triangle Park, North Carolina.

Godish T. (1990). *Air Quality,* Lewis Publishers, Michigan, 422 pp.

Goldreich Y and Tyson P D (1988). Diurnal and Inter-Diurnal Variations in Large-Scale Atmospheric Turbulence over Southern Africa, *South African Geographical Journal,* 70(1), 48-56.

Hanna S. R., Egan B. A. Purdum J. and Wagler J. (1999) *Evaluation of the ADMS, AERMOD, and ISC3 Dispersion Models with the Optex, Duke Forest, Kincaid, Indianapolis, and Lovett Field Data Sets,* International Journal of Environment and Pollution (Volume 16, Nos. 1-6, 2001).

IFC (2007). *Environmental, Health, and Safety Guidelines; General EHS Guidelines: Environmental Air Emissions and Ambient Air Quality*. International Finanace Corporation, World Bank Group. 30 April 2007. http://www.ifc.org/ifcext/enviro.nsf/Content/EnvironemntalGuidelines

Jewell R J and Newson T A (1997). Decommissioning of Gold Tailings Storage Facilities in Western Australia, in Bouazza A, Kodikara J and Parker R (eds), Balkema, *Environmetnal Geotechnics*, Rotterdam.

Oke T T (1990). *Boundary Layer Climates*, Routledge, London and New York, 435 pp.

Pasquill F and Smith F B (1983). *Atmospheric Diffusion: Study of the Dispersion of Windborne Material from Industrial and Other Sources*, Ellis Horwood Ltd, Chichester, 437 pp.

Ritcey G M (1989). *Tailings Management. Problems and Solutions in the Mining Industry*, Eslevier, Amsterdam.

SABS (2004). *South African National Standards: Ambient air quality – Limits for common pollutants.* Standards South Africa (a division of SABS). SANS 1929:2004, Edition 1.

Shaw R W and Munn R E (1971). Air Pollution Meteorology, in BM McCormac (Ed), *Introduction to the Scientific Study of Air Pollution*, Reidel Publishing Company, Dordrecht-Holland, 53-96.

WHO (2000). *Guidelines for Air Quality*, World Health Organisation, Geneva.

WHO (2005). *WHO Air Quality Guidelines Global Update*, World Health Organisation, October 2005, Germany.