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Air Quality Impact Assessment for the Proposed Valley TSF near Welkom, South Africa

Project done on behalf of **EIMS (Pty) Ltd**

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Revision Record

Revision Number	**Date**	**Reason for Revision**
Rev0	August 2023	Provided for client review
Rev1	October 2023	Added section on impacts on vegetation

Competency Profiles

Report author and Project Manager: H Liebenberg-Enslin, PhD Geography (University of Johannesburg).

Hanlie Liebenberg-Enslin started her professional career in Air Quality Management in 2000 when she joined Environmental Management Services (EMS) after completing her MSc degree at the University of Johannesburg (then RAU) in the same field. She is one of the founding members of Airshed Planning Professionals in 2003 where she has worked as a company Director until she took over as Managing Director in May 2013.

She has extensive experience on the various components of air quality management including emissions quantification for a range of source types, using different dispersion models, and conducting impact assessments and health risk screening assessments. Hanlie was the project manager on a number of ground-breaking air quality management plan (AQMP) projects and the principal air quality specialist on regional environmental assessments. Her work experience, although mostly in South Africa, range over various countries in Africa, including extensive experience in Namibia, providing her with an inclusive knowledge base of international legislation and requirements pertaining to air quality.

Hanlie has lectured several Air Quality Management Courses and is actively involved in the International Union of Air Pollution Prevention and Environmental Protection Associations (IUAPPA) and the South African National Association for Clean Air (NACA), where she served as President for both organisations. Being an avid student, she received her PhD from the University of Johannesburg in June 2014, specialising in Aeolian dust transport.

Report author: R Bornman (M.Phil in GIS and Remote Sensing, University of Cambridge)

Rochelle Bornman started her professional career in Air Quality in 2008 when she joined Airshed Planning Professionals (Pty) Ltd after having worked in malaria research at the Medical Research Council in Durban. Rochelle has worked on several air quality specialist studies between 2008 and 2022. She has experience on the various components including emissions quantification for a range of source types, simulations using a range of dispersion models, impacts assessment and health risk screening assessments. Her project experience range over various countries in Africa, providing her with an inclusive knowledge base of international legislation and requirements pertaining to air quality. Whilst most of his working experience has been in South Africa, a number of investigations were made in countries elsewhere, including Mozambique, Namibia, Saudi Arabia and Mali.

Abbreviations

AERMIC	AMS/EPA Regulatory Model Improvement Committee
AERMOD	AERMIC Dispersion Model
Airshed	Airshed Planning Professionals (Pty) Ltd
APCS	Air pollution control systems
AQA	Air Quality Assessment
AQSRs	Air Quality Sensitive Receptors
ASTM	American Standard Testing Methodology
DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries and the Environment
DMP	Dust Management Plan
EIMS	Environmental Impact Management Services (Pty) Ltd
LMo	Monin-Obukhov length
NA	Not applicable
NAAQ Limit	National Ambient Air Quality Limit concentration
NAAQS	National Ambient Air Quality Standards
NDCR	National Dust Control Regulations
NEMAQA	National Environmental Management Air Quality Act
NPI	National Protection Agency
PBL	Planetary boundary layer
SABS	South African Bureau of Standards
SAWS	South African Weather Service
US-EPA	United States Environmental Protection Agency

Symbols and Units

°C	Degree Celsius
C_6H_6	Benzene
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
ha	Hectare
H_2S	Hydrogen Sulfide
HC	Hydrocarbons
HFC	Hydrofluorocarbons
kg	Kilograms
1 kilogram	1 000 grams
km	Kilometre
m	Metres
mamsl	Metres above mean sea level
m/s	Metres per second
mm	Millimetres
NO	Nitrogen oxide
N_2O	Nitrous oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
O_3	Ozone
Pb	Lead
PFC	Perfluorocarbons
PM	Particulate Matter
$PM_{2.5}$	Inhalable particulate matter (aerodynamic diameter less than 2.5 µm)
PM_{10}	Thoracic particulate matter (aerodynamic diameter less than 10 µm)
SF6	Sulfur hexafluoride
SO_2	Sulfur dioxide (1)
tpa	Tonnes per annum
VOC	Volatile organic compound(s)
1 ton	1 000 000 grams

Notes:

(1) The spelling of "sulfur" has been standardised to the American spelling throughout the report. The International Union of Pure and Applied Chemistry, the international professional organisation of chemists that operates under the umbrella of UNESCO, published, in 1990, a list of standard names for all chemical elements. It was decided that element 16 should be spelled "sulfur". This compromise was to ensure that in future searchable data bases would not be complicated by spelling variants. (IUPAC. Compendium of Chemical Terminology, 2nd ed. (the "Gold Book"). Compiled by A. D. McNaught and A. Wilkinson. Blackwell Scientific Publications, Oxford (1997). XML on-line corrected version: http://goldbook.iupac.org (2006) created by M. Nic, J. Jirat, B. Kosata; updates compiled by A. Jenkins. ISBN 0-9678550-9-8.doi: 10.1351/goldbook)"

Glossary

Air pollution[(a)]	The presence of substances in the atmosphere, particularly those that do not occur naturally
Atmospheric dispersion model	A mathematical representation of the physics governing the dispersion of pollutants in the atmosphere
Atmospheric stability	A measure of the propensity for vertical motion in the atmosphere
Calm / stagnation	A period when wind speeds of less than 0.5 m/s persist
Cartesian grid	A co-ordinate system whose axes are straight lines intersecting at right angles
Dispersion	The lowering of the concentration of pollutants by the combined processes of advection and diffusion
Dust	Solid materials suspended in the atmosphere in the form of small irregular particles, many of which are microscopic in size
Instability[(a)]	A property of the steady state of a system such that certain disturbances or perturbations introduced into the steady state will increase in magnitude, the maximum perturbation amplitude always remaining larger than the initial amplitude
Mechanical mixing[(a)]	Any mixing process that utilizes the kinetic energy of relative fluid motion
Oxides of nitrogen (NO_x)	The sum of nitrogen oxide (NO) and nitrogen dioxide (NO_2) expressed as nitrogen dioxide (NO_2)
Particulate matter (PM)	Total particulate matter, that is solid matter contained in the gas stream in the solid state as well as insoluble and soluble solid matter contained in entrained droplets in the gas stream
PM_{10}	Particulate Matter with an aerodynamic diameter of less than 10 µm
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter of less than 2.5 µm
Stability[(a)]	The characteristic of a system if sufficiently small disturbances have only small effects, either decreasing in amplitude or oscillating periodically; it is asymptotically stable if the effect of small disturbances vanishes for long time periods

Notes:

(a) Definition from American Meteorological Society's glossary of meteorology (AMS, 2014)

Symbols and Units

CO	Carbon monoxide
C_6H_6	Benzene
hPa	Hector Pascal
km	Kilometre
mm	Millimetre
m	Metre
m^2	Metre squared
m^3	Meter cubed
m/s	Metres per second
$mg/m^2/day$	Milligram per metre squared per day
$\mu g/m^3$	Microgram per cubic metre
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
O_3	Ozone
Pb	Lead
PM	Particulate matter
$PM_{2.5}$	Particulate matter less than 2.5 µm in diameter
PM_{10}	Particulate matter less than 10 µm in diameter
SO_2	Sulfur dioxide
tpa	Tonnes per annum
tpd	Tonnes per day
tpa	Tonnes per annum
TSP	Total suspended particulates
°C	Degrees Celsius
%	Percent
<	Less than
>	Greater than
~	Approximately

Executive Summary

Harmony Gold Mining Company Limited (Harmony) own and operate a number of Gold Mines and Plants in the Welkom region in the Free State. Harmony currently deposit tailings onto the Free State South (FSS) 2 Tailings Storage Facility (TSF), St. Helena 4 TSF, St. Helena 123 TSF, Dam 23 TSF, Brand D TSF and Target 1&2 TSF. The current planned Life of Mine (LOM) of the Free State Operations exceed the available deposition capacity of these TSFs and Harmony is undertaking a feasibility assessment to construct the new Valley TSF to replace the FSS2 and St Helena 4 TSFs.

Airshed Planning Professionals (Pty) Limited was appointed by Environmental Impact Management Services (EIMS) to undertake an air quality impact assessment for the project.

The aim of the investigation was to quantify the possible impacts resulting from the project activities on the surrounding environment and human health. To achieve this, a good understanding of the 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.

Study Approach and Methodology

The investigation followed the methodology required for a specialist report as prescribed in the Environmental Impact Assessment (EIA) Regulations (Government Notice R.543 in Government Gazette 33306 of 18 June 2010).

Baseline Assessment

The baseline study encompassed the analysis of meteorological data. Meteorological data (including wind speed, wind direction and temperature) was obtained from the South African Weather Station (SAWS) for Welkom for the period 2020 to 2022.

Impact Assessment Criteria

Particulates represent the main pollutants of concern in the assessment of operations from the project. Daily and annual $PM_{2.5}$ and PM_{10} impacts and dust deposition were assessed. For the current study, the impacts were assessed against published National Ambient Air Quality Standards (NAAQS) and National Dust Control Regulations (NDCR).

Emissions Inventory

Emissions inventories provide the source input required for the simulation of ambient air concentrations. Fugitive source emissions as a result of wind erosion from the existing sources (surrounding tailings storage facilities and waste rock dumps) and the proposed tailings storage facility were quantified. Point source emissions from the ventilation shafts were taken from a previous study for Harmony.

Impact Prediction Study

Particulate matter concentrations and deposition rates due to the current operations were simulated using the AERMET/AERMOD dispersion modelling suite. Ambient concentrations were simulated to ascertain daily and annual averaging levels occurring as a result of the project operations.

Assumptions, Exclusions and Limitations

The main assumptions, exclusions and limitations are summarized below:

- Use was made of measured Welkom meteorological data and this is regarded representative of the project area.
- The quantification of sources of emission was restricted to the project activities and baseline Harmony operations within the study domain only. Although other background sources were identified, such sources were not quantified.

- Information required for the calculation of emissions from fugitive dust sources for the project operations was taken from a previous study for Harmony Welkom (Grobler and Liebenberg-Enslin, 2017). The assumption was made that this information was accurate and correct.
- Routine emissions from the operations were estimated and modelled. Atmospheric releases occurring as a result of accidents were not accounted for.

Main Findings

The main findings from the air quality assessment study are as follows:

- The receiving environment:
  - The area is dominated by winds from the north to east, followed by northerly and easterly winds, with an average wind speed of 3.5 m/s and calm conditions occurring for 8.5% of the time.
  - Ambient air pollutant levels in the project area are currently affected by the following sources of emission: agricultural activities, gold mining and ore processing, fugitive and process emissions, vehicle tailpipe emissions, household fuel combustion, biomass burning and windblown dust from exposed areas.
  - AQSRs include residential areas, farmsteads, schools and hospitals. The closest towns in the immediate region of the project include Welkom and its suburbs (located about 3.7 km southeast of the project boundary) and Odendaalsrus (located about 3 km northeast of the project boundary).

- Impact of the Project:
  - Construction Phase Impacts:
    - Impacts were assessed qualitatively by taking into consideration the likely air quality impacts that may arise due to construction activities.
    - Resulting potential air quality health and nuisance impacts were assessed to have **Medium** significance without mitigation and **Low** significance with mitigation. The final environmental significance rating is **Low**.
  - Operational Phase Impacts:
    - Impacts were assessed by taking into consideration the cumulative impact from existing sources (ventilation shafts and windblown dust from the existing tailings storage facilities and WRDs within the study domain) and the proposed Valley TSF.
    - Simulated PM_{10} and $PM_{2.5}$ concentrations due to baseline operations were well within NAAQS at the closest identified sensitive receptors. The simulated dust deposition was within NDCR for residential areas at the closest sensitive receptors.
    - Simulated PM_{10} concentrations due to project operations were within the daily PM_{10} NAAQS at all of the identified sensitive receptors, as were simulated $PM_{2.5}$ concentrations within the post-2030 daily $PM_{2.5}$ NAAQS at all sensitive receptors. Annual average PM_{10} and $PM_{2.5}$ concentrations were within the respective NAAQSs at all receptors. The simulated dust deposition was within NDCR for residential areas at the closest sensitive receptors.
    - The environmental risk due to both unmitigated and mitigated operations is classified as **Medium,** although affecting a smaller area with mitigation in place. The final environmental significance rating is **Medium**.
  - Decommissioning Phase Impacts:
    - Impacts were assessed qualitatively by taking into consideration the likely air quality impacts that may arise due to decommissioning and closure activities.
    - Resulting potential air quality health and nuisance impacts were assessed to have **Medium** significance without mitigation and **Low** significance with mitigation. The final environmental significance rating is **Low**.

In conclusion, it is the specialist opinion that the project may be authorised provided that the recommended air quality management measures are implemented. These air quality management measures include:

- Dustfall monitoring ensuring dustfall rate in compliance with the NDCR limits; and
- Mitigation measures aimed at reducing emissions at source, i.e. the grassing of TSF side slopes.

Table of Contents

List of Tables

List of Figures

Air Quality Impact Report for the Proposed Valley TSF near Welkom, South Africa

1 INTRODUCTION

Harmony Gold Mining Company Limited (Harmony) own and operate a number of Gold Mines and Plants in the Welkom region in the Free State. Harmony currently deposit tailings onto the Free State South (FSS) 2 Tailings Storage Facility (TSF), St. Helena 4 TSF, St. Helena 123 TSF, Dam 23 TSF, Brand D TSF and Target 1&2 TSF. The current planned Life of Mine (LOM) of the Free State Operations exceed the available deposition capacity of these TSFs and Harmony is undertaking a feasibility assessment to construct the new Valley TSF to replace the FSS2 and St Helena 4 TSFs.

Airshed Planning Professionals (Pty) Ltd (Airshed) was appointed by Environmental Impact Management Services (EIMS) (Pty) Ltd to conduct an air quality impact assessment (AQIA) for the project. The main objective of the air quality study is to determine air quality related impacts as a result of the proposed project on air quality sensitive receptors (AQSRs). 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.

Typical of specialist investigations conducted, the air quality investigation comprises both a baseline study and an impact assessment. The baseline study includes the review of site-specific atmospheric dispersion potentials, and existing ambient air quality in the region, in addition to the identification of potentially sensitive receptors. The ambient air quality impact assessment comprised the establishment of an emissions inventory for the project activities, the simulation of ambient air pollutant concentrations occurring due to project operations, and the evaluation of the resultant potential for impacts and non-compliance.

1.1 Description of Project Activities from an Air Quality Perspective

Sources of emissions from the baseline include ventilation shafts and windblown dust from the existing tailings storage facilities and waste rock dumps (WRDs) within the study domain. The project consists of windblown dust from the proposed Valley TSF. Cumulative impacts consist of both baseline operations and project activities.

1.2 Approach and Methodology

The methodology followed in the assessment to quantify the air quality impacts associated with the project is discussed below. The general tasks included:

- The establishment of the baseline air quality (based on available information);
- Quantification of air emissions from the project;
- Discussion of meteorological parameters required to establish the atmospheric dispersion potential;
- Calculation of the air concentrations from the project using a suitable atmospheric dispersion model;
- Assessment of the significance of the impact through the comparison of simulated air concentrations with local National Ambient Air Quality Standards (NAAQS) (for compliance).

1.2.1 Potential Air Emissions from the Project

The pollutants of concern from the project are particulate matter (PM). Gaseous emissions such as sulfur dioxide (SO_2), oxides of nitrogen (NOx), carbon monoxide (CO), and Total Organic Compounds (TOC) are pollutants that would result from vehicles and the ventilation shafts, but these are likely to be at low levels and not included in the current assessment.

Airborne particulate matter (PM) comprises a mixture of organic and inorganic substances, varying in size, shape, and density. These can be divided into Total Suspended Particulates (TSP), thoracic particles or PM_{10} (particulate matter with an aerodynamic diameter of less than 10 µm) and respirable particles or $PM_{2.5}$ (particulate matter with an aerodynamic diameter of less than 2.5 µm). PM_{10} and $PM_{2.5}$ are associated with health impacts; TSP is associated with nuisance caused by dust fallout (Colls, 2002).

1.2.2 Regulatory Requirements and Assessment Criteria

In the evaluation of air emissions and ambient air quality impacts reference is made to Minimum Emission Limits (MES) as part of the Listed Activities, National Ambient Air Quality Standards (NAAQS) and the National Dust Control Regulations (NDCR) as set out in the National Environmental Management Air Quality Act (Act No. 39 of 2004) (NEMAQA). These standards generally apply only to a number of common air pollutants, collectively known as criteria pollutants. Criteria pollutants typically include SO_2, NO_2, CO, PM, benzene, ozone and lead.

1.2.3 Description of the Baseline Environment

An understanding of the atmospheric dispersion potential of the area is essential to an air quality impact assessment. For this assessment, measured South African Weather Service Station data was available for Welkom for the period 2020 to 2022.

1.2.4 Existing Ambient Air Quality

No data was provided on the current ambient PM_{10} and $PM_{2.5}$ concentrations. Dustfall measurements were available for July 2016 to May 2017.

1.2.5 Emissions Inventory

The establishment of a comprehensive emission inventory formed the basis for the assessment of the air quality impacts from the project operations. Project operations result in point and fugitive gaseous and particulate emissions.

Point sources are well defined with set parameters and emission concentrations. The information on the point sources was sourced from a previous study for Harmony Welkom (Grobler and Liebenberg-Enslin, 2017).

Fugitive emissions refer to emissions that are spatially distributed over a wide area. In the quantification of fugitive dust, use was made of emission factors which associate the quantity of a pollutant to the activity associated with the release of that pollutant.

1.2.6 Atmospheric Dispersion Modelling

1.2.6.1 Dispersion model selection

Dispersion models compute ambient pollutant 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 from 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.

The US Environmental Protection Agency's (US-EPA) approved regulatory model – AERMOD – was selected for this study. It is one of the models recommended for Level 2 assessments, for near-source (less than 50 km from source) applications in all terrain types, in the South African Regulations Regarding Air Dispersion Modelling (Government Gazette No. 37804, 11 July 2014).

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. AERMET is a meteorological pre-processor for AERMOD. Input data can come from hourly cloud cover observations, surface meteorological observations and twice-a-day upper air soundings. Output includes surface meteorological observations and parameters and vertical profiles of several atmospheric parameters. AERMAP is a terrain pre-processor designed to simplify and standardise the input of terrain data for AERMOD. Input data includes receptor terrain elevation data. The terrain data may be in the form of digital terrain data. The output includes, for each receptor, location, and height scale, which are elevations used for the computation of air flow around hills.

A disadvantage of the model is that spatial varying wind fields, due to topography or other factors cannot be included. Input data types required for the AERMOD model include: source data, meteorological data (supplied in the required format with the SAWS data), terrain data, information on the nature of the receptor grid and pre-development or background pollutant concentrations or dustfall rates.

1.2.6.2 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). Use was made of measured SAWS data for Welkom for the period 2020 to 2022. The Breeze AERMET 7 v7.7.0.4 was used with the executable version 21112.

1.2.6.3 Source Data Requirements

The AERMOD model is able to model point, area, volume and line sources. The windblown dust from the existing TSFs and WRDs as well as the proposed Valley TSF was modelled as area sources and vents were modelled as point sources.

1.2.6.4 Modelling Domain

The dispersion of pollutants was modelled for an area covering 13 km (east-west) by 13 km (north-south) for the project site. The modelling domain was selected on the basis of the sources of emissions and potential impact areas. This area was divided into a grid with a resolution of 100 m (east-west) by 100 m (north-south). AERMOD simulates ground-level concentrations for each of the receptor grid points. The receptors were modelled at 1.5 m above ground.

1.3 Assumptions, Exclusions and Limitations

The main assumptions, exclusions and limitations are summarized below:

- **Meteorological data:** Use was made of measured SAWS data for Welkom for the period 2020 to 2022, and this is regarded representative of the project area.
- **Emissions:**
    - The quantification of sources of emission was restricted to the project activities and baseline Harmony operations within the study domain only. Although other background sources were identified, such sources were not quantified.
    - Information required for the calculation of emissions from fugitive dust sources for the project operations was taken from a previous study for Harmony (Grobler and Liebenberg-Enslin, 2017). The assumption was made that this information was accurate and correct.
    - Routine emissions from the operations were estimated and modelled. Atmospheric releases occurring as a result of accidents were not accounted for.

1.4 Outline of Report

Regulatory requirements applicable to the study are presented in Section 2. The synoptic climatology and atmospheric dispersion potential of the area as well as information on existing sources and baseline air quality are discussed in Section 3. Section 4 presents the impact assessment of the project. The dust management plan for the site is provided in Section 5. Conclusions are presented in Section 6.

2 REGULATORY REQUIREMENTS AND ASSESSMENT CRITERIA

2.1 National Ambient Air Quality Standards for Criteria Pollutants

The 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 standards are intended to provide safe hourly, daily and annual exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime.

The South African Bureau of Standards (SABS) was engaged to assist Department of Forestry, Fisheries and the Environment (DFFE) (previously the Department of Environmental Affairs (DEA)) in the facilitation of the development of ambient air quality standards. This included the establishment of a technical committee to oversee the development of standards. NAAQS were determined based on international best practice for $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, ozone (O_3), lead (Pb) and benzene (C_6H_6). Since the focus of this assessment is on PM, the applicable standards for PM_{10} and $PM_{2.5}$ are listed (Table 1).

Table 1: Applicable National Ambient Air Quality Standards

Pollutant	Averaging Period	Concentration (µg/m³)	Permitted Frequency of Exceedance	Compliance Date
$PM_{2.5}$	24 hour	65	4	Immediate till 31 December 2015
	24 hour	40	4	1 January 2016 till 31 December 2029
	24 hour	25	4	1 January 2030
	1 year	25	0	Immediate till 31 December 2015
	1 year	20	0	1 January 2016 till 31 December 2029
	1 year	15	0	1 January 2030
PM_{10}	24 hour	75	4	1 January 2015
	1 year	40	0	1 January 2015

2.2 National Dust Control Regulations

Dustfall is assessed for nuisance impact and not for inhalation health impact. The National Dust Control Regulations (NDCR) (Department of Environmental Affairs, 2013) prescribes measures for the control of dust in residential and non-residential areas.

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

In addition to the dustfall limits, the NDCR prescribe monitoring procedures and reporting requirements.

Table 2: Acceptable dustfall rates

Restriction Area	Dustfall rate ($mg/m^2/day$, 30-days average) (D)	Permitted frequency of exceeding dustfall rate
Residential area	D < 600	Two within a year, not sequential months
Non-residential area	600 < D < 1 200	Two within a year, not sequential months

2.3 Dispersion Modelling Guidelines

Air dispersion modelling provides a cost-effective means for assessing the impact of air emission sources, the major focus of which is to determine compliance with the relevant ambient air quality standards. Draft Regulations Regarding Air Dispersion Modelling was published in Government Gazette No. 35981, Notice Number 1035 of 2012 (14 December 2012), and recommends a suite of dispersion models to be applied for regulatory practices as well as guidance on modelling input requirements, protocols and procedures to be followed. The guideline to air dispersion modelling is applicable –

(a) in the development of an air quality management plan, as contemplated in Chapter 3 of the AQA;
(b) in the development of a priority area air quality management plan, as contemplated in section 19 of the AQA;
(c) in the development of an atmospheric impact report, as contemplated in section 30 of the AQA; and,
(d) in the development of a specialist air quality impact assessment study, as contemplated in Chapter 5 of the AQA.

The Guideline is therefore applicable to the development of this report. The first step in the dispersion modelling exercise requires a clear objective of the modelling exercise and thereby gives clear direction to the choice of the dispersion model most suited for the purpose. Chapter 2 of the Guideline presents the typical levels of assessments, technical summaries of the prescribed models (SCREEN3, AERSCREEN, AERMOD, SCIPUFF, and CALPUFF) and good practice steps to be taken for modelling applications.

Dispersion modelling provides a versatile means of assessing various emission options for the management of emissions from existing or proposed installations. Chapter 3 of the Guideline prescribes the source data input to be used in the models. Dispersion modelling can typically be used in the:

- Apportionment of individual sources for installations with multiple sources. In this way, the individual contribution of each source to the maximum ambient predicted concentration can be determined. This may be extended to the study of cumulative impact assessments where modelling can be used to model numerous installations and to investigate the impact of individual installations and sources on the maximum ambient pollutant concentrations.
- Analysis of ground level concentration changes as a result of different release conditions (e.g. by changing stack heights, diameters and operating conditions such as exit gas velocity and temperatures).
- Assessment of variable emissions as a result of process variations, start-up, shut-down or abnormal operations.
- Specification and planning of ambient air monitoring programs which, in addition to the location of sensitive receptors, are often based on the prediction of air quality hotspots.

The above options can be used to determine the most cost-effective strategy for compliance with the NAAQS. Dispersion models are particularly useful under circumstances where the maximum ambient concentration approaches the ambient air quality limit value and provide a means for establishing the preferred combination of mitigation measures that may be required including:

- Stack height increases;

- Reduction in pollutant emissions through the use of air pollution control systems (APCS) or process variations;
- Switching from continuous to non-continuous process operations or from full to partial load.

Chapter 4 of the Guideline prescribes meteorological data input from onsite observations to simulated meteorological data. The chapter also gives information on how missing data and calm conditions are to be treated in modelling applications. Meteorology is fundamental for the dispersion of pollutants because it is the primary factor determining the diluting effect of the atmosphere. Therefore, it is important that meteorology is carefully considered when modelling.

New generation dispersion models, including models such as AERMOD and CALPUFF[1], simulate the dispersion process using planetary boundary layer (PBL) scaling theory. PBL depth and the dispersion of pollutants within this layer are influenced by specific surface characteristics such as surface roughness, albedo and the availability of surface moisture:

- Roughness length (z_o) is a measure of the aerodynamic roughness of a surface and is related to the height, shape and density of the surface as well as the wind speed.
- Albedo is a measure of the reflectivity of the Earth's surface. This parameter provides a measure of the amount of incident solar radiation that is absorbed by the Earth/atmosphere system. It is an important parameter since absorbed solar radiation is one of the driving forces for local, regional, and global atmospheric dynamics.
- The Bowen ratio provides measures of the availability of surface moisture injected into the atmosphere and is defined as the ratio of the vertical flux of sensible heat to latent heat, where sensible heat is the transfer of heat from the surface to the atmosphere via convection and latent heat is the transfer of heat required to evaporate liquid water from the surface to the atmosphere.

Topography is also an important geophysical parameter. The presence of terrain can lead to significantly higher ambient concentrations than would occur in the absence of the terrain feature. In particular, where there is a significant relative difference in elevation between the source and off-site receptors large ground level concentrations can result. Thus, the accurate determination of terrain elevations in air dispersion models is very important.

The modelling domain would normally be decided on the expected zone of influence; the latter extent being defined by the predicted ground level concentrations from initial model runs. The modelling domain must include all areas where the ground level concentration is significant when compared to the air quality limit value (or other guideline). Air dispersion models require a receptor grid at which ground-level concentrations can be calculated. The receptor grid size should include the entire modelling domain to ensure that the maximum ground-level concentration is captured and the grid resolution (distance between grid points) sufficiently small to ensure that areas of maximum impact adequately covered. No receptors however should be located within the property line as health and safety legislation (rather than ambient air quality standards) is applicable within the site.

Chapter 5 provides general guidance on geophysical data, model domain and coordinates system required in dispersion modelling, whereas Chapter 6 elaborates more on these parameters as well as the inclusion of background air concentration data. The chapter also provides guidance on the treatment of NO_2 formation from oxides of nitrogen (NO_x) emissions, chemical transformation of sulfur dioxide into sulfates and deposition processes. Chapter 7 of the Guideline outlines how the plan of study and modelling assessment reports are to be presented to authorities.

[1] The CALMET modelling system require further geophysical parameters including surface heat flux, anthropogenic heat flux and leaf area index (LAI).

3 Description of the Receiving/Baseline Environment

3.1 Air Quality Sensitive Receptors

Air quality sensitive receptors (AQSRs) refer to places where humans reside. Ambient air quality guidelines and standards, as discussed under section 2.2, have been developed to protect human health. Ambient air quality, in contrast to occupation exposure, pertains to areas outside of an industrial site or boundary where the public has access to and according to the Air Quality Act, excludes air regulated by the Occupational Health and Safety Act (Act No 85 of 1993).

A map showing locations of AQSRs within the study domain is included in Figure 1. These include residential areas, farmsteads, schools and hospitals. The closest towns in the immediate region of the project include Welkom and its suburbs (located about 3.7 kilometres (km) southeast of the project boundary) and Odendaalsrus (located about 3 km north of the project boundary).

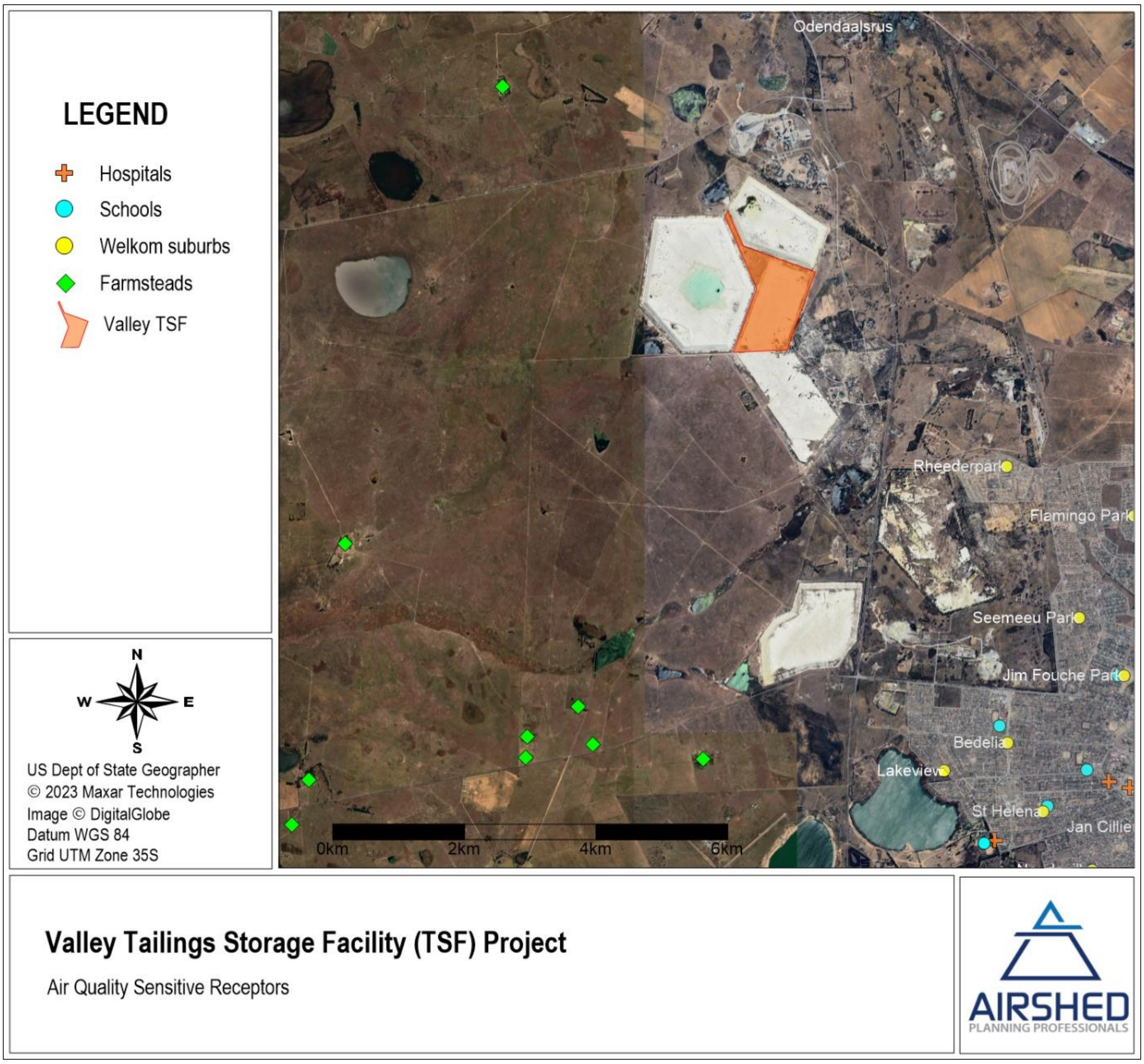

Figure 1: Location map and Air Quality Sensitive Receptors of the proposed project

3.2 Atmospheric Dispersion Potential

In the assessment of the possible impacts from air pollutants on the surrounding environment and human health, a good understanding of the regional climate and local air dispersion potential of a site is essential. Meteorological characteristics of a site govern the dispersion, transformation, and eventual removal of pollutants from the atmosphere (Pasquill and Smith, 1983; Godish, 1990). The extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal and mechanical turbulence within the earth's boundary layer.

Dispersion comprises vertical and horizontal components of motion. The vertical component is defined by the stability of the atmosphere and the depth of the surface mixing layer. The horizontal dispersion of pollution in the boundary layer is primarily a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of plume 'stretching'. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness.

The wind direction and the variability in wind direction, determine the general path pollutants will follow, and the extent of crosswind spreading (Shaw and Munn, 1971; Pasquill and Smith, 1983; Oke, 1990).

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

3.2.1 Surface Wind Field

In characterising the dispersion potential of the site reference was made to measured SAWS data for Welkom for the period 2020 to 2022.

Wind roses comprise 16 spokes, which represent the directions from which winds blew during a specific period. The colours used in the wind roses below, reflect the different categories of wind speeds; for example, red representing winds greater than 10 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. The frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s are also indicated. The period wind field and diurnal variability in the wind field are shown in Figure 2. Seasonal variation in the wind field is presented in Figure 3.

During the 2020 to 2022 period, the wind field was dominated by winds from the north to east, followed by westerly winds. During the day (6AM – 6PM), the prevailing wind field is from the north to northeast and the west, with less frequent winds from the north-westerly sector, the easterly sector and the south-west. During the night, the wind field shifts to the easterly sector (north-northeast to east-southeast), with very little flow from the westerly sector. Long-term air quality impacts are therefore expected to be the most significant to the south and southwest of the project area. The strongest winds (more than 6 m/s) were also from the north and northeast and occurred mostly during the day, with 15 m/s the highest wind speed recorded. The average wind speed over the three years is 3.5 m/s, with calm conditions occurring for 8.5% of the time.

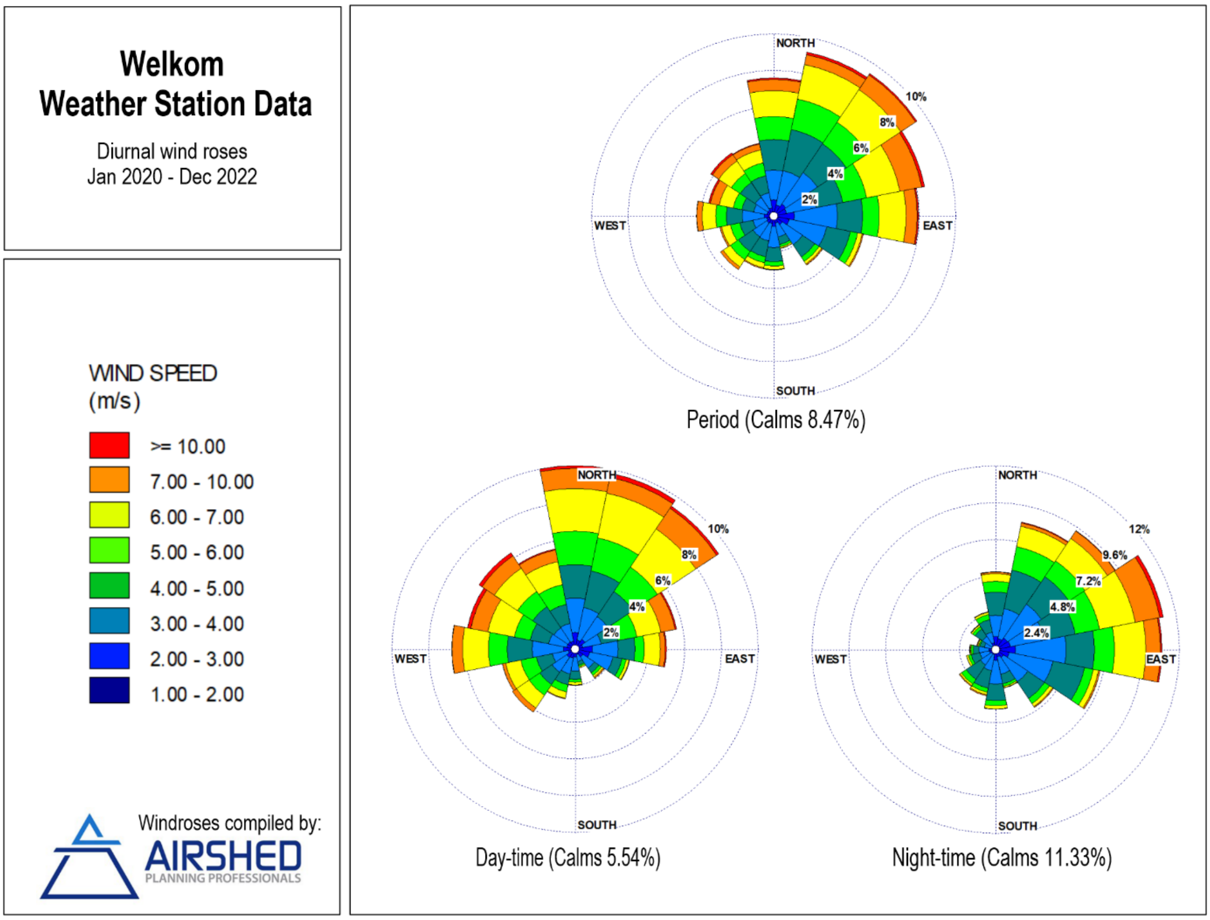

Figure 2: Period, day and night-time wind roses (SAWS data – 2020 to 2022)

Seasonally, the wind flow pattern conforms to the period average wind flow pattern. The seasonal wind field shows little seasonal differences in the wind fields. During summer and spring, the dominant winds are from the north-northeast to east, with more frequent westerly winds during spring. Autumn reflects dominant north-easterly and easterly winds, with a similar wind field during winter, but with more frequent north-northeasterly and east-southeasterly winds (Figure 3).

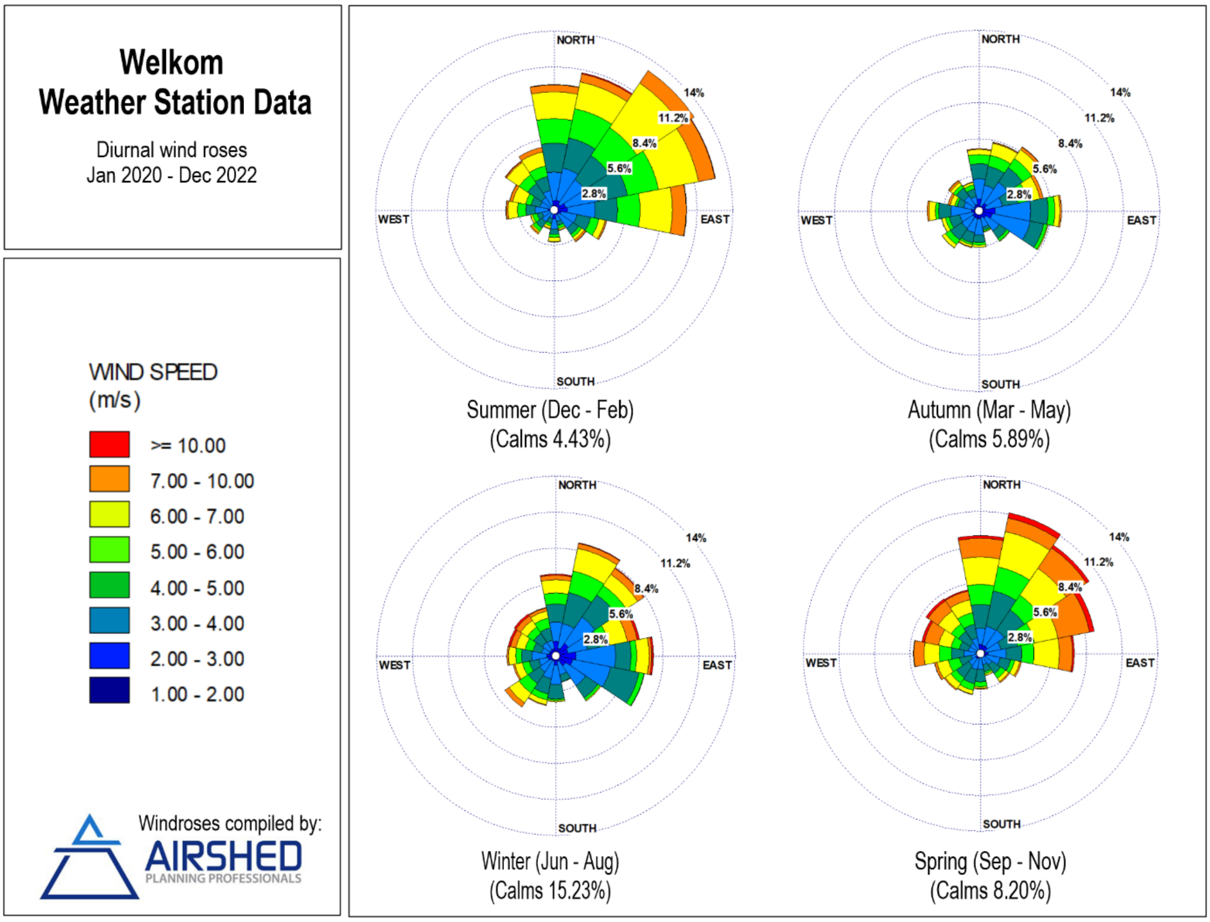

Figure 3: Seasonal wind roses (SAWS data – 2020 to 2022)

According to the Beaufort wind force scale (https://www.metoffice.gov.uk/guide/weather/marine/beaufort-scale), wind speeds between 6-8 m/s equates to a moderate breeze, with wind speeds between 9-11 m/s referred to as a fresh breeze. Wind speeds between 11-14 m/s are described as a strong breeze with winds between 14-17 m/s near gale force winds and 17-21 m/s as gale force winds. Over the 3-year period, wind speeds within 14-17 m/s occurred for 0.03% of the time, and winds between 11-14 m/s for 0.42%. The likelihood for wind erosion to occur from open and exposed surfaces, with loose fine material, but taking into account that the TSF surfaces are typically crusted, was estimated when the wind speed exceeds 9 m/s (Mian & Yanful, 2003). Wind speeds exceeding 9 m/s occurred for 2.03% over the 3-year period.

3.2.2 Temperature

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the emission plume and the ambient air, the higher the plume is able to rise), and determining the development of the mixing and inversion layers.

Diurnal and average monthly temperature trends are presented in Figure 4. Monthly average and hourly maximum and minimum temperatures are given in Figure 5. Temperatures ranged between -6.1 °C and 37.3°C. The highest monthly temperatures occurred in October and the lowest in July. During the day, temperatures increase to reach maximum at around 13:00 in the afternoon. Ambient air temperatures decrease to reach a minimum at around 06:00 (summer) to 07:00 (winter) i.e. just before sunrise.

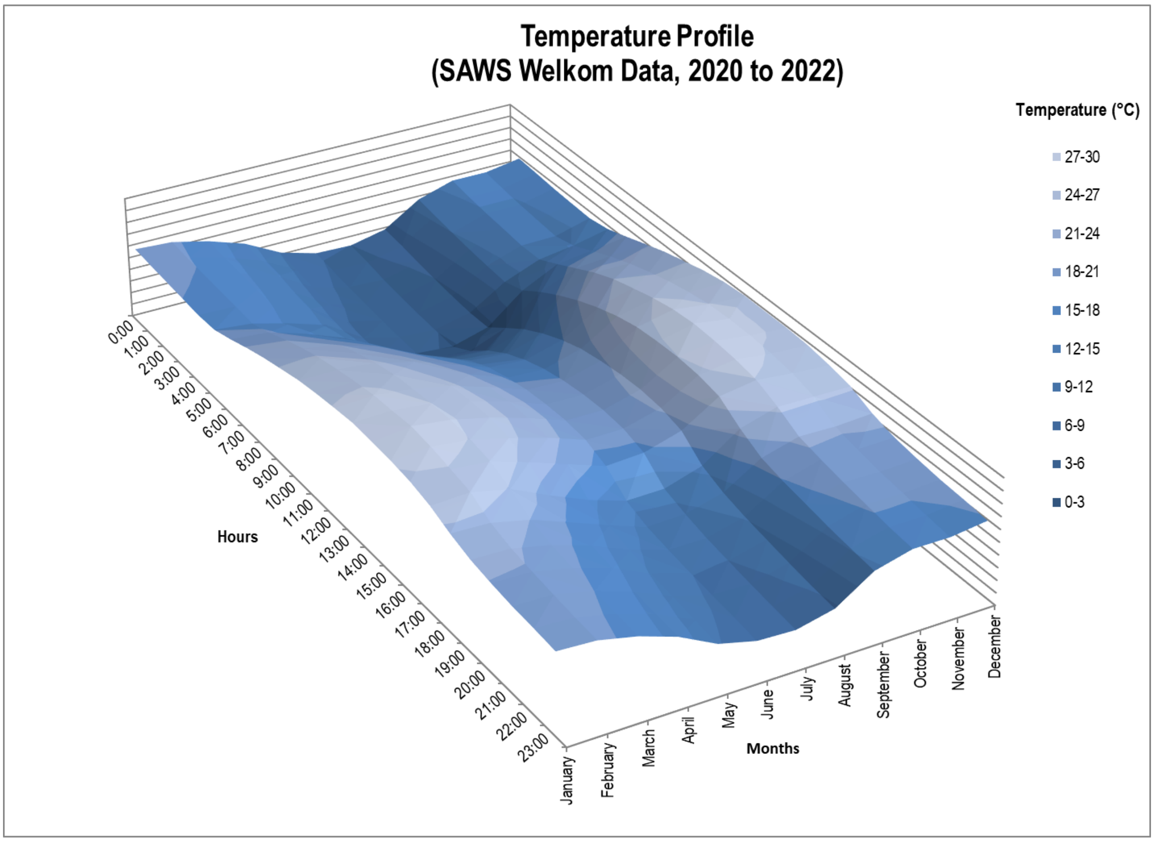

Figure 4: Diurnal monthly temperature trends at the study area (SAWS data for the period 2020 to 2022)

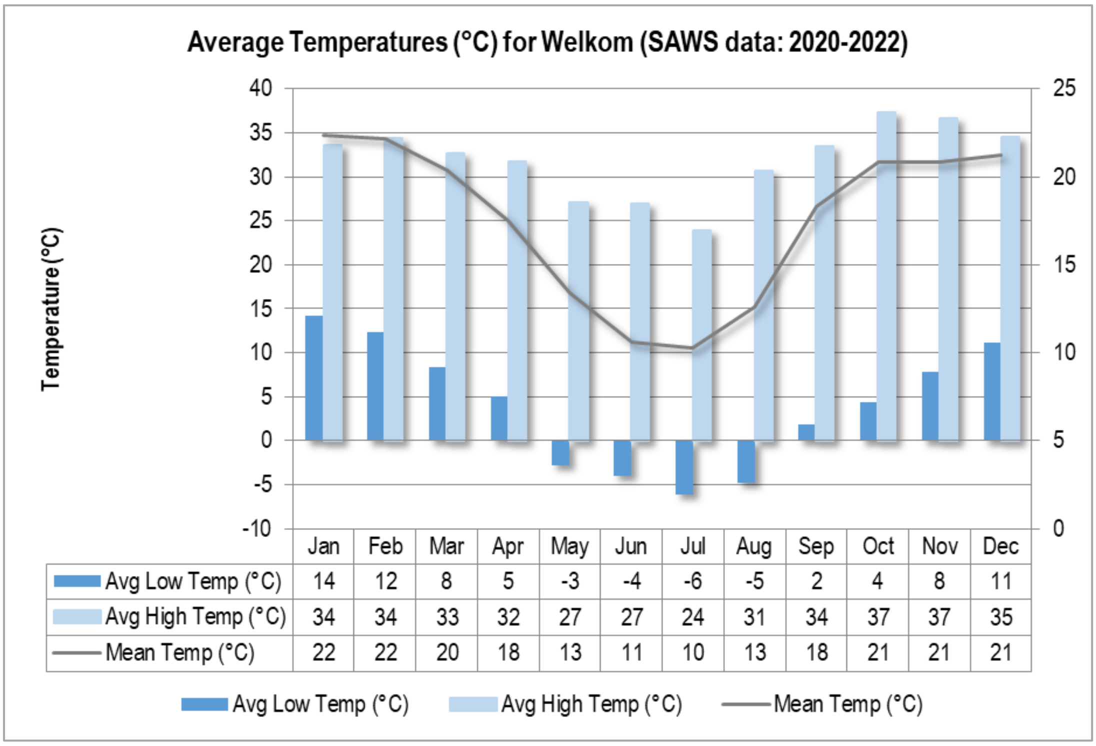

Figure 5: Monthly average and hourly minimum and maximum temperatures (°C)

3.2.3 Rainfall

Precipitation represents an effective removal mechanism of atmospheric pollutants. Precipitation reduces wind erosion potential by increasing the moisture content of materials. Rain-days are defined as days experiencing 0.1 mm or more rainfall.

Rainfall in the region is almost exclusively due to showers and thunderstorms and falls mainly in summer, from October to March. The maximum rainfall occurs during the December-January period. The long term annual average rainfall (1955- 1978) for Welkom is given in Table 3 (Schulze, 1986).

Table 3: Long-term average monthly rainfall at Welkom

Rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average (mm)	99	67	67	49	23	8	7	5	17	49	63	56	526
No. of rain days	10	9	9	7	4	2	2	1	2	7	9	10	72

3.2.4 Atmospheric Stability

Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table 3-1. New generation air dispersion models differ from the models traditionally used in a number of aspects, the most important of which are the description of atmospheric stability as a continuum rather than discrete classes. The atmospheric boundary layer properties are therefore described by two parameters; the boundary layer depth and the Obukhov length, rather than in terms of the single parameter Pasquill Class.

Table 4: Atmospheric stability classes and frequency of occurrence

A	very unstable	calm wind, clear skies, hot daytime conditions	5%
B	moderately unstable	clear skies, daytime conditions	12%
C	unstable	moderate wind, slightly overcast daytime conditions	22%
D	neutral	high winds or cloudy days and nights	19%
E	stable	moderate wind, slightly overcast night-time conditions	16%
F	very stable	low winds, clear skies, cold night-time conditions	27%

The Obukhov length (LMo) provides a measure of the importance of buoyancy generated by the heating of the ground and mechanical mixing generated by the frictional effect of the earth’s surface. Physically, it can be thought of as representing the depth of the boundary layer within which mechanical mixing is the dominant form of turbulence generation (CERC, 2004). The atmospheric boundary layer constitutes the first few hundred metres of the atmosphere. During daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth’s surface. Night-times are characterised by weak vertical mixing and the predominance of a stable layer. These conditions are normally associated with low wind speeds and lower dilution potential.

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 speed, the plume will reach the ground relatively far downwind. With stronger wind speeds, on the other hand, the plume may reach the ground closer to the source, but due to increased ventilation, would be more diluted. A wind speed between these extremes would therefore be responsible for the highest ground level concentration. In contrast, the highest concentration for ground level, or near-ground level releases would occur during weak wind speeds and stable (night-time) atmospheric conditions. Figure 6 shows the stability class frequency for all the major wind directions for the period January 2020 to December 2022.

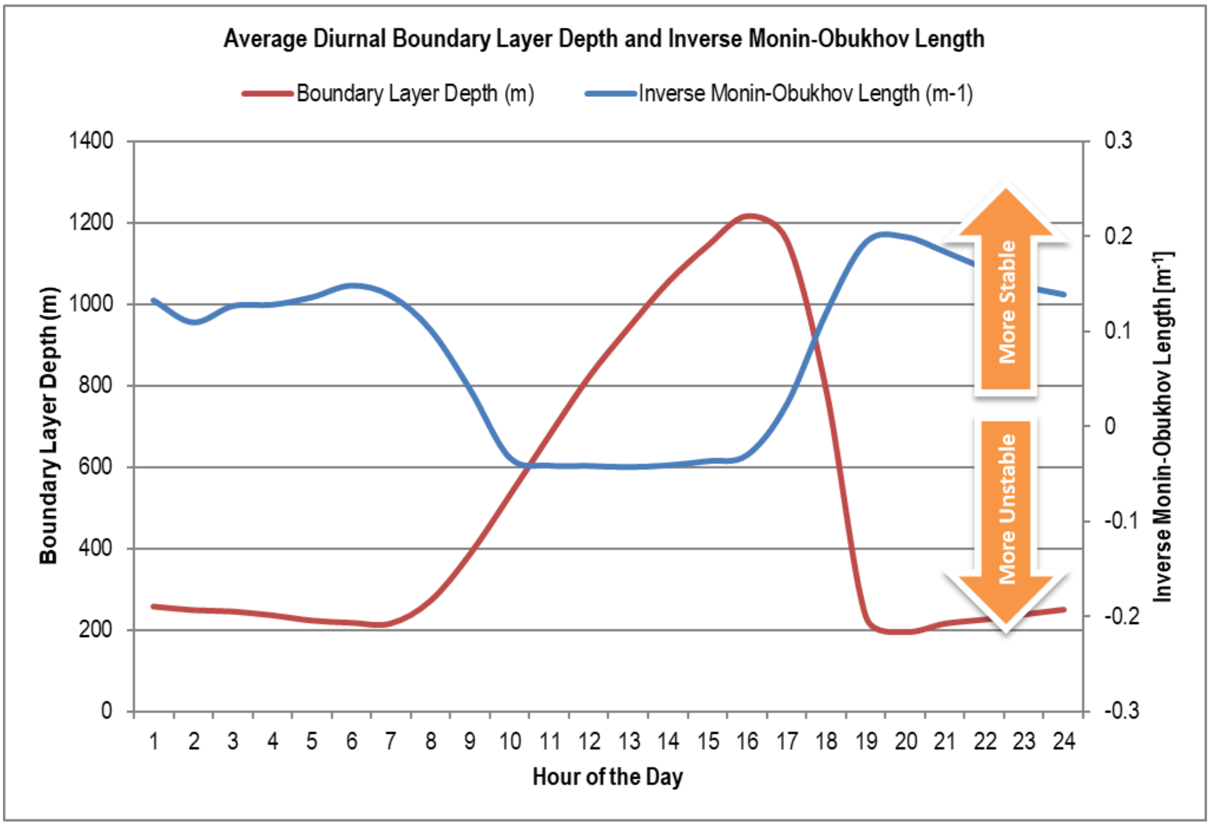

Figure 6: Diurnal atmospheric stability for Welkom (SAWS data, 2020 to 2022)

Stability class frequency is shown in Figure 7. Calculations indicate very stable, stable, and unstable occur 27%, 16% and 22% of the time respectively.

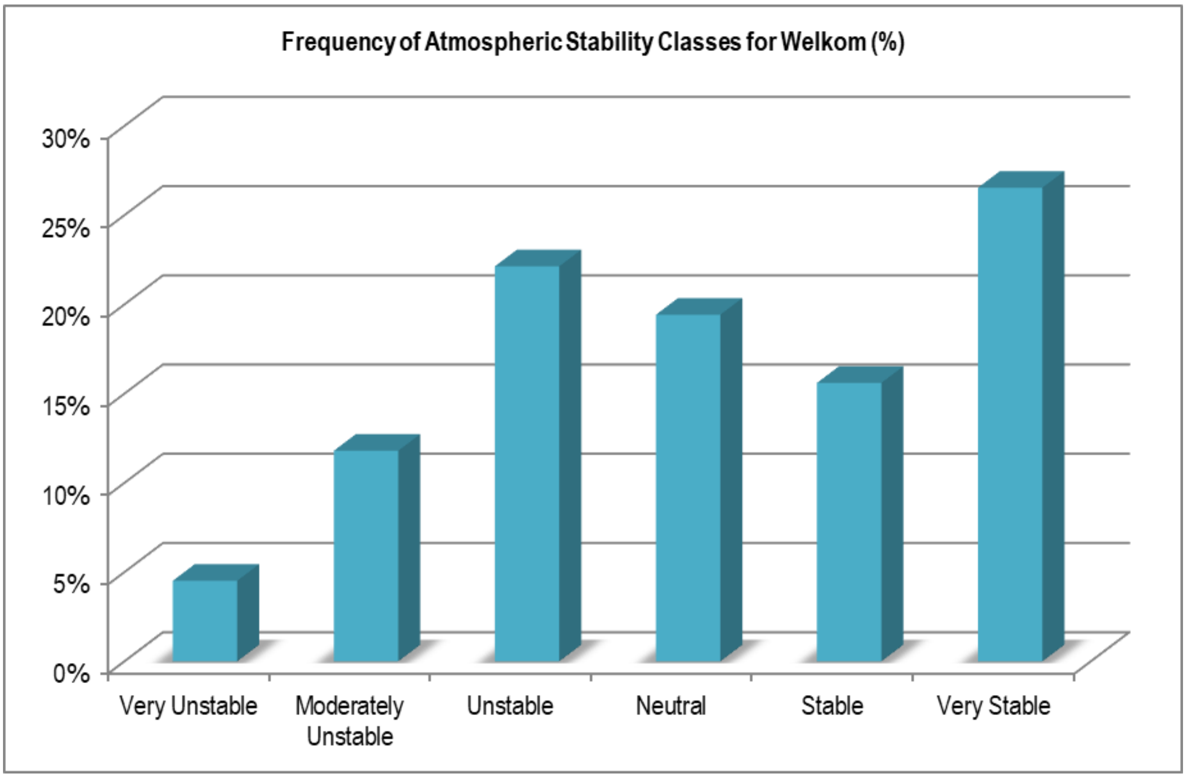

Figure 7: Atmospheric stability class frequency (SAWS data, 2020 to 2022)

3.3 Status Quo Ambient Air Quality

3.3.1 Existing Sources of Atmospheric Emission

Neighbouring land-use in the surrounding of the proposed project comprises predominantly of agriculture activities. These land-uses contribute to baseline pollutant concentrations via fugitive and process emissions, vehicle tailpipe emissions, household fuel combustion, biomass burning and windblown dust from exposed areas.

3.3.1.1 Agriculture

Agriculture is a major land-use activity within and beyond the project boundary. These activities include crop farming such as maize, and livestock farming. Particulate matter is the main pollutant of concern from agricultural activities as particulate emissions are derived from windblown dust, burning crop residue, and dust entrainment as a result of vehicles travelling along dirt roads. In addition, pollen grains, mould spores and plant and insect parts from agricultural activities all contribute to the particulate load. Should chemicals be used for crop spraying, they would typically result in odiferous emissions. Crop residue burning is also an additional source of particulate emissions and other toxins. Due to the small scale of farming activities these are regarded to have an insignificant cumulative impact.

Livestock farms, especially cattle, are also significant sources of fugitive dust especially when feedlots are used and the cattle trample in confined areas. Pollutants associated with dairy production for instance include ammonia (NH_3), hydrogen sulfide (H_2S), methane (CH_4), carbon dioxide (CO_2), oxides of nitrogen (NOx) and odour related trace gasses. According to the US-EPA, cattle emit methane through a digestive process that is unique to ruminant animals called enteric fermentation. The calf-cow sector of the beef industry was found to be the largest emitter of methane emissions. Where animals are densely confined the main pollutants of concern include dust from the animal movements, their feed and their manure, ammonia (NH_3) from the animal urine and manure, and hydrogen sulfide (H_2S) from manure pits.

Organic dust includes dandruff, dried manure, urine, feed, mould, fungi, bacteria and endotoxins (produced by bacteria, and viruses). Inorganic dust is composed of numerous aerosols from building, materials and the environment. Since the dust is biological it may react with the defence system of the respiratory tract. Odours and VOCs associated with animal manure is also a concern when cattle are kept in feedlots. The main impact from methane is on the dietary energy due to the reduction of carbon from the rumen. Dust and gasses levels are higher in winter or whenever animals are fed, handled or moved.

3.3.1.2 Mining Sources

Particulates represent the main pollutant of concern at mining operations, whether it is underground or opencast. The amount of dust emitted by these activities depends on the physical characteristics of the material, the way in which the material is handled and the weather conditions (e.g. high wind speeds, rainfall, etc.). Mining of gold, as well as ore extraction and processing plants are all commercial activities situated in the region of the project.

3.3.1.3 Domestic Fuel Combustion

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

Coal is relatively inexpensive in the region and is easily accessible due to the proximity of the region to coal mines and the well-developed coal merchant industry. Coal burning emits a large amount of gaseous and particulate pollutants including SO_2, heavy metals, PM including heavy metals and inorganic ash, CO, PAHs (recognized carcinogens), NO_2 and various toxins. The main pollutants emitted from the combustion of paraffin are NO_2, particulates, CO and PAHs.

3.3.1.4 Biomass Burning

Biomass burning includes the burning of evergreen and deciduous forests, woodlands, grasslands, and agricultural lands. Within the project vicinity, crop-residue burning and wildfires (locally known as veld fires) may represent significant sources of combustion-related emissions. The frequency of wildfires in the grasslands varies between annual and triennial.

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

3.3.1.5 Fugitive Dust Sources

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

3.3.1.6 Unpaved and paved roads

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

Emissions from paved roads are significantly less than those originating from unpaved roads, however they do contribute to the particulate load of the atmosphere. Particulate emissions occur whenever vehicles travel over a paved surface. The fugitive dust emissions are due to the re-suspension of loose material on the road surface. Paved roads in the region include the R710, R73, R30 and R34.

3.3.1.7 Wind erosion of open areas

Windblown dust generates from natural and anthropogenic sources. For wind erosion to occur, the wind speed needs to exceed a certain threshold, called the threshold velocity. This relates to gravity and the inter-particle cohesion that resists removal. Surface properties such as soil texture, soil moisture and vegetation cover influence the removal potential. Conversely, the friction velocity or wind shear at the surface is related to atmospheric flow conditions and surface aerodynamic properties. Thus, for particles to become airborne, its erosion potential has to be restored; that is, the wind shear at the surface must exceed the gravitational and cohesive forces acting upon them, called the threshold friction velocity. Every time a surface is disturbed, its erosion potential is restored (US EPA, 2004). Erodible surfaces may occur as a result of agriculture and/or grazing activities.

3.3.1.8 Vehicle Tailpipe Emissions

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

Transport in the vicinity of the project is via trucks and private vehicles along the R710, R73, R30 and R34 roads (which are the main sources of vehicle tailpipe emissions), as well as vehicles and machinery travelling on unpaved and private roads.

3.3.2 Dustfall Monitoring

Harmony samples dust fallout at 44 locations (4 samplers each at 11 sites, Figure 8). Of these sites, five are within the study domain, i.e. Odendaalsrus, Rheederpark, Flamingo Park, Bedelia and St Helena. Dust fallout rates sampled during the most recent period for which data was available (July 2016 to May 2017) are shown in Table 5 and Figure 9. Exceedances of the NDCR residential limit (600 mg/m²/day) and non-residential limit (1 200 mg/m²/day) are highlighted in yellow and red respectively in Table 5.

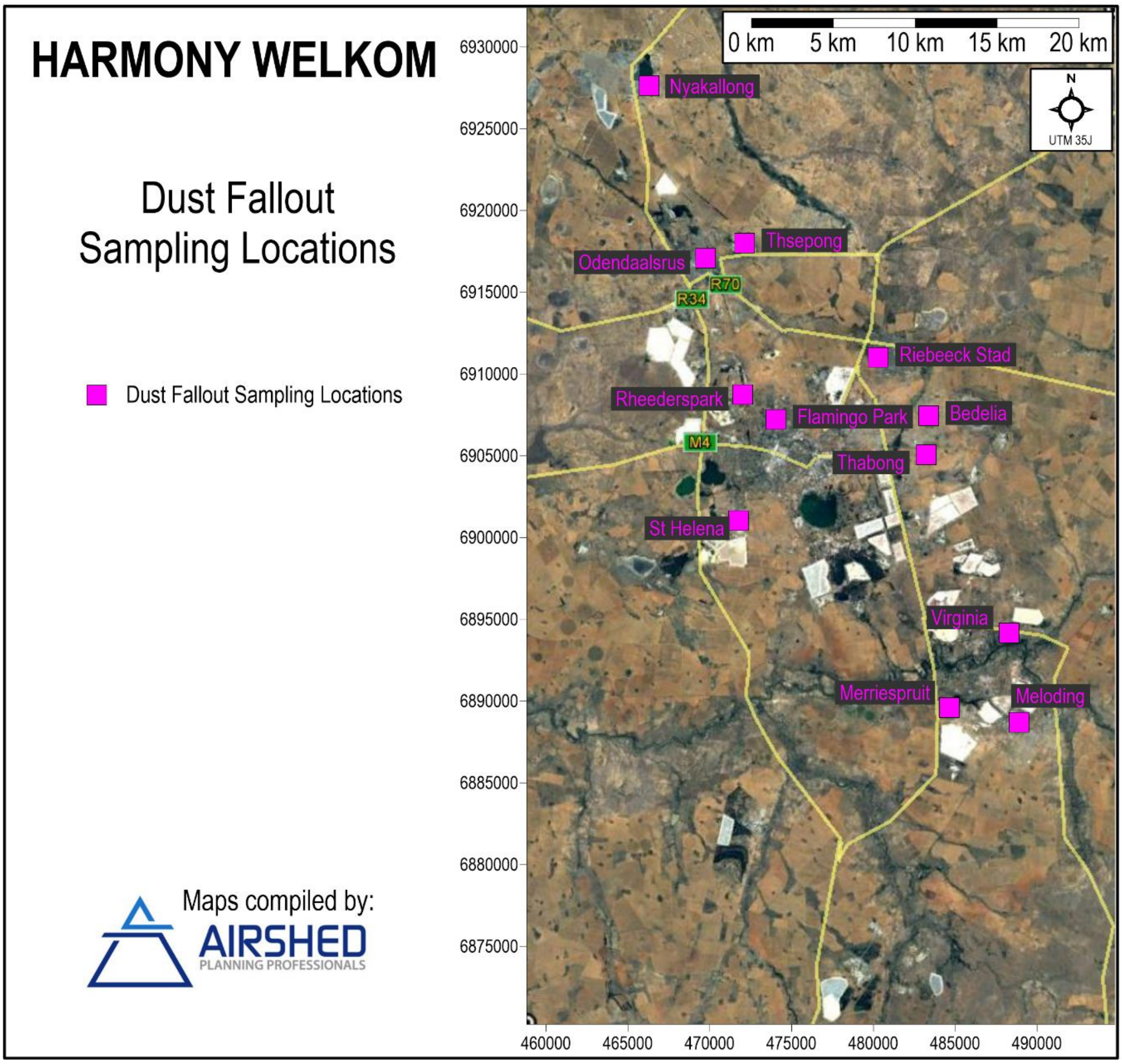

Figure 8: Harmony dust fallout sampling locations

Most of the sites, but specifically the ones in the vicinity of the Project (i.e. Odendaalsrus, Rheederpark, Flamingo Park, Bedelia and St Helena) are in non-compliance, where it exceeded the residential and non-residential limits more than two months in 2017 and for two sequential months (Table 6).

Table 5: Sampled dust fallout rates (July 2016 to May 2017)

Month	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17
Rheederspark South	582.8	407.7	503	445	288	4295					
Rheederspark North	816	479	488	1058	335	3243					
Rheederspark East	519	598	584	757	398	3399					
Rheederspark West	866	388	522	1028	98	4032					
Odendaalsrus South	1306	366	631	1208	266	6543	899	620	1502	999	184
Odendaalsrus North	849	353	553	516	145	3885	1320	1177	1814	822	228
Odendaalsrus East	500	461	504	517	313	5263	1577	1039	1688	1086	278
Odendaalsrus West	696	279	560	1377	172	7539	1501	1165	1531	1032	139
Bedelia South	860			725	390	5349		2163	1848	1208	1870
Bedelia North	490			1587	485	4548		1498	1932	2765	2915
Bedelia East	366			231	301	5337		1498	1928	1224	2335
Bedelia West	631			728	323	5079		648	1895	1174	1846
Flamingo South	127	6	737	912	228		1552	1097	1862	776	1531
Flamingo North	150	90.6	578	1291	254		1469	914	1705	540	1186
Flamingo East	190	157	372	852	395		2018	1248	1793	1204	1587
Flamingo West	107	264	345	383	428		2973	1097	2324	527	1230
St Helena South	142	519	377	1129	442	1583	445		1210	822	2074
St Helena North	329	532	310	730	399	1142	1573		976	2016	1429
St Helena East	188	272	400	1561	851	2513	1577		1562	1224	944
St Helena West	132	448	839	927	356	1640	988		1909	1726	2206

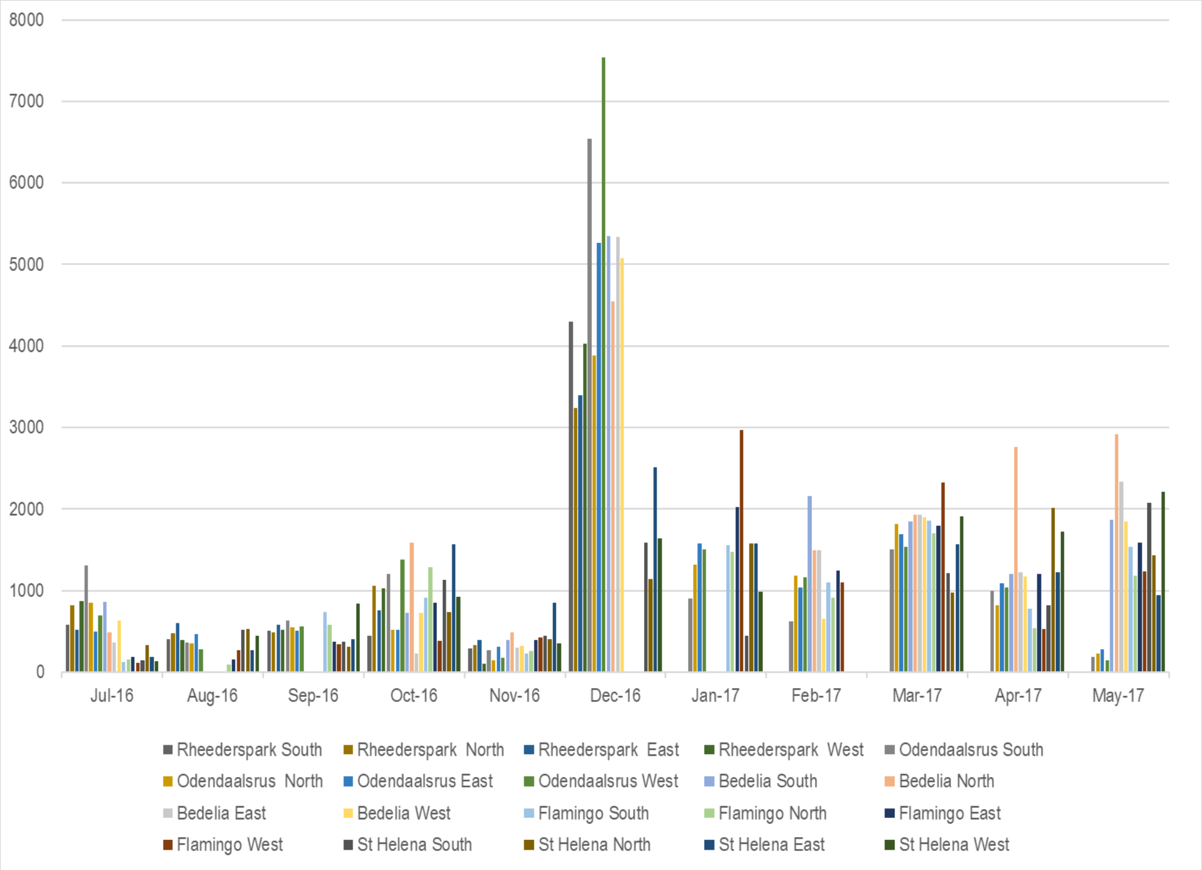

Figure 9: Sampled dust fallout rates in mg/m²/day (July 2016 to May 2017) – by month

4 IMPACT ASSESSMENT

4.1 Atmospheric Emissions

4.1.1 Construction Phase

TSFs are built over three stages: initial construction, operation, and closure (Cox et. al., 2022). The initial construction of a TSF includes constructing the infrastructure and structures that need to be in place before depositing any waste products. During operation, as more tailings are produced, the initial dam is raised through a series of 'lifts.' This stage of construction for the TSF may occur over decades, depending on the life of mine. At the end of mine life, the closure plan will be implemented. The closure plan progressively reclaims the TSF to an extent wherein the facility is integrated into the surrounding landscape. This process requires active dam maintenance and monitoring post-closure.

The main pollutant of concern from initial construction operations is particulate matter, including PM_{10}, $PM_{2.5}$ and TSP. PM_{10} and $PM_{2.5}$ concentrations are associated with potential health impacts due to the size of the particulates being small enough to be inhaled. Nuisance effects are caused by the TSP fraction (20 µm to 75 µm in diameter) resulting in soiling of materials and visibility reductions. This could in effect also have financial implications due to the requirement for more cleaning materials.

Activities resulting in the release of these pollutants include topsoil removal, material loading and hauling, stockpiling, grading, bulldozing, as well as metal and concrete works for the establishment of infrastructure. Each of these operations has its own duration and potential for dust generation. It is anticipated that the extent of dust emissions would vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing meteorological conditions. This contrasts with most other fugitive dust sources where emissions are either relatively steady or follow a discernible annual cycle. It is often necessary to estimate area wide construction emissions, without regard to the actual plans of any individual construction process.

Quantified construction emissions are usually lower than operational phase emissions and since the construction schedule was not available (and due to their temporary nature); and the likelihood that these activities will not occur concurrently at all portions of the site; dispersion simulation was not undertaken for construction emissions.

4.1.2 Operational Phase

A specific concern is windblown dust from the Valley TSF resulting in dust deposits and potentially health impacts in the nearby residential area of Welkom and surrounding AQSRs. Wind-blown dust from mine waste facilities can be a significant source of dust emissions with high dust concentrations reported near mining sites, affecting both the environment and human health. A number of studies have been conducted on the impact from mine tailings – specifically gold mine tailings – on residential areas around and close to the base of these tailings facilities (Ojelede *et al*., 2012; Phakedi, 2011; Annegarn, 2006; Annegarn *et al*., 2000; 2010). These studies indicated that slimes dams in close proximity to human settlements pose a health risk, with measured PM_{10} concentrations during storm events reported to be between 171 µg/m³ and 462 µg/m³ (Ojelede *et al*., 2012).

Aside from the concern for dust impacts, the metal content in the slimes pose potential health risks. A study conducted by Maseki (2013) found a range of heavy metals within four gold slimes dams assessed – these included amongst others potassium (K), chromium (Cr) manganese (Mn), nickel (Ni), cadmium (Cd), gold (Au), lead (Pb), Iron (Fe), zinc (Zn), arsenic (As) and uranium (U). In addition, radionuclides are also associated with gold mine tailings.

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

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

The US EPA indicates a friction velocity of 5.4 m/s to initiate erosion from coal storage piles (US EPA, 2006) and Mian & Yanful (2003) calculated a wind speed in excess of 9 m/s is required to initiate wind erosion from two tailings storage facilities in in New Brunswick and Ontario, Canada. Thus, the likelihood exists for wind erosion to occur from open and exposed surfaces, with loose fine material, when the wind speed exceeds at least 5.4 m/s.

As indicated, any binding properties would reduce the potential for wind erosion. One of the most effective measures of minimizing wind erosion emissions from tailings storage facilities is re-vegetation. The control efficiency of vegetation is given as 40% for non-sustaining vegetation and 90% for re-vegetation. Secondary rehabilitation would up the control efficiency to 60% for non-sustaining vegetation (NPI, 2012). The proposed TSF would not be covered and therefore pose the largest risk for wind-blown dust.

4.1.2.1 Emissions Quantification

Sources of emissions from the baseline include active ventilation shafts and windblown dust from the existing tailings storage facilities and WRDs within the 13 km by 13 km study domain (Figure 10). These sources were identified from a previous study for Harmony Welkom (Grobler and Liebenberg-Enslin, 2017). Sources of emissions for the project include the baseline and the proposed Valley TSF (Figure 10).

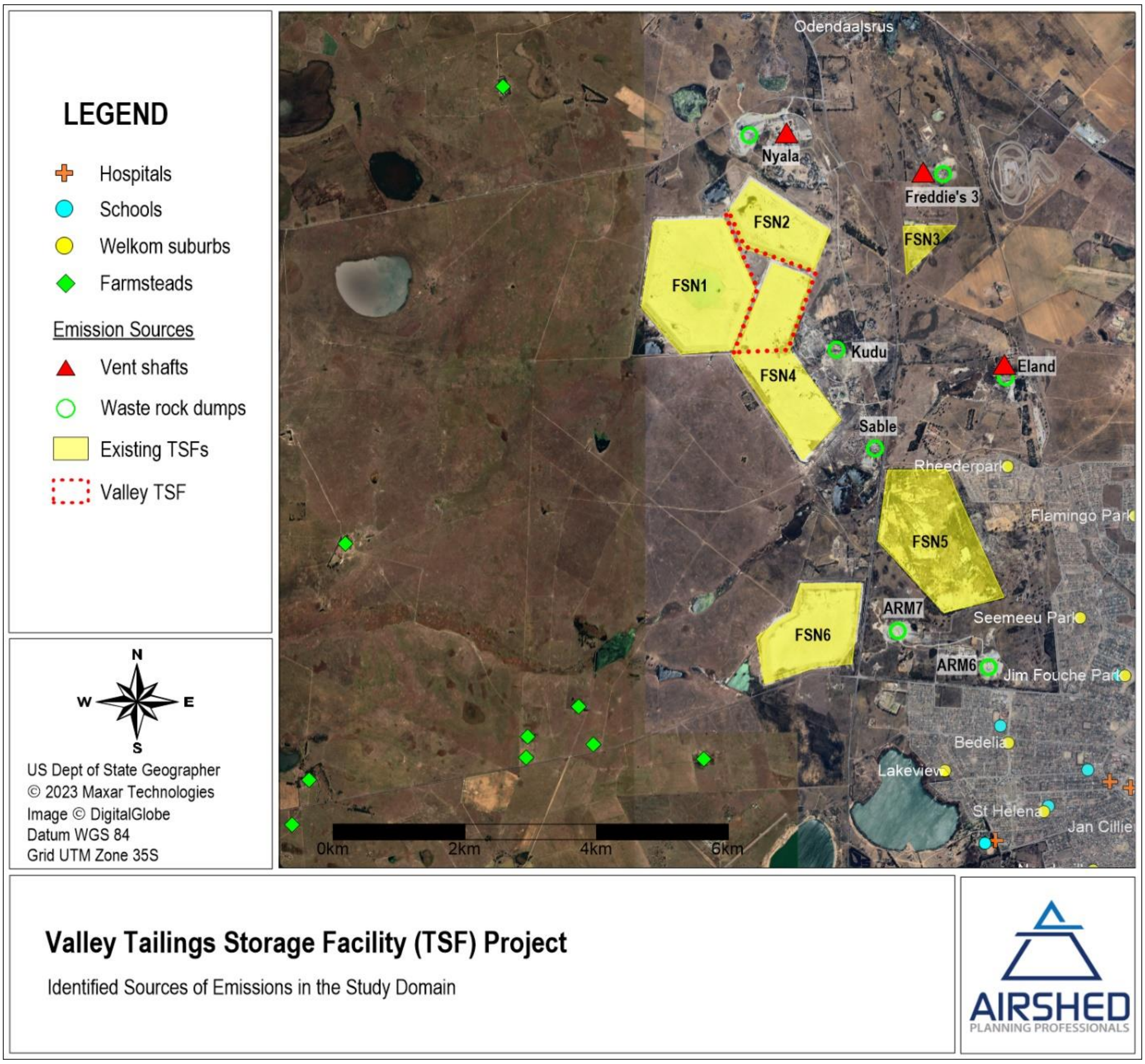

Figure 10: Identified sources of emissions within the study domain

4.1.2.1.1 Tailings Storage Facilities (TSFs)

Emissions from TSFs were calculated for every hour of the simulation period using the Airborne Dust Dispersion from Area Sources (ADDAS) model (Burger *et al*., 1997; Burger, 2010, Liebenberg-Enslin, 2014). This model is based on the dust emission scheme of Marticorena and Bergametti (1995) referred to as MB95 (from this point forward) and Shao *et al*. (2011) (referred to as SH11), which was tested in the study conducted by Liebenberg-Enslin (2014). Site specific particle size distribution data, bulk density and moisture content were used in the dust flux schemes of MB95, and SH11 to test the effects on a local scale. This was done by coupling these schemes with the US EPA regulatory Gaussian plume AERMOD dispersion model for the simulation of ground level concentrations resulting from aeolian dust from gold mine tailings facilities. Simulated ambient near surface concentrations were validated with ambient monitoring data for the same period as used in the model. Coupling the dust flux schemes with a regulatory Gaussian plume model provided simulated ground level PM_{10} concentrations in good agreement with measured data.

For the purposes of this study the Shao model was selected, as it gave a more conservative estimate. Particle size distributions (PSD) were available for FSN6 (within the study area) and three TSFs whose available deposition capacity have been exceeded (St Helena 1, 2, 3; Brand D and FSS2). The PSD for FSN6 was assumed to be representative of the other TSFs in the area (TSF1 – TSF5) and an average of the PSDs for (St Helena 1, 2, 3; Brand D and FSS2) was assumed to be representative of the tailings material of Valley TSF. The particle size distribution used to calculate emissions for wind erosion from the existing TSFs and proposed TSF are shown in Table 6. The moisture content of the current TSFs material was assumed as 0.68% and that of the new TSF material as 1.9%. A particle density of 2000 kg/m³ was assumed. The existing TSFs were assumed to be inactive (undisturbed) with a friction velocity of 11.5 m/s whereas the new TSF was assumed to be active with a friction velocity of 9.5 m/s. All TSFs were assumed to have an erodible fraction of 100%. The calculated emission rates due to wind erosion from the existing and proposed TSFs are provided in Table 7.

Table 6: Particle size distributions of materials (given as a fraction)

Size µm	Fraction Current TSFs	Fraction Proposed TSF
2100	0	0
1110	0.0009	0.0011
756	0.0039	0.0035
516	0.0141	0.0078
352	0.0736	0.0445
211	0.2383	0.1746
111	0.0584	0.0466
98.1	0.0572	0.0467
86.4	0.0542	0.0450
76	0.0499	0.0420
66.9	0.0841	0.0726
51.8	0.0645	0.0581
40.1	0.0499	0.0488
31.1	0.0584	0.0658
21.2	0.0713	0.1006
11.2	0.0564	0.1063
5.21	0.0249	0.0535
3.12	0.0130	0.0265
2.13	0.0140	0.0262
1.13	0.0100	0.0210
0.594	0.0030	0.0090

Table 7: Calculated emissions rates for TSFs (in tonnes per annum per hectare)

Activity/ Source	Emission rate (unmitigated) (tpa/ha)		
	TSP	PM_{10}	$PM_{2.5}$
Wind Erosion Current TSFs	0.762	0.687	0.318
Wind Erosion Proposed TSF	7.326	6.796	3.206

4.1.2.1.2 Waste Rock Dumps (WRDs)

Fugitive dust emissions from WRDs were calculated using the Australian NPI single valued emission factor (ADE, 2008) of 0.4 kg/ha/h for TSP and 0.2 kg/ha/h for PM_{10}. $PM_{2.5}$ emissions were assumed to be 10% of PM_{10}, i.e. 0.02 kg/ha/h. It is suspected that this emission factor over-estimates fugitive dust emissions, it was therefore decided to make use of the built in Variable Emission Rates function in AERMOD. The single value emission factor was adjusted by the following percentages based on wind speed categories:

- 0% of NPI emission factor for wind speeds lower than 5.14 m/s
- 50% of NPI emission factor for wind speeds between 5.14 m/s and 8.23 m/s

- 100% of NPI emissions factor for wind speeds higher than 8.23 m/s

The WRDs were modelled as circular area sources in AERMOD, with an estimated area of 4 ha each (from Grobler and Liebenberg-Enslin, 2017). The calculated emission rates due to wind erosion from the WRDs are provided in Table 8.

Table 8: Calculated emissions rates for WRDs (in tonnes per annum per hectare)

Activity/ Source	Emission rate (unmitigated) (tpa/ha)		
	TSP	PM_{10}	$PM_{2.5}$
Wind Erosion Current WRDs	0.366	0.183	0.018

4.1.2.1.3 Ventilation Shafts

The three active ventilation shafts within the study domain are Nyala, Eland and Freddie's 3 (Figure 10). Ventilation shaft parameters and estimated particulate emissions (as required by the AERMOD model) for Nyala and Eland were taken from (Grobler and Liebenberg-Enslin, 2017) (Table 9). Freddie's 3 Shaft was assumed to have the same parameters and particulate emissions as Eland Shaft.

Table 9: Ventilation shaft parameters and emission rates (in g/s)

Description	Flow Rate	Exit Velocity	Diameter	Particulate Emission Rate
	m^3/s	m/s	m	g/s
Nyala Shaft	497	49	3.6	2.485
Eland Shaft	620	61	3.6	3.1
Freddie's 3 Shaft	620	61	3.6	3.1

4.1.2.2 Summary of Estimated Particulate Emissions

Table 10: Calculated particulate emission rates due to unmitigated operations

Activity/ Source	Area (hectares)	Emission rate (unmitigated) (tpa)		
		TSP	PM_{10}	$PM_{2.5}$
Wind Erosion TSFs				
FSN1	270.91	206.53	186.00	86.14
FSN2	117.83	89.83	80.90	37.47
FSN3	29.21	22.27	20.05	9.29
FSN4	223.50	170.38	153.45	71.07
FSN5	258.59	197.14	177.55	82.23
FSN6	161.78	123.33	111.08	51.44
Valley	124.77	914.02	847.91	400.05
Wind Erosion WRDs				
Nyala	4	1.46	0.73	0.07
Eland	4	1.46	0.73	0.07
Freddie's 3	4	1.46	0.73	0.07
Kudu	4	1.46	0.73	0.07
Sable	4	1.46	0.73	0.07
ARM6	4	1.46	0.73	0.07
ARM7	4	1.46	0.73	0.07
Ventilation Shafts				
Nyala	–	–	78.37	39.18

Activity/ Source	Area (hectares)	Emission rate (unmitigated) (tpa)		
		TSP	PM_{10}	$PM_{2.5}$
Eland	–	–	97.76	48.88
Freddie's 3	–	–	97.76	48.88
Total (baseline)		**819.7**	**1008.03**	**475.07**
Total (project)		**1563.34**	**1702.49**	**804.05**

4.1.3 Closure Phase

All operational activities will have ceased by the closure (decommissioning and post-closure) phase of the project. This will result in a positive impact on the surrounding environment and human health. The potential for impacts during the closure phase will therefore depend on the extent of rehabilitation efforts to be undertaken at the Valley TSF. In general, a combination of soil or rock covers in association with vegetation offers the most protection and stability to the often highly erosive tailings material.

During construction of the vegetative cover, earth and civil works are likely to generate vehicle and wind entrained dust from deposition of material on the TSF. Although the impact is likely to be site-specific, dust suppression techniques such as wetting roads, or application of dust palliatives, are required. Once vegetated the potential for wind entrained particulates should become similar to background conditions.

4.2 Impact Assessment

Dispersion simulation was undertaken to determine highest daily, frequency of exceedance and annual average ground level concentrations for PM_{10} and $PM_{2.5}$ and dustfall rates for the baseline and project scenarios. These averaging periods were selected to facilitate the comparison of simulated pollutant concentrations with relevant air quality guidelines and health effect screening levels as well as dustfall regulations.

4.2.1 Baseline Scenario

Isopleth contour plots for simulated highest daily PM_{10} and $PM_{2.5}$ concentrations for the baseline scenario are provided in Figure 11 and Figure 12 respectively. No annual plots are provided as simulated PM_{10} and $PM_{2.5}$ concentrations do not exceed their respective NAAQSs. Simulated ground level concentrations at AQSRs are provided in Table 11 and Table 12 for PM_{10} and $PM_{2.5}$ respectively. Highest daily dustfall rates are provided in Figure 13 and Table 13.

Simulated PM_{10} and $PM_{2.5}$ concentrations due to baseline operations were well within NAAQS at the closest identified sensitive receptors. The simulated dust deposition was within NDCR for residential areas at the closest sensitive receptors.

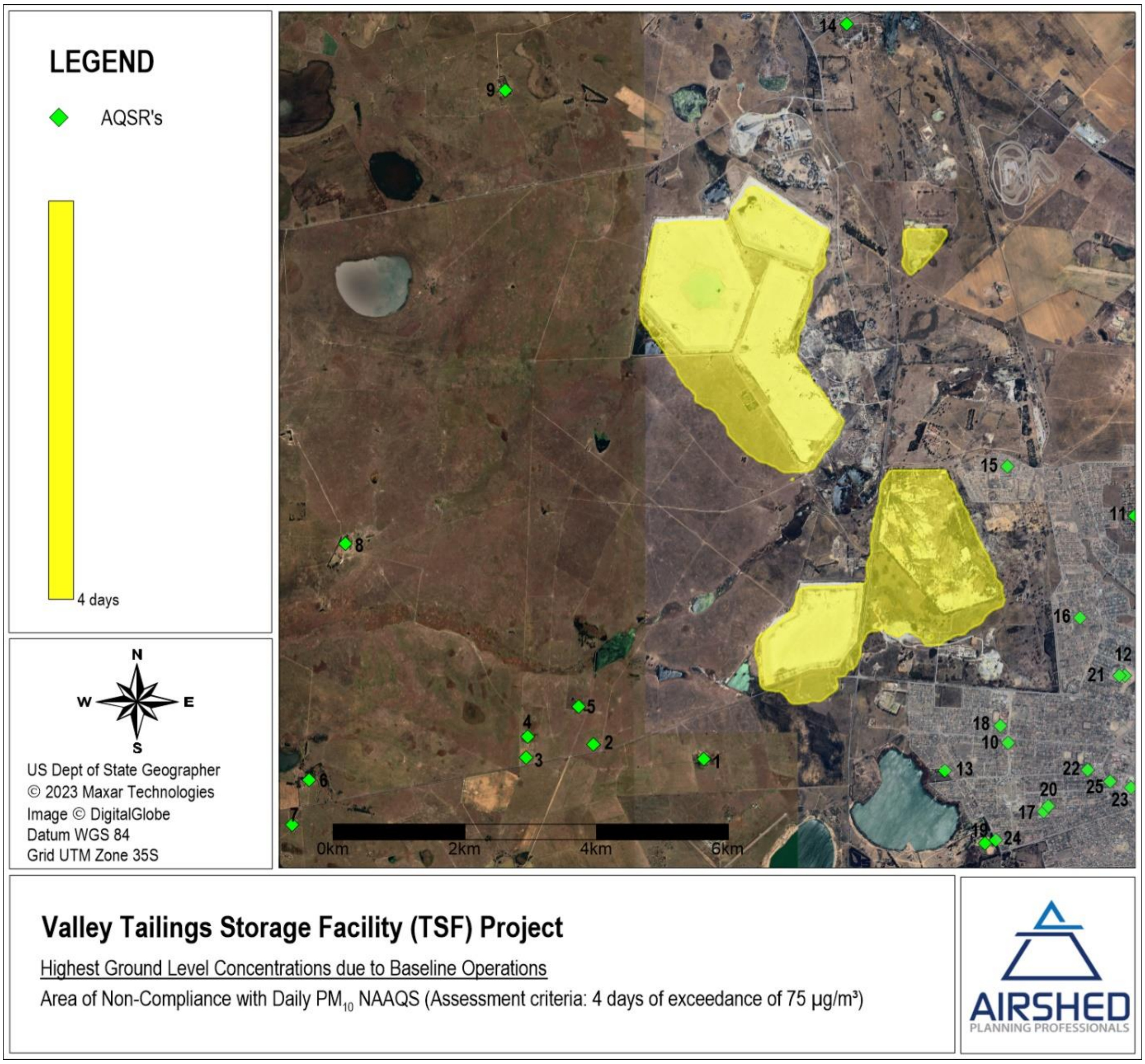

Figure 11: Baseline scenario – Area of non-compliance with daily PM_{10} NAAQS

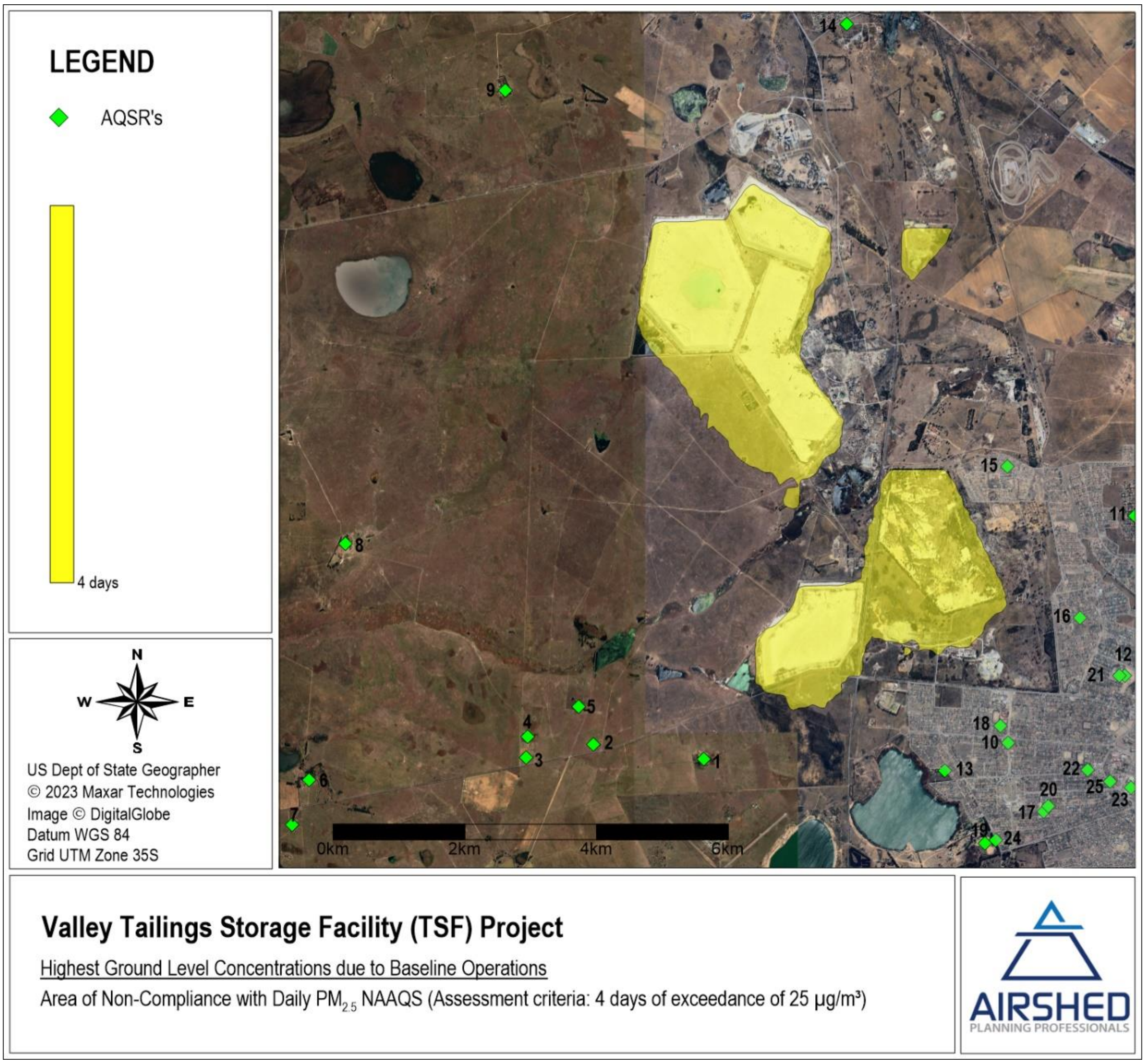

Figure 12: Baseline scenario – Area of non-compliance with daily $PM_{2.5}$ NAAQS

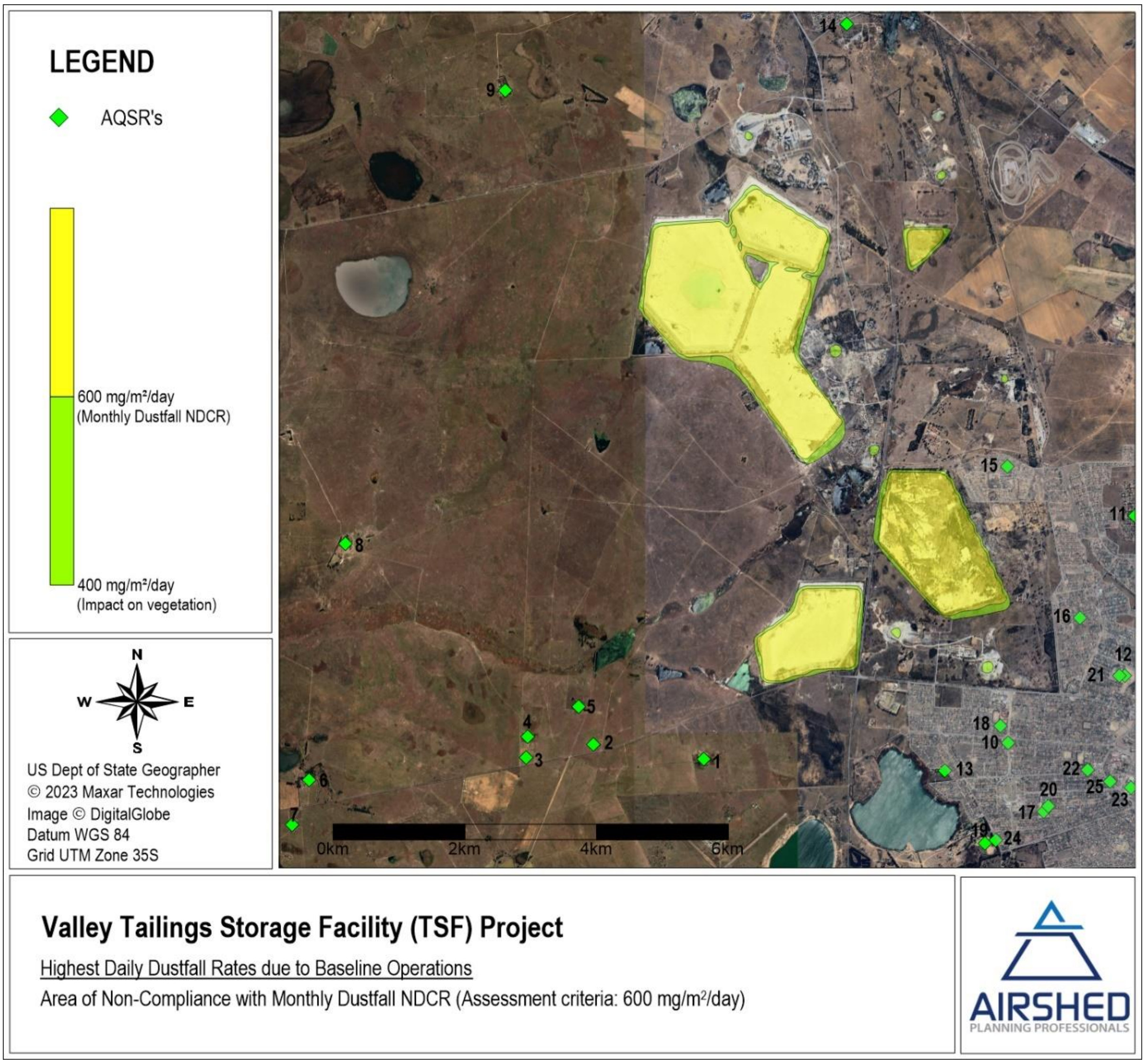

Figure 13: Baseline scenario – Area of non-compliance with monthly dustfall NDCR

Table 11: Simulated AQSR PM_{10} concentrations (in µg/m³) due to baseline operations

Baseline Operations					
AQSRs	**Name**	**Highest Daily**	**Annual**	**No of Exceedances**	**Compliance (Yes/No)**
	NAAQS	**75**	**40**	**4**	**-**
AQSR1	Farmstead 1	39.74	0.43	0	Yes
AQSR2	Farmstead 2	68.09	0.55	0	Yes
AQSR3	Farmstead 3	73.63	0.43	0	Yes
AQSR4	Farmstead 4	60.43	0.44	1	Yes
AQSR5	Farmstead 5	66.09	0.53	1	Yes
AQSR6	Farmstead 6	20.19	0.27	0	Yes
AQSR7	Farmstead 7	26.31	0.24	0	Yes
AQSR8	Farmstead 8	44.81	0.38	0	Yes
AQSR9	Farmstead 9	0.80	0.10	0	Yes
AQSR10	Bedelia	129.61	0.50	2	Yes
AQSR11	Flamingo Park	12.78	0.18	0	Yes

Baseline Operations					
AQSR12	Jim Fouche Park	84.41	0.29	2	Yes
AQSR13	Lakeview	145.53	0.56	2	Yes
AQSR14	Odendaalsrus	0.85	0.12	0	Yes
AQSR15	Rheederpark	65.89	0.32	1	Yes
AQSR16	Seemeeu Park	85.25	0.40	2	Yes
AQSR17	St Helena	69.93	0.34	1	Yes
AQSR18	Bedelia Primary School	160.18	0.58	2	Yes
AQSR19	St Andrew's School	95.20	0.35	2	Yes
AQSR20	St Helena School	80.74	0.35	2	Yes
AQSR21	Welkom Gymnasium School	98.02	0.32	2	Yes
AQSR22	Welkom Preparatory School	217.78	0.63	2	Yes
AQSR23	Mediclinic Welkom Hospital	211.07	0.57	2	Yes
AQSR24	St Helena Private Hospital	90.12	0.34	2	Yes
AQSR25	Welkom Sub-Acute Hospital	216.69	0.61	2	Yes

Table 12: Simulated AQSR $PM_{2.5}$ concentrations (in µg/m³) due to baseline operations

Baseline Operations					
AQSRs	**Name**	**Highest Daily**	**Annual**	**No of Exceedances**	**Compliance (Yes/No)**
	NAAQS	**25**	**15**	**4**	**-**
AQSR1	Farmstead 1	8.85	0.19	0	Yes
AQSR2	Farmstead 2	14.65	0.25	1	Yes
AQSR3	Farmstead 3	8.75	0.20	1	Yes
AQSR4	Farmstead 4	7.81	0.20	1	Yes
AQSR5	Farmstead 5	10.48	0.24	1	Yes
AQSR6	Farmstead 6	3.20	0.12	1	Yes
AQSR7	Farmstead 7	3.00	0.11	0	Yes
AQSR8	Farmstead 8	9.24	0.18	0	Yes
AQSR9	Farmstead 9	0.34	0.05	0	Yes
AQSR10	Bedelia	20.34	0.22	2	Yes
AQSR11	Flamingo Park	2.27	0.08	1	Yes
AQSR12	Jim Fouche Park	13.46	0.13	2	Yes
AQSR13	Lakeview	22.63	0.24	2	Yes
AQSR14	Odendaalsrus	0.33	0.05	0	Yes
AQSR15	Rheederpark	10.60	0.13	2	Yes
AQSR16	Seemeeu Park	13.90	0.18	2	Yes
AQSR17	St Helena	10.98	0.15	2	Yes
AQSR18	Bedelia Primary School	25.23	0.25	2	Yes
AQSR19	St Andrew's School	14.89	0.16	2	Yes
AQSR20	St Helena School	12.65	0.16	2	Yes
AQSR21	Welkom Gymnasium School	15.55	0.14	2	Yes
AQSR22	Welkom Preparatory School	33.95	0.29	2	Yes
AQSR23	Mediclinic Welkom Hospital	32.89	0.26	2	Yes
AQSR24	St Helena Private Hospital	14.11	0.16	2	Yes
AQSR25	Welkom Sub-Acute Hospital	33.76	0.28	2	Yes

Table 13: Simulated AQSR dustfall rates (in mg/m²/day) due to baseline operations

Baseline Operations		
AQSRs	**Name**	**30-day average**
	NDCR	**600**
AQSR1	Farmstead 1	8.85
AQSR2	Farmstead 2	14.65
AQSR3	Farmstead 3	8.75
AQSR4	Farmstead 4	7.81
AQSR5	Farmstead 5	10.48
AQSR6	Farmstead 6	3.20
AQSR7	Farmstead 7	3.00
AQSR8	Farmstead 8	9.24
AQSR9	Farmstead 9	0.34
AQSR10	Bedelia	20.34
AQSR11	Flamingo Park	2.27
AQSR12	Jim Fouche Park	13.46
AQSR13	Lakeview	22.63
AQSR14	Odendaalsrus	0.33
AQSR15	Rheederpark	10.60
AQSR16	Seemeeu Park	13.90
AQSR17	St Helena	10.98
AQSR18	Bedelia Primary School	25.23
AQSR19	St Andrew's School	14.89
AQSR20	St Helena School	12.65
AQSR21	Welkom Gymnasium School	15.55
AQSR22	Welkom Preparatory School	33.95
AQSR23	Mediclinic Welkom Hospital	32.89
AQSR24	St Helena Private Hospital	14.11
AQSR25	Welkom Sub-Acute Hospital	33.76

4.2.2 Project Scenario

Isopleth contour plots for simulated highest daily and annual average PM_{10} concentrations for the project scenario are provided in Figure 14 and Figure 15 respectively. Simulated highest daily and annual average $PM_{2.5}$ concentrations for the project scenario are provided in Figure 16 and Figure 17 respectively. Simulated ground level concentrations at AQSRs are provided in Table 14 and Table 15 for PM_{10} and $PM_{2.5}$ respectively. Highest daily dustfall rates are provided in Figure 18 and Table 16.

Simulated PM_{10} concentrations due to project operations were within the daily PM_{10} NAAQS at all of the identified sensitive receptors, as were simulated $PM_{2.5}$ concentrations within the post-2030 daily $PM_{2.5}$ NAAQS at all sensitive receptors. Annual average PM_{10} and $PM_{2.5}$ concentrations were within the respective NAAQSs at all receptors. The simulated dust deposition was within NDCR for residential areas at the closest sensitive receptors.

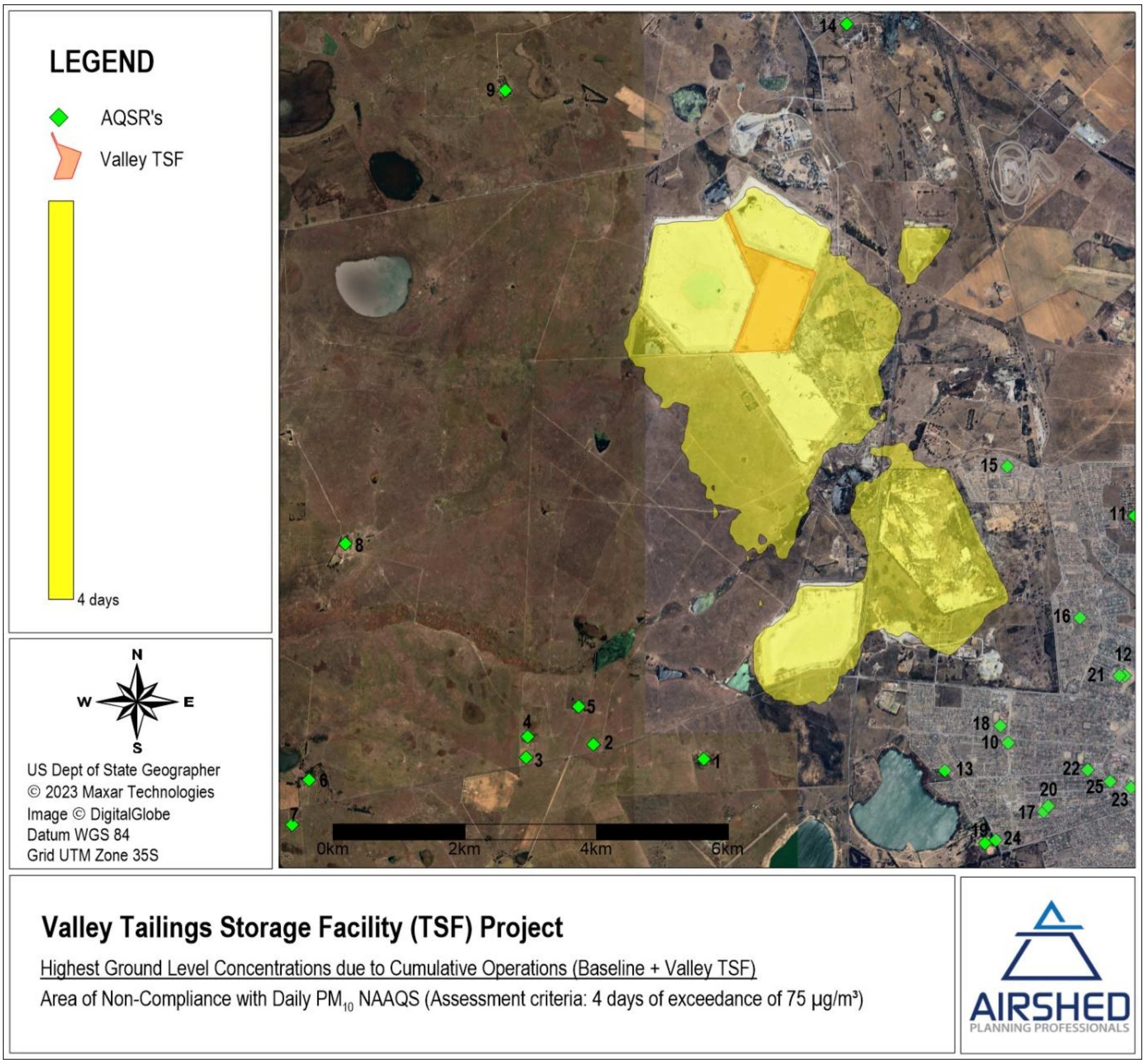

Figure 14: Project scenario – Area of non-compliance with daily PM_{10} NAAQS

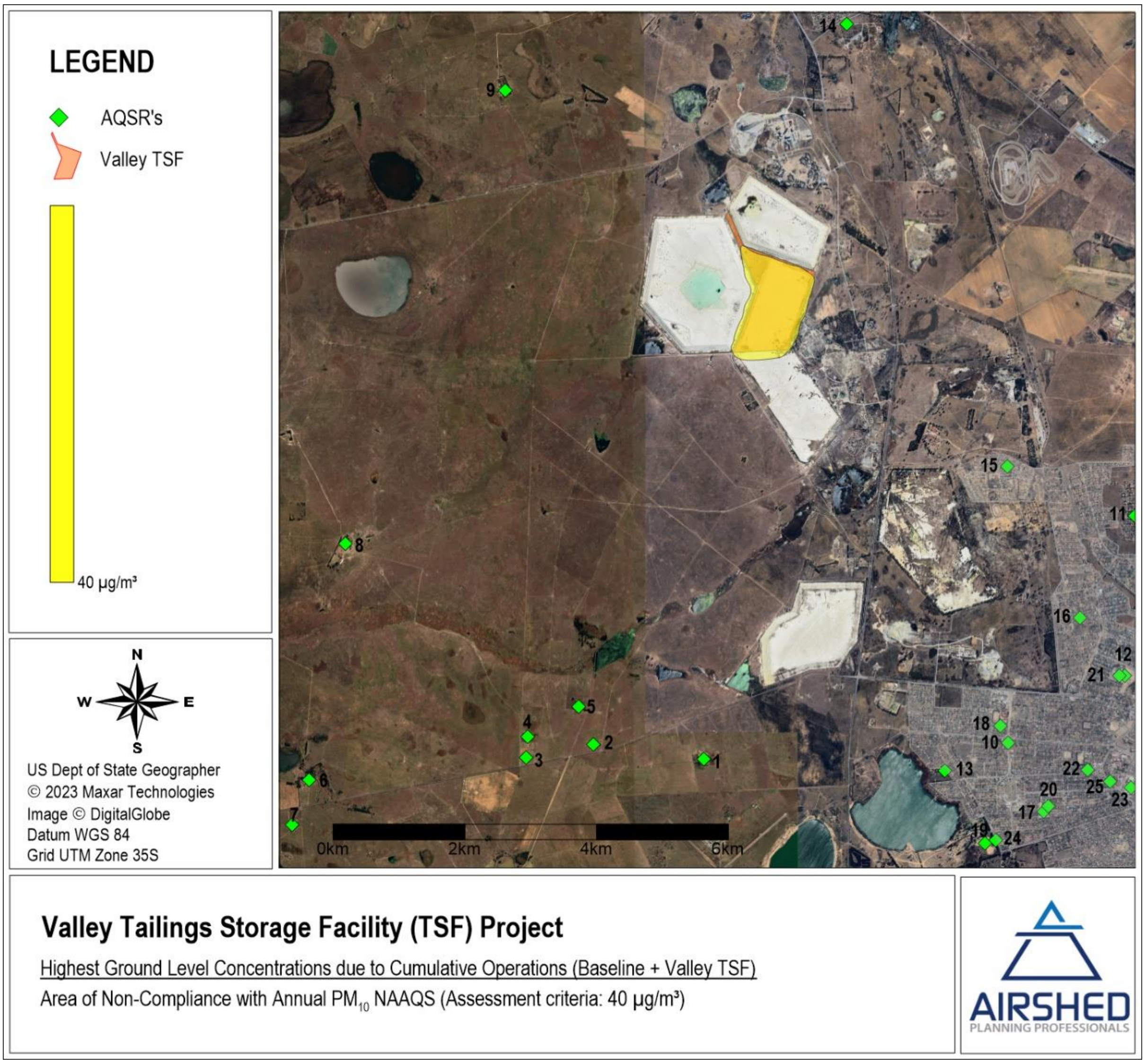

Figure 15: Project scenario – Area of non-compliance with annual PM_{10} NAAQS

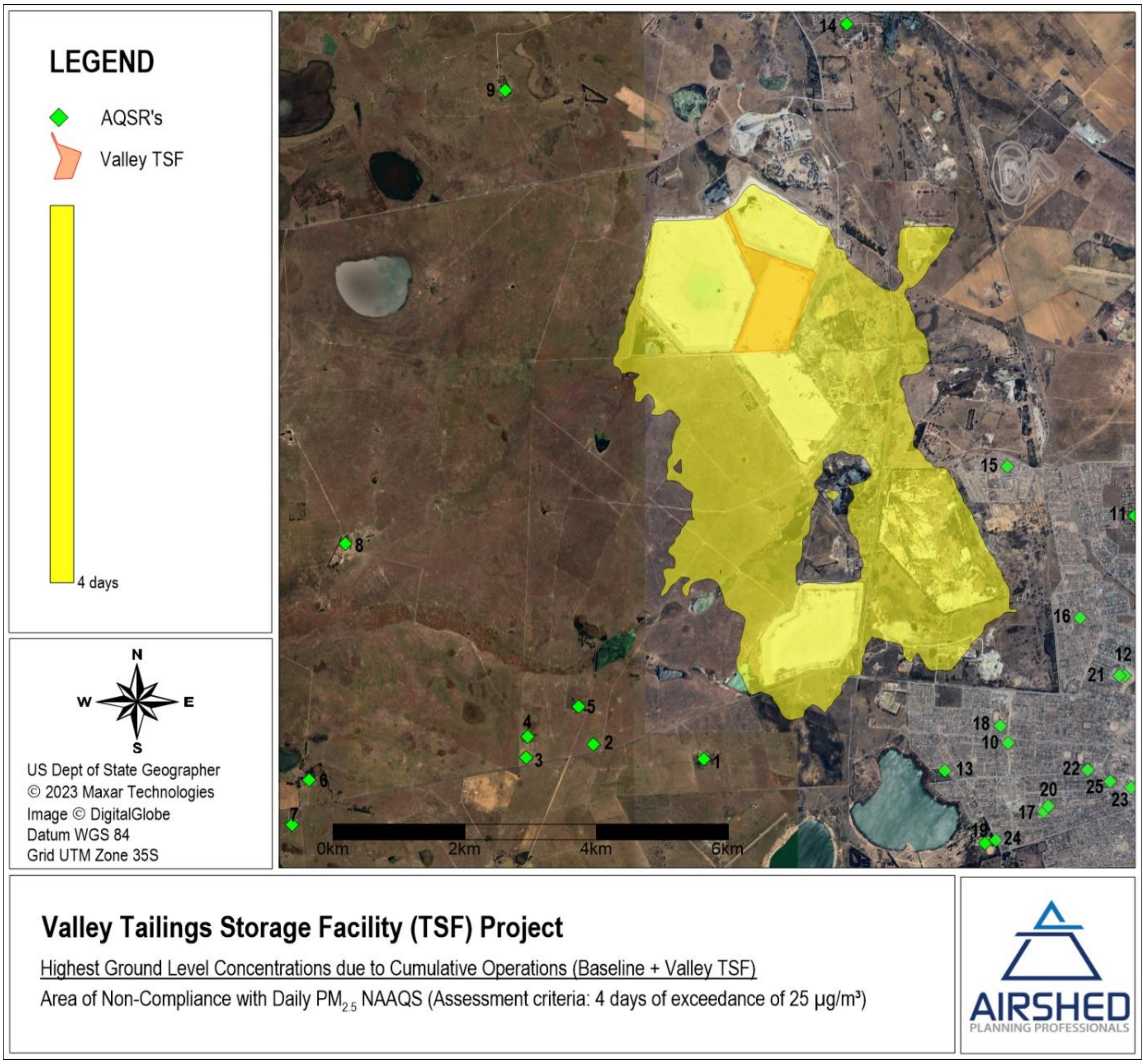

Figure 16: Project scenario – Area of non-compliance with daily $PM_{2.5}$ NAAQS

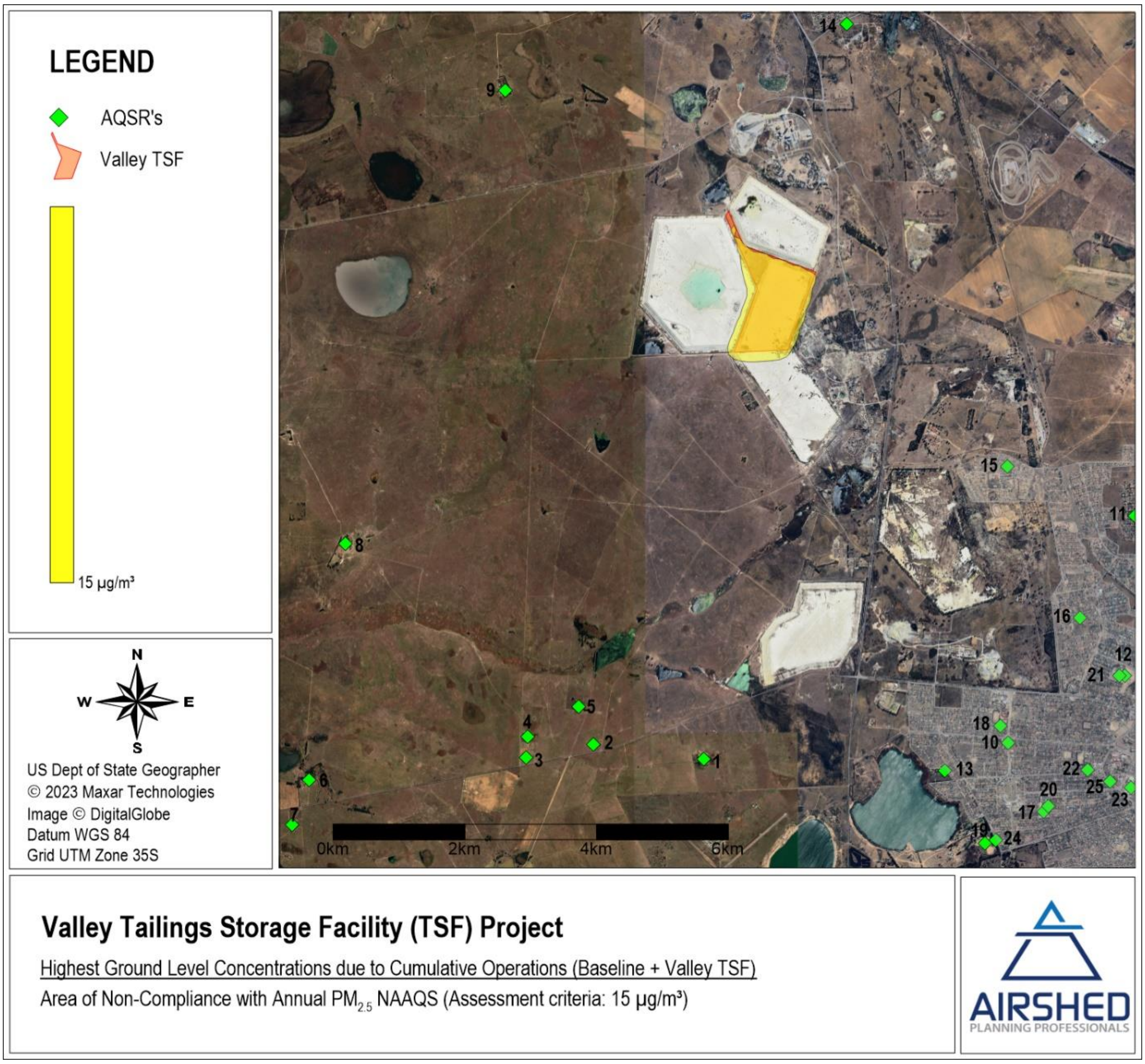

Figure 17: Project scenario – Area of non-compliance with annual $PM_{2.5}$ NAAQS

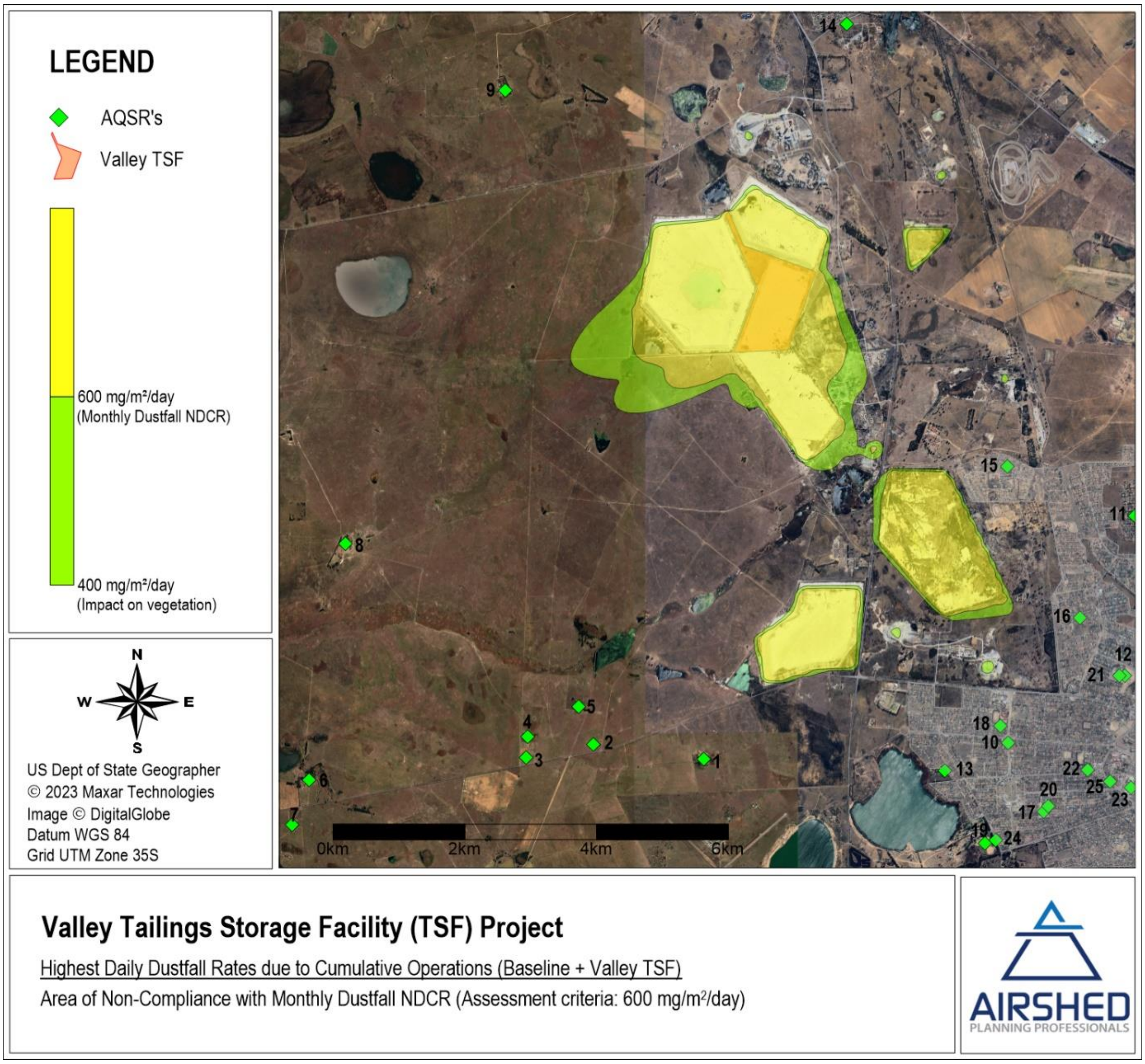

Figure 18: Project scenario – Area of non-compliance with monthly dustfall NDCR

Table 14: Simulated AQSR PM_{10} concentrations (in µg/m³) due to project operations

Project Operations					
AQSRs	**Name**	**Highest Daily**	**Annual**	**No of Exceedances**	**Compliance (Yes/No)**
	NAAQS	**75**	**40**	**4**	**-**
AQSR1	Farmstead 1	61.74	0.56	0	Yes
AQSR2	Farmstead 2	117.79	0.81	1	Yes
AQSR3	Farmstead 3	73.63	0.55	0	Yes
AQSR4	Farmstead 4	60.43	0.56	1	Yes
AQSR5	Farmstead 5	98.80	0.74	2	Yes
AQSR6	Farmstead 6	57.03	0.33	0	Yes
AQSR7	Farmstead 7	35.25	0.28	0	Yes
AQSR8	Farmstead 8	100.36	0.94	1	Yes
AQSR9	Farmstead 9	1.00	0.11	0	Yes
AQSR10	Bedelia	143.79	0.63	3	Yes
AQSR11	Flamingo Park	27.31	0.30	1	Yes

Project Operations					
AQSR12	Jim Fouche Park	151.90	0.52	2	Yes
AQSR13	Lakeview	148.20	0.68	2	Yes
AQSR14	Odendaalsrus	0.85	0.12	0	Yes
AQSR15	Rheederpark	81.61	0.59	2	Yes
AQSR16	Seemeeu Park	167.31	0.69	2	Yes
AQSR17	St Helena	76.83	0.43	2	Yes
AQSR18	Bedelia Primary School	177.99	0.73	3	Yes
AQSR19	St Andrew's School	96.20	0.44	2	Yes
AQSR20	St Helena School	90.97	0.46	2	Yes
AQSR21	Welkom Gymnasium School	167.49	0.56	2	Yes
AQSR22	Welkom Preparatory School	255.65	0.84	3	Yes
AQSR23	Mediclinic Welkom Hospital	245.79	0.77	2	Yes
AQSR24	St Helena Private Hospital	90.71	0.44	2	Yes
AQSR25	Welkom Sub-Acute Hospital	252.67	0.82	2	Yes

Table 15: Simulated AQSR $PM_{2.5}$ concentrations (in µg/m³) due to project operations

Project Operations					
AQSRs	**Name**	**Highest Daily**	**Annual**	**No of Exceedances**	**Compliance (Yes/No)**
	NAAQS	**25**	**15**	**4**	**-**
AQSR1	Farmstead 1	13.69	0.25	1	Yes
AQSR2	Farmstead 2	19.24	0.38	2	Yes
AQSR3	Farmstead 3	11.98	0.25	1	Yes
AQSR4	Farmstead 4	11.03	0.26	1	Yes
AQSR5	Farmstead 5	19.73	0.34	2	Yes
AQSR6	Farmstead 6	4.23	0.15	1	Yes
AQSR7	Farmstead 7	5.42	0.13	0	Yes
AQSR8	Farmstead 8	35.08	0.44	2	Yes
AQSR9	Farmstead 9	0.42	0.05	0	Yes
AQSR10	Bedelia	23.02	0.28	3	Yes
AQSR11	Flamingo Park	7.29	0.13	1	Yes
AQSR12	Jim Fouche Park	24.41	0.24	2	Yes
AQSR13	Lakeview	23.21	0.30	2	Yes
AQSR14	Odendaalsrus	0.33	0.05	0	Yes
AQSR15	Rheederpark	16.33	0.26	3	Yes
AQSR16	Seemeeu Park	27.40	0.31	2	Yes
AQSR17	St Helena	12.49	0.20	3	Yes
AQSR18	Bedelia Primary School	28.37	0.32	3	Yes
AQSR19	St Andrew's School	15.16	0.20	2	Yes
AQSR20	St Helena School	14.68	0.21	3	Yes
AQSR21	Welkom Gymnasium School	26.87	0.26	2	Yes
AQSR22	Welkom Preparatory School	40.41	0.39	3	Yes
AQSR23	Mediclinic Welkom Hospital	38.94	0.36	2	Yes
AQSR24	St Helena Private Hospital	14.38	0.20	2	Yes
AQSR25	Welkom Sub-Acute Hospital	40.00	0.38	3	Yes

Table 16: Simulated AQSR dustfall rates (in mg/m²/day) due to Project operations

Project Operations		
AQSRs	**Name**	**30-day average**
	NDCR	**600**
AQSR1	Farmstead 1	36.91
AQSR2	Farmstead 2	60.74
AQSR3	Farmstead 3	36.55
AQSR4	Farmstead 4	41.51
AQSR5	Farmstead 5	59.00
AQSR6	Farmstead 6	24.45
AQSR7	Farmstead 7	19.49
AQSR8	Farmstead 8	118.52
AQSR9	Farmstead 9	3.45
AQSR10	Bedelia	67.23
AQSR11	Flamingo Park	24.12
AQSR12	Jim Fouche Park	46.21
AQSR13	Lakeview	64.58
AQSR14	Odendaalsrus	2.76
AQSR15	Rheederpark	41.29
AQSR16	Seemeeu Park	72.35
AQSR17	St Helena	45.80
AQSR18	Bedelia Primary School	76.20
AQSR19	St Andrew's School	45.34
AQSR20	St Helena School	47.39
AQSR21	Welkom Gymnasium School	50.41
AQSR22	Welkom Preparatory School	101.77
AQSR23	Mediclinic Welkom Hospital	94.11
AQSR24	St Helena Private Hospital	44.11
AQSR25	Welkom Sub-Acute Hospital	99.62

4.3 Effect of Particulate Matter on Vegetation

Since plants are constantly exposed to air, they are the primary receptors for both gaseous and particulate pollutants of the atmosphere. In terrestrial plant species, the enormous foliar surface area acts as a natural sink for pollutants especially the particulate ones. Vegetation is an effective indicator of the overall impact of air pollution particularly in context of PM (Rai, 2016).

There are two main types of direct injury that PM pollution can cause on plants: acute and chronic injury. Acute injury results from exposure to a high concentration of gas for a relatively short period and is manifested by clear visible symptoms on the foliage, often in the form of necrotic lesions. While this type of injury is very easy to detect (although not necessarily to diagnose), chronic injury is subtler: it results from prolonged exposure to lower gas concentrations and takes the form of growth and/or yield reductions, often with no clear visible symptoms. Plants that are constantly exposed to environmental pollutants absorb, accumulate and integrate these pollutants into their systems. It is reported that depending on their sensitivity level, plants show visible changes which would include alteration in the biochemical processes or accumulation of certain metabolites (Rai, 2016). Pollutants can cause leaf injury, stomatal damage (Ricks and Williams, 1974; Hirano et al., 1995;

Naidoo and Chirkoot, 2004; Harmens et al., 2005), premature senescence, decrease photosynthetic activity, disturb membrane permeability (Ernst, 1981; Naidoo and Chirkoot, 2004; Harmens et al., 2005) and reduce growth and yield in sensitive plant species. The long term, low-concentration exposures of air pollution produce harmful impacts on plant leaves without visible injury. Several studies have been conducted to assess the effects of pollution on different aspects of plant life such as overall growth and development, foliar morphology, anatomy, and biochemical changes (Rai, 2016).

Plant leaves are the primary receptors for both gaseous and PM pollutants of the atmosphere. Before these pollutants enter the leaf tissue, they interact with foliar surface and modify its configuration. Dust deposition on leaf surface, consisting of ultra-fine and coarse particles, showed reduction in plant growth through its effect on leaf gas exchange, flowering and reproduction of plants, number of leaves and leaf area, one of the most common driving variables in growth analyses. Reduction in leaf area and leaf number may be due to decreased leaf production rate and enhanced senescence (Rai, 2016). The chemical composition of the dust particles can also affect exposed plant tissue and have indirect effects on the soil pH (Spencer, 2001).

To determine the impact of dust deposition on vegetation, two factors are of importance: (i) Does dust accumulate on vegetation surfaces and if it does, what are the factors influencing the rate of deposition, and (ii) Once the dust has been deposited, what is the impact of the dust on the vegetation? Regarding the first question, there is adequate evidence that dust does accumulate on all types of vegetation. Any type of vegetation causes a change in the local wind fields, increasing turbulence and enhancing the collection efficiency. Vegetation structure alters the rate of dust deposition such that the larger the “collecting elements” (branches and leaves), the lower the impaction efficiency per element. Therefore, for the same volume of tree/shrub canopy, finer leaves will have better collection efficiencies. However, the roughness of the leaves themselves, in particular the presence of hairs on the leaves and stems, plays a significant role, with venous surfaces increasing deposition of 1-5 µm particles by up to seven-times compared to smooth surfaces. Collection efficiency rises rapidly with particle size; wind tunnel studies show a relationship of deposition velocity on the fourth power of particle size for moderate wind speeds (Tiwary and Colls, 2010). Wind tunnel studies also show that windbreaks or “shelter belts” of three rows of trees have a decrease of between 35 and 56% of the downwind mass transport of inorganic particles.

After deposition onto vegetation, the effect of particulate matter depends on the composition of the dust. South African ambient standards are set in terms of $PM_{2.5}$ and PM_{10} but internationally it is recognised that there are major differences in the chemical composition of the fine PM (the fraction between 0 and 2.5 µm in aerodynamic diameter) and coarse PM (the fraction between 2.5 µm and 10 µm in aerodynamic diameter). The former is often the result of chemical reactions in the atmosphere, whereas the latter often consists of primary particles due to abrasion, crushing, soil disturbances and wind erosion (Grantz, Garner, & Johnson, 2003).

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

Exposure to a given concentration of airborne PM may therefore lead to widely differing phytotoxic responses, depending on the mix of the deposited particles. Most documented toxic effects indicate responses to the chemical composition of the particles. Direct effects have most often been observed around heavily industrialised point sources, but even there, effects are often associated with the chemistry of the particulate rather than with the mass of particulate. Little direct evidence of the effects of dust-fall on South African vegetation, including crops, exists.

While there is little direct evidence of the impact of dustfall on vegetation in the South African context, a review of European studies has shown the potential for reduced growth and photosynthetic activity in sunflower and cotton plants exposed to dust fall rates greater than 400 mg/m²-day (Farmer, 1993). In addition, there is anecdotal evidence to indicate that over extended periods, high dustfall levels in grazing lands can soil vegetation and this can impact the teeth of livestock (Farmer, 1993).

The baseline and project impacts on vegetation are illustrated in Figure 13 and Figure 18 respectively, with the green impact area showing plant exposure to dust fall rates greater than 400 mg/m²-day.

4.4 Impact Significance Rating

The significance of environmental air quality impacts due to the proposed project was assessed according to the methodology adopted by EIMS (Appendix A).

Table 17: Significance rating for potential air quality impacts due to the construction phase

Impact Name	**Increase in air quality impacts due to construction of the TSF**				
Alternative	NA				
Phase	Construction				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	3
Extent of Impact	3	2	Reversibility of Impact	2	2
Duration of Impact	2	2	Probability	4	3
Environmental Risk (Pre-mitigation)					-10.00
Mitigation Measures					
○ Air quality impacts during construction would be reduced through basic control measures such as limiting the speed of haul trucks; limit unnecessary travelling of vehicles on untreated roads; and to apply water sprays on regularly travelled, unpaved sections. ○ When haul trucks need to use public roads, the vehicles need to be cleaned of all mud and the material transported must be covered to minimise windblown dust.					
Environmental Risk (Post-mitigation)					-6.75
Degree of confidence in impact prediction:					Medium
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.13
Final Significance					-7.90

Table 18: Significance rating for potential air quality impacts due to the operational phase

Impact Name	**Increase in air quality impacts due to the operation of Valley TSF**				
Alternative	NA				
Phase	Operations				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	2
Extent of Impact	3	3	Reversibility of Impact	4	3
Duration of Impact	4	4	Probability	3	3
Environmental Risk (Pre-mitigation)					-10.5
Mitigation Measures					
In assessing the mitigated impact, it was assumed that the slopes of the TSF was vegetated, and a control efficiency of 80% as measured by Blight (1989) was achieved. Mitigation measures are detailed in Section 5.					
Environmental Risk (Post-mitigation)					-9.00
Degree of confidence in impact prediction:					Medium
Impact Prioritisation					
Public Response					2
Issue has received a meaningful and justifiable public response					
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.17
Final Significance					-10.53

Table 19: Significance rating for potential air impacts due to the decommissioning and closure phase of the project

Impact Name	**Increase in air quality impacts due to decommissioning and closure**				
Alternative	NA				
Phase	Decommissioning				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	3
Extent of Impact	3	2	Reversibility of Impact	2	2
Duration of Impact	2	2	Probability	4	3
Environmental Risk (Pre-mitigation)					-10.00
Mitigation Measures					
During construction of the vegetative cover, earth and civil works are likely to generate vehicle and wind entrained dust from deposition of material on the TSF. Although the impact is likely to be site-specific, dust suppression techniques such as wetting roads, or application of dust palliatives, are required.					
Environmental Risk (Post-mitigation)					-6.75
Degree of confidence in impact prediction:					Medium
Impact Prioritisation					
Public Response					1
Low: Issue not raised in public responses					
Cumulative Impacts					1
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1.00
Final Significance					-6.75

5 DUST MANAGEMENT PLAN

A Dust Management Plan (DMP) for the Valley operations should follow an iterative process, including: implementation, monitoring, reporting, reviewing and adjustment to the necessary steps. The following sections of this DMP aim to detail the starting point with regards to fugitive dust emissions management. Included below are the definition of objectives and targets to achieve through dust suppression strategies. Monitoring, reporting, and review allow for the assessment of operations and adjustment of implemented strategies to meet objectives.

5.1 Objectives and Targets

The establishment of objectives and targets with regards to fugitive emissions are important to minimise the impacts of these emissions on the surrounding environment. The objective of the DMP generally is to reduce dust emissions within specific target ranges, by employing appropriate dust suppression strategies.

Operational activities due to the Valley operation considered to be significant sources of dust emissions are:

1. Windblown dust from the TSF.

5.2 Dust Management Measures

Target control efficiencies are presented for the main dust emission sources identified in the emissions inventory, so that the overall objective is achieved.

5.2.1 Wind Erosion

Any approach that either binds the particles together and make it more resistant to wind erosion or reduce to the force of the wind will result in a reduction in windblown dust emissions.

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

Substantial research has been done on erosion from gold mine tailings. Parameters which have the potential to impact on the rate of emission of fugitive dust include the extent of surface compaction, moisture content, ground cover, the shape of the storage pile, particle size distribution, wind speed and precipitation. Any factor that binds the erodible material, or otherwise reduces the availability of erodible material on the surface, decreases the erosion potential of the fugitive source. High moisture contents, whether due to precipitation or deliberate wetting, promote the aggregation and cementation of fines to the surfaces of larger particles, thus decreasing the potential for dust emissions. Surface compaction and ground cover similarly reduces the potential for dust generation (Burger *et al*., 1997).

Rock cladding or armouring of the sides of tailings dams has been shown in various international studies to be effective in various instances in reducing wind erosion of slopes. Cases in which rock cladding has been found to be effective in this regard generally involve rock covers of greater than 0.5 m in depth (Ritcey, 1989; Jewell and Newson, 1997). The application of a 300 mm layer of fine rock was found to be the most successful of the non-vegetative measures, resulting in an erosion control efficiency of 90% if the base is levelled and compacted – wind erosion is considered to reduce by 100% through the addition of such a rock cover.

In addition, screens could be installed on the crest of the tailings dam walls mainly to act as windbreaks and to reduce the potential for dust deposition on the vegetated side walls, hence curbing the growth of the grass.

Vegetal cover retards erosion by binding the residue with a root network, by sheltering the residue surface and by trapping material already eroded. Sheltering occurs by reducing the wind velocity close to the surface, thus reducing the erosion potential and volume of material removed. Vegetation is also considered the most effective control measure in terms of its ability to also control water erosion. In investigating the feasibility of vegetation types the following properties are normally taken into account: indigenous plants; ability to establish and regenerate quickly; proven effective for reclamation elsewhere; tolerant to the climatic conditions of the area; high rate of root production; easily propagated by seed or cuttings; and nitrogen-fixing ability. The long-term effectiveness of suitable vegetation selected for the site will be dependent on (a) the nature of the cover, and (b) the availability of aftercare. Multi-layer covers are frequently being used to ensure the best results (Dixon, 1997; Jewell and Newson, 1997; Ritchey, 1989). Erosion losses from grassed slopes measured by Blight (1989) was found to be in the order of 100 t/ha/year compared to uncontrolled slopes from which losses of up to 500 t/ha/year were recorded.

The removal of the TSF would be the most effective mitigation measure, providing the exposed footprint be vegetated and rehabilitated.

In assessing the mitigated impact, it was assumed that the slopes of the TSF was vegetated, and a control efficiency of 80% as measured by Blight (1989) was achieved.

5.3 Performance Indicators

Key performance indicators against which progress of implemented mitigation and management measures 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 (source monitoring) and the impact on the receiving environment (ambient air quality monitoring). Ensuring that no visible evidence of windblown dust exists represents an example of a source-based indicator, whereas maintaining off-site dustfall levels, at the identified AQSRs, to below 600 mg/m²-day represents an impact- or receptor-based performance indicator.

Source monitoring at operational activities can be challenging due to the fugitive and wind-dependent nature of particulate emissions. The focus is therefore rather on receptor-based performance indicators i.e. compliance with ambient air quality standards and dustfall regulations.

5.3.1 Ambient Air Quality Monitoring

It is recommended that the current dustfall monitoring network be maintained, with the possible addition of two dustfall buckets 2 km to the west and 1 km to the southeast of the new Valley TSF to monitor the impact on vegetation, and the monthly dustfall results used as indicators to tract the effectiveness of the applied mitigation measures. Dustfall collection should follow the ASTM method as per the NDCRs. The ASTM method covers the procedure of collection of dustfall and its measurement and employs a simple device consisting of a cylindrical container exposed for one calendar month (30 ±2 days). The method provides for a dry bucket, which is advisable in the dry environment.

The cause of the high dustfall rates (section 3.3.2) should be investigated and these levels should be reduced to be within compliance with the NDCR.

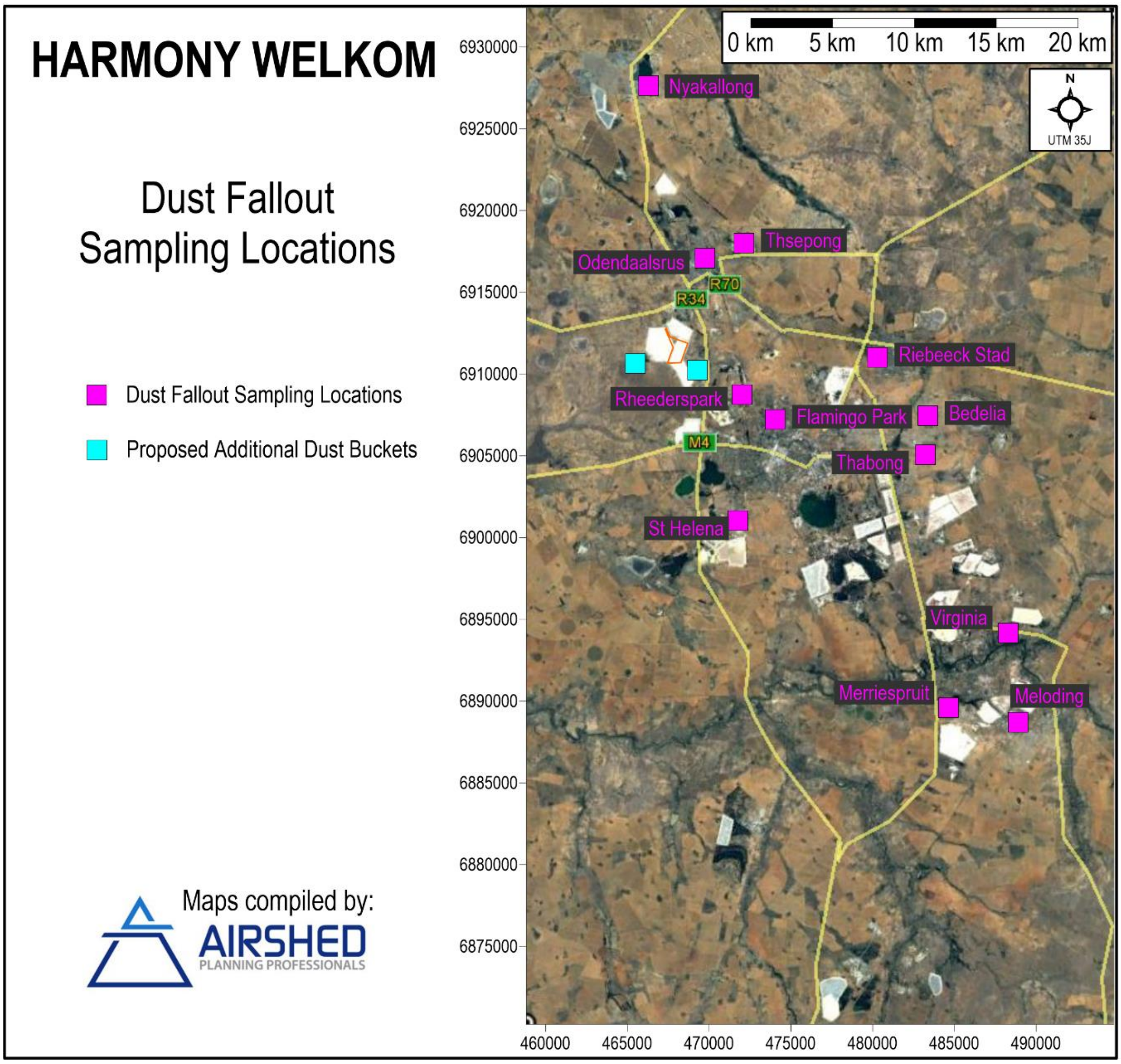

Figure 19: Proposed additional dust buckets to monitor impact on vegetation

5.3.2 Periodic Inspections and Audits

Periodic inspections and external audits are essential for progress measurement, evaluation, and reporting purposes. It is recommended that site inspections and progress reporting be undertaken at regular intervals (at least quarterly), with annual environmental audits being conducted. Annual environmental audits should be continued at least until closure. Results from site inspections and monitoring efforts should be combined to determine progress against source- and receptor-based performance indicators. Progress should be reported to all interested and affected parties (I&APs), including authorities and persons affected by pollution.

The criteria to be taken into account in the inspections and audits must be made transparent by way of minimum requirement checklists included in the management plan. 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.

5.3.3 Liaison Strategy for Communication with Interested and Affected Parties (I&APs)

Stakeholder forums provide possibly the most effective mechanisms for information dissemination and consultation. Management plans should stipulate specific intervals at which forums will be held and provide information on how people will be notified of such meetings. Given the proximity of the study site to the nearby communities and farmsteads, it is recommended that such meetings be scheduled and held at least on an annual basis. A complaints register must be kept at all times.

5.3.4 Financial Provision

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&APs 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.

6 CONCLUSIONS

The main findings from the air quality assessment study are as follows:

- The receiving environment:
  - The area is dominated by winds from the north to east, followed by northerly and easterly winds, with an average wind speed of 3.5 m/s and calm conditions occurring for 8.5% of the time.
  - Ambient air pollutant levels in the project area are currently affected by the following sources of emission: agricultural activities, gold mining and ore processing, fugitive and process emissions, vehicle tailpipe emissions, household fuel combustion, biomass burning and windblown dust from exposed areas.
  - AQSRs include residential areas, farmsteads, schools and hospitals. The closest towns in the immediate region of the project include Welkom and its suburbs (located about 3.7 km southeast of the project boundary) and Odendaalsrus (located about 3 km northeast of the project boundary).

- Impact of the Project:
  - Construction Phase Impacts:
    - Impacts were assessed qualitatively by taking into consideration the likely air quality impacts that may arise due to construction activities.
    - Resulting potential air quality health and nuisance impacts were assessed to have **Medium** significance without mitigation and **Low** significance with mitigation. The final environmental significance rating is **Low**.
  - Operational Phase Impacts:
    - Impacts were assessed by taking into consideration the cumulative impact from existing sources (ventilation shafts and windblown dust from the existing tailings storage facilities and WRDs within the study domain) and the proposed Valley TSF.
    - Simulated PM_{10} and $PM_{2.5}$ concentrations due to baseline operations were well within NAAQS at the closest identified sensitive receptors. The simulated dust deposition was within NDCR for residential areas at the closest sensitive receptors.
    - Simulated PM_{10} concentrations due to project operations were within the daily PM_{10} NAAQS at all of the identified sensitive receptors, as were simulated $PM_{2.5}$ concentrations within the post-2030 daily $PM_{2.5}$ NAAQS at all sensitive receptors. Annual average PM_{10} and $PM_{2.5}$ concentrations were within the respective NAAQSs at all receptors. The simulated dust deposition was within NDCR for residential areas at the closest sensitive receptors.
    - The environmental risk due to both unmitigated and mitigated operations is classified as **Medium,** although affecting a smaller area with mitigation in place. The final environmental significance rating is **Medium**.
  - Decommissioning Phase Impacts:
    - Impacts were assessed qualitatively by taking into consideration the likely air quality impacts that may arise due to decommissioning and closure activities.
    - Resulting potential air quality health and nuisance impacts were assessed to have **Medium** significance without mitigation and **Low** significance with mitigation. The final environmental significance rating is **Low**.

In conclusion, it is the specialist opinion that the project may be authorised provided that the recommended air quality management measures are implemented. These air quality management measures include:

- Dustfall monitoring ensuring dustfall rate in compliance with the NDCR limits; and
- Mitigation measures aimed at reducing emissions at source, i.e. the grassing of TSF side slopes.

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8 Appendix A – Impact Significance Rating Methodology

The impact assessment methodology is guided by the requirements of the NEMA EIA Regulations (2010). The broad approach to the significance rating methodology is to determine the environmental risk (ER) by considering the consequence (C) of each impact (comprising Nature, Extent, Duration, Magnitude, and Reversibility) and relate this to the probability/likelihood (P) of the impact occurring. This determines the environmental risk. In addition, other factors, including cumulative impacts, public concern, and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF) which is applied to the ER to determine the overall significance (S).

Determination of Environmental Risk:

The significance (S) of an impact is determined by applying a prioritisation factor (PF) to the environmental risk (ER). The environmental risk is dependent on the consequence (C) of the particular impact and the probability (P) of the impact occurring. Consequence is determined through the consideration of the Nature (N), Extent (E), Duration (D), Magnitude (M), and reversibility (R) applicable to the specific impact.

For the purpose of this methodology the consequence of the impact is represented by:

$$C = \frac{(E+D+M+R)}{4} \times N$$

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in Table 20.

Table 20: Criteria for determining impact consequence

Aspect	Score	Definition
Nature	- 1	Likely to result in a negative/ detrimental impact
	+1	Likely to result in a positive/ beneficial impact
Extent	1	Activity (i.e. limited to the area applicable to the specific activity)
	2	Site (i.e. within the development property boundary),
	3	Local (i.e. the area within 5 km of the site),
	4	Regional (i.e. extends between 5 and 50 km from the site
	5	Provincial / National (i.e. extends beyond 50 km from the site)
Duration	1	Immediate (<1 year)
	2	Short term (1-5 years),
	3	Medium term (6-15 years),
	4	Long term (the impact will cease after the operational life span of the project),
	5	Permanent (no mitigation measure of natural process will reduce the impact after construction).
Magnitude/ Intensity	1	Minor (where the impact affects the environment in such a way that natural, cultural and social functions and processes are not affected),
	2	Low (where the impact affects the environment in such a way that natural, cultural and social functions and processes are slightly affected),
	3	Moderate (where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way),
	4	High (where natural, cultural or social functions or processes are altered to the extent that it will temporarily cease), or
	5	Very high / don't know (where natural, cultural or social functions or processes are altered to the extent that it will permanently cease).

Aspect	Score	Definition
Reversibility	1	Impact is reversible without any time and cost.
	2	Impact is reversible without incurring significant time and cost.
	3	Impact is reversible only by incurring significant time and cost.
	4	Impact is reversible only by incurring prohibitively high time and cost.
	5	Irreversible Impact

Once the C has been determined the ER is determined in accordance with the standard risk assessment relationship by multiplying the C and the P (Table 22). Probability is rated/scored as per Table 21.

Table 21: Probability scoring

Probability	1	Improbable (the possibility of the impact materialising is very low as a result of design, historic experience, or implementation of adequate corrective actions; <25%),
	2	Low probability (there is a possibility that the impact will occur; >25% and <50%),
	3	Medium probability (the impact may occur; >50% and <75%),
	4	High probability (it is most likely that the impact will occur- > 75% probability), or
	5	Definite (the impact will occur)

The result is a qualitative representation of relative ER associated with the impact. ER is therefore calculated as follows:

ER= C x P

Table 22: Determination of environmental risk

Consequence	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
	Probability					

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25. These ER scores are then grouped into respective classes as described in Table 23.

Table 23: Significance classes

Environmental Risk Score	
Value	**Description**
< 9	Low (i.e. where this impact is unlikely to be a significant environmental risk),
≥9; <17	Medium (i.e. where the impact could have a significant environmental risk),
≥ 17	High (i.e. where the impact will have a significant environmental risk).

The impact ER will be determined for each impact without relevant management and mitigation measures (pre-mitigation), as well as post implementation of relevant management and mitigation measures (post-mitigation). This allows for a prediction in the degree to which the impact can be managed/mitigated.

Impact Prioritisation:

In accordance with the requirements of Regulation 31 (2)(l) of the EIA Regulations (GNR 543), and further to the assessment criteria presented in the Section above it is necessary to assess each potentially significant impact in terms of:

- Cumulative impacts; and
- The degree to which the impact may cause irreplaceable loss of resources.

In addition, it is important that the public opinion and sentiment regarding a prospective development and consequent potential impacts is considered in the decision-making process.

In an effort to ensure that these factors are considered, an impact prioritisation factor (PF) will be applied to each impact ER (post-mitigation). This prioritisation factor does not aim to detract from the risk ratings but rather to focus the attention of the decision-making authority on the higher priority/significance issues and impacts. The PF will be applied to the ER score based on the assumption that relevant suggested management/mitigation impacts are implemented.

Table 24: Criteria for determining prioritisation

Public response (PR)	Low (1)	Issue not raised in public response.
	Medium (2)	Issue has received a meaningful and justifiable public response.
	High (3)	Issue has received an intense meaningful and justifiable public response.
Cumulative Impact (CI)	Low (1)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.
	Medium (2)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.
	High (3)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/definite that the impact will result in spatial and temporal cumulative change.
Irreplaceable loss of resources (LR)	Low (1)	Where the impact is unlikely to result in irreplaceable loss of resources.
	Medium (2)	Where the impact may result in the irreplaceable loss (cannot be replaced or substituted) of resources but the value (services and/or functions) of these resources is limited.
	High (3)	Where the impact may result in the irreplaceable loss of resources of high value (services and/or functions).

The value for the final impact priority is represented as a single consolidated priority, determined as the sum of each individual criteria represented in Table 24. The impact priority is therefore determined as follows:

Priority = PR + CI + LR

The result is a priority score which ranges from 3 to 9 and a consequent PF ranging from 1 to 2 (refer to Table 25).

Table 25: Determination of prioritisation factor

Priority	Ranking	Prioritisation Factor
3	Low	1
4	Medium	1.17
5	Medium	1.33
6	Medium	1.5
7	Medium	1.67
8	Medium	1.83
9	High	2

In order to determine the final impact significance the PF is multiplied by the ER of the post mitigation scoring (Table 26). The ultimate aim of the PF is to be able to increase the post mitigation environmental risk rating by a full ranking class, if all the priority attributes are high (i.e. if an impact comes out with a medium environmental risk after the conventional impact rating, but there is significant cumulative impact potential, significant public response, and significant potential for irreplaceable loss of resources, then the net result would be to upscale the impact to a high significance).

Table 26: Final environmental significance rating

Environmental Significance Rating	
Value	**Description**
< 10	Low (i.e. where this impact would not have a direct influence on the decision to develop in the area),
≥10 <20	Medium (i.e. where the impact could influence the decision to develop in the area),
≥ 20	High (i.e. where the impact must have an influence on the decision process to develop in the area).