Air Quality Impact Assessment for the Twin Hills Gold Project near Karibib in Namibia

Project done for **Environmental Compliance Consultancy (ECC)**

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Revision Record

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Rev 0	25 August 2021	Draft report	Submitted to client for review
Rev 1	10 November 2022	Final report	Addressed client comments

Abbreviations

ADMS	Air Dispersion Modelling System
AQG	Air Quality Guidelines
AQIA	Air Quality Impact Assessment
AQMP	Air Quality Management Plan
AQO	Air Quality Objectives
AQSRs	Air Quality Sensitive Receptors
ASTM	American Society for Testing and Materials standard method
CERC	Cambridge Environmental Research Consultants
CIL	Carbon-in-Leach
CO	carbon monoxide
CO_2	carbon dioxide
CS_2	carbon disulphide
EAADT	estimated annual average daily traffic
EC	European Community
EHS	Environmental, Health and Safety
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EQOs	Environmental Quality Objectives
FEL	front-end-loaders
GHG	greenhouse gas
GIIP	Good International Industry Practice
GLCs	ground level concentrations
H_2SO_4	sulphuric acid
HCl	Hydrochloric acid
HCN	cyanide
HSE	UK Health and Safety Executive
IFC	International Finance Corporation
IT	interim target
LOM	life of mine
mamsl	mean sea level
NAAQS	National Ambient Air Quality Standards
NDCR	National Dust Control Regulations
NOx	oxides of nitrogen
NPI	Australian National Pollutant Inventory
PAH	polycyclic aromatic hydrocarbons
PEA	Preliminary Economic Assessment
PM	Particulate Matter
PM_{10}	Particulate matter with an aerodynamic diameter of less than 2.5 µm (thoracic particles)
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 10 µm (respirable particles)
PSD	particle size distribution
RA	Roads Authority
ROM	Run-of-Mine
SA	South African
SEA	Strategic Environmental Assessment
SEMP	Strategic Environmental Management Plan

SEPA	Scottish Environmental Protection Agency
SO_2	sulfur dioxide
TEQ	toxic equivalent quantities
TOC	Total Organic Compounds
TSF	tailings storage facility
TSP	Total Suspended Particulates
TVOC	Total Volatile Organic Compounds
UK	United Kingdom
US	United States
VKT/day	vehicle kilometres travelled per day
VOCs	Volatile Organic Compounds
WBG	World Bank Group
WHO	World Health Organisation
WRDs	waste rock dumps
WRD1/TSF	waste rock / TSF co-disposal dump

Units

°C	Degree Celsius
Gg CO_2-eq	Greenhouse gas carbon dioxide equivalent
K	Kelvin
km	kilometre
kPa	kilo pascal
m	metres
mm	millimetre
mg/m²/day	milligram per metre squared per day
t	ton
tpa	tons per annum
tpm	tons per month
µg/m³	microgram per cubic metre
%	percent

Glossary

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

Atmospheric emission: means any emission or entrainment process emanating from a point, non-point or mobile sources that result in air pollution.

Averaging period: This implies a period of time over which an average value is determined.

Dust: Solid materials suspended in the atmosphere in the form of small irregular particles, many of which are microscopic in size.

Frequency of Exceedance: A frequency (number/time) related to a limit value representing the tolerated exceedance of that limit value, i.e. if exceedances of limit value are within the tolerances, then there is still compliance with the standard.

Particulate Matter (PM): These comprise a mixture of organic and inorganic substances, ranging in size and shape and can be divided into coarse and fine particulate matter. The former is called Total Suspended Particulates (TSP), whilst PM_{10} and $PM_{2.5}$ fall in the finer fraction referred to as Inhalable particulate matter.

TSP: Total suspended particulates refer to all airborne particles and may have particle sizes as large as 150 µm, depending on the ability of the air to carry such particles. Generally, suspended particles larger than 75 to 100 micrometre (µm) do not travel far and deposit close to the source of emission.

PM_{10}: Thoracic particulate matter is that fraction of inhalable coarse particulate matter that can penetrate the head airways and enter the airways of the lung. PM_{10} consists of particles with a mean aerodynamic diameter of 10 µm or smaller, and deposit efficiently along the airways. Particles larger than a mean size of 10 µm are generally not inhalable into the lungs. These PM_{10} particles are typically found near roadways and dusty industries.

$PM_{2.5}$: Respirable particulate fraction is that fraction of inhaled airborne particles that can penetrate beyond the terminal bronchioles into the gas-exchange region of the lungs. Also known as fine particulate matter, it consists of particles with a mean aerodynamic diameter equal to or less than 2.5 µm ($PM_{2.5}$) that can be inhaled deeply into the lungs. These particles can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air.

Point sources: are discrete, stationary, identifiable sources of emissions that release pollutants to the atmosphere (International Finance Corporation (IFC), 2007).

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

Executive Summary

Osino Resources Corp (Osino) plans to develop a new gold mine, called the Twin Hills Gold Project (the Project), outside of Karibib in the Erongo Region of Namibia.

Mining will comprise of opencast mining operations, a processing plant, and waste facilities. Conventional mining methods such as drilling, blasting and excavation are used at two open pit areas: Twin Hills & Bulge and Clouds. Ore and waste will be removed with haul trucks and taken to the Run of Mine (RoM) stockpile area and waste rock dumps (WRDs), respectively. Ore will be crushed at a primary crusher where after it will undergo secondary crushing and milling at the processing plant. The waste from the processing plant will be sent to the tailings storage facility (TSF), which will be a co-disposal of waste rock and tailings material. Ore production is estimated at 3.5 million tonnes per annum (mtpa), realising a total production of 50.39 million tons over the life of mine (LOM) which is estimated at 15 years.

Airshed Planning Professionals (Pty) Ltd (Airshed) was appointed by Environmental Compliance Consultancy (ECC) to conduct an air quality impact assessment study as part of the Project Environmental Impact Assessment (EIA).

The main objective of the investigation was to quantify the potential air quality impacts resulting from the proposed activities on the surrounding environment and human health. As part of the air quality assessment, 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 current and potential future activities resulting in air quality related impacts.

The scope of work (SoW) included the review of technical information and legislative context relevant to Namibia. A baseline assessment was required to get an understanding of the receiving environment, looking at existing sources of air pollution and the status of air quality within the region, as well as sensitive receptors in the form of human settlements. Site specific meteorological data was available for a 12-month period (23 July 2020 to 22 July 2021) to determine the dispersion potential of the site, influencing the spreading and removal of air pollution. To determine the potential impacts from the proposed mining operations, an emissions inventory had to be established accounting for all sources of air pollution associated with the mining activities (open pit, and processing operations). Emissions were based on the process description and mine layout plan as provided and were quantified for two operational years representing the two open pit areas with the highest mining rates (i.e. mining year 7 and 10). The ADMS 5 dispersion model was used to simulate the expected impacts from these emission sources, with the simulated particulate matter ground level concentrations (GLCs) and dustfall rates screened against the applicable air quality guidelines and standards to determine the significance of the proposed project on the receiving environment. Once the significance of these impacts has been established, the main contributing sources could be identified, and mitigation measures defined to ensure reduced impacts from these activities.

Baseline Characterisation

The Project covers an area with dimensions of about 25 km northeast-southwest and 11 km north-south. The terrain is hilly, with a ridge to the north and northwest, and a ridge on the southern side. There are no villages or homesteads near the project, with the closest settlement – farmhouses – directly to the south of Twin Hills & Bulge pit, and one at the proposed Processing Plant (this one is assumed to be relocated). The town of Karibib (and Usab suburb) is located about 3.5 km to the southwest from the site boundary. Other settlements in the vicinity include scattered homesteads to the north of the mine boundary, along the Khan River.

The on-site weather data available for the period 23 July 2020 – 22 July 2021, which provided the following understanding of the conditions in the area:

- The wind field is dominated by winds from the southwest and the east to south-east, with the strongest winds from the southwest. During the day, easterly winds prevailed with strong but less frequent winds from the southwest, and at night the wind field shifted to the southwest. Calm conditions were recorded for 7.5% of the time with a period average wind speed of 2.3 m/s. Higher wind speeds occurred during the night, with the strongest winds recorded from the southwest. A maximum wind speed of 8.9 m/s were recorded.
- Monthly variation in the wind field showed more frequent south-westerly winds during the summer months and a shift to easterly winds in May, and then to the southeast in April until July – the so called "east-winds". Winds from the northwest prevailed during August, whereafter it shifted to the southwest in September with a remaining easterly component.
- Maximum, minimum, and mean temperatures were given as 42°C, -3°C and 23°C respectively from the Twin Hills weather station for the period 23 July 2020 – 22 July 2021.
- Rainfall over the 12-month period totalled 254 mm, with the highest rainfall month January 2021 (115 mm).

The main pollutant of concern in the region is particulate matter (TSP; PM_{10} and $PM_{2.5}$) resulting from vehicle entrainment on the roads (paved, unpaved and treated surfaces), windblown dust, and mining and exploration activities. Gaseous pollutants such as SO_2, NOx, CO and CO_2 would result from vehicles and combustion sources, but these are expected to be at low concentrations due to the few sources in the region.

Sources of atmospheric emissions in the vicinity of the proposed Project include:

- Vehicle entrainment from roads: The national road to the south (B2) of the Project is the main road between Windhoek and Swakopmund, and one of the roads in the region with the highest traffic counts. paved road with vehicle entrainment calculated to be a significant contributor to the regional paved road $PM_{2.5}$ and PM_{10} emissions. The C33, is a paved road connecting the Karibib Airport to the B2, and although no information was available for this road, it is expected to have very low traffic counts and low $PM_{2.5}$ and PM_{10} emissions.
- Windblown dust: Windblown particulates from natural exposed surfaces, mine waste facilities, and product stockpiles can result in significant dust emissions with high particulate concentrations near the source locations, potentially affecting both the environment and human health. Windblown dust from natural exposed surfaces in and at the Project is only likely to result in particulate matter emissions under high wind speed conditions (>10 m/s), and since recorded wind speeds did not exceed 10 m/s, this source is likely to be of low significance.
- Mines and Exploration operations: Pollutants typically emitted from mining and quarrying activities are particulates, with smaller quantities associated with vehicle exhaust emissions. Mining and quarrying activities, especially open-cast mining methods, emit pollutants near ground-level over (potentially) large areas. Mines in proximity to the proposed Project are Navachab Gold Mine located west-southwest of Karibib, approximately 20 km from the Project site, and a number of marble quarries – Capra Hill, Dreamland and Savanna Marble.
- Regional transport of pollutants: regional-scale transport of mineral dust and ozone (due to vegetation burning) from the north of Namibia is a significant contributing source to background PM concentrations.

A dustfall monitoring network comprising of eight (8) single dustfall units are in place at the Project, with dustfall data available for the period June 2020 to June 2021. Dustfall rates were generally low for the sampling period and well within the dustfall limit of 600 mg/m²/day (adopted limit for residential areas) and 1 200 mg/m²/day (adopted limit for non-residential areas). Dustfall rates were the lowest during the months of June to September 2020 and might have been influenced by the regional lockdown due to COVID-19. The highest dustfall of 520 mg/m²/day was collected at AQ-02 in March 2021. The dustfall results show no clear spatial trend.

Impact Assessment

A quantitative air quality impact assessment was conducted for the operational phase activities of the proposed Project. Construction, closure, and post-closure activities were assessed qualitatively. The assessment included an estimation of atmospheric emissions, the simulation of pollutant concentrations and determination of the significance of impacts.

Construction normally comprises a series of different operations including land clearing, topsoil removal, road grading, material loading and hauling, stockpiling, grading, bulldozing, compaction, etc., with particulate matter the main pollutants of concern from these activities. 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, and how close these activities are to AQSRs. Due to the intermittent nature of construction operations, the impacts are expected to have a small but potentially harmful impact at the nearby AQSRs (#1 and #2) depending on the level of activity. With mitigation measures in place these impacts are expected to be low.

Operational Phase:

- Two mining scenarios were assessed to determine the worst-case impacts, based on the mining rates as well as hauling distances from the open pits to the ROM pad and WRDs. The two scenarios assessed are:
  - Operational Year 7 (Scenario 1) – representative of maximum throughput from Clouds pit of 1.85 mtpa of ore, and 0.32 mtpa from Twin Hills & Bulge, and a total of 22.89 mtpa of waste rock.
  - Operational Year 10 (Scenario 2) – representative of maximum throughput from Twin Hills & Bulge pits of 4.25 mtpa of ore and 20.75 mtpa of waste.
- Emissions quantified for the proposed Project were restricted to fugitive releases (non-point releases) with particulates the main pollutant of concern. Gaseous emissions (i.e. SO_2, NOx, CO and VOCs) will primarily result from diesel combustion, both from mobile and stationary sources, with point-source releases limited to the Kiln stack, Roaster/ Dryer stack, and Furnace stack. Emissions were quantified based on provided information on mining rates, mine layout plan and estimated fuel consumption.
  - Quantified PM (TSP, PM_{10} and $PM_{2.5}$) emissions were higher for Scenario 2 (Year 10) compared to Scenario 1 (Year 7) due to almost double the ore to be mined during Year 10 compared to Year 7, thus resulting in more truck trips and higher emissions. Other activities such as drilling and blasting, materials handling and FEL operations are slightly lower for Scenario 2, with all other activities remaining the same. With the proposed mitigation measures in place, PM emissions would reduce by between 54% and 59%.
  - The main sources of $PM_{2.5}$, PM_{10} and TSP emissions are vehicle entrainment from unpaved haul roads, crushing and screening and a combination of in-pit activities (drilling, materials handling, hauling, etc.).
  - Gaseous emissions were quantified for all mobile combustion sources based on diesel fuel use, with NOx the main gaseous pollutant of concern. Emissions from the point sources could not be quantified due to insufficient stack parameter information.
- For each of the two scenarios, unmitigated and mitigated options were modelling. Mitigation was applied was based on design mitigation measures provided, which included the following:
  - in-pit operations including haul roads, FEL, Bulldozers and Graders: water sprays assuming 50% CE;
  - drilling: water sprays assuming 70% CE;
  - surface haul roads: water sprays combined with chemical suppressant on resulting in 90% CE;
  - materials handling (loading and unloading ROM and waste rock): water sprays at tip points resulting in 50% CE; and

- crushing and screening of ROM (primary; secondary and tertiary): resulting in 50% CE from water sprays to keep ore wet.

- Dispersion modelling results for Scenario 1 (Year 7):
  - PM_{10} daily GLCs, for unmitigated activities, exceed the 24-hour AQO (WHO IT-3 and SA NAAQS) at the two AQSRs within the site boundary. For mitigated activities, PM_{10} daily GLCs only exceed the AQO at the AQSR located on the southern side of Twin Hills & Bulge Pit. PM_{10} annual GLCs, for both unmitigated and mitigated activities, are within the AQO outside the site boundary.
  - $PM_{2.5}$ daily GLCs, for unmitigated activities, exceed the AQO (WHO IT-3) only at one AQSR located to the south of Twin Hills & Bulge Pit and for a small area on the north-western boundary. For mitigated activities, there are no exceedances outside the site boundary or at any of the AQSRs. There are no exceedances of the annual $PM_{2.5}$ AQO, without and with mitigation in place.
  - Maximum daily dustfall rates, for both unmitigated and mitigated activities, do not exceed the AQO (SA NDCR residential limit of 600 mg/m²/day) at any of the AQSRs or outside the site boundary.

- Dispersion modelling results for Scenario 2 (Year 10):
  - The daily PM_{10} AQO (WHO IT-3 and SA NAAQS) is exceeded towards the north, north-west, west and southeast of the site boundary with no mitigation in place but reduce to smaller areas of exceedance when mitigation is applied. Over an annual average only the unmitigated operations result in exceedances outside the site boundary. Unmitigated PM_{10} GLCs result in exceedances at the two AQSRs located within the site boundary and remains to exceed the daily AQO with mitigation in place, however with fewer exceedances.
  - Unmitigated and mitigated $PM_{2.5}$ GLCs are in exceedance of the daily AQO towards the west, north-west and southeast of the site boundary, but for much smaller areas when mitigation is applied and with no exceedances of the annual AQO. With no mitigation on place, the daily and annual average AQOs are exceeded at AQSR#1, with daily exceedances at AQSR#2. With mitigation measures in place, the concentrations are lower, but still exceeding the daily AQO at AQSR#1.
  - Maximum daily dustfall rates, for both unmitigated and mitigated activities, are within the AQO (SA NDCR residential limit of 600 mg/m²/day) at all of the AQSRs and outside the site boundary.

- Cumulative air quality impacts could not be assessed since no background PM_{10} and $PM_{2.5}$ data are available. The localised PM_{10} and $PM_{2.5}$ impacts from the proposed Project modelling results indicate the potential for low regional cumulative impacts, and only high cumulative impacts in the immediate vicinity of the mine. Off-site impacts are likely to be managed with proper mitigation measures in place.

Closure operations are likely to include demolishing existing structures, scraping and moving surface material to cover the remaining exposed surfaces (WRDs and WRD/TSF) and contouring of the surface areas. The impacts are expected to be similar to that of construction operations – potentially small but harmful impacts at nearby AQSRs (#1 and #2), depending on the level of activity but low impacts with mitigation measures in place. **Post-closure** operations, likely to include vegetation cover maintenance, would result in very low air quality related impacts.

Conclusion

The proposed Project is likely result in $PM_{2.5}$ and PM_{10} ground level concentrations in exceedance of the selected AQOs in the immediate vicinity of the mine, with no mitigation on place but can be reduced to compliance levels with mitigation measures in place. Dustfall rates are likely to be low throughout the life of mine, with gaseous concentrations (SO_2, NO_2 and CO) also expected to result in low air quality impacts. The two AQSRs (farmhouses) located within the mine boundary are likely to be negatively affected by the mining operations, irrespective of mitigation measures applied, and should be relocated.

It is the specialist's opinion that the proposed project could be authorised provided strict enforcement of mitigation measures and the tracking of the effectiveness of these measures to ensure the lowest possible off-site impacts.

Recommendations

Based on the findings from the air quality impact assessment for the Project following recommendations are included:

- Construction and closure phases:
  - 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 applying dust-a-side 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.
  - The access road to the Project site also needs to be kept clean to minimise carry-through of mud on to public roads.
- Operational phases:
  - For the control of vehicle entrained dust a control efficiency (CE) of 90% on unpaved surface roads through the application of chemical surfactants is recommended, with water sprays on the in-pit haul roads to ensure a 50% CE.
  - Drilling operations should be controlled through the application of water sprays at the drill holes ensuring 70% CE.
  - In controlling dust from crushing and screening operations, it is recommended that water sprays be applied to keep the ore wet, to achieve a control efficiency of up to 50%.
  - Mitigation of materials transfer points should be done using water sprays at the tip points. This should result in a 50% control efficiency. Regular clean-up at loading points is recommended.
- Air Quality Monitoring:
  - The current dustfall monitoring network, comprising of eight (8) single dustfall units, should be maintained and the monthly dustfall results used as indicators to tract the effectiveness of the applied mitigation measures. Dustfall collection should follow the ASTM method.

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1 INTRODUCTION

Osino Resources Corp (Osino) plans to develop a new gold mine, called the Twin Hills Gold Project (the Project), outside of Karibib in the Erongo Region of Namibia. The Exclusive Prospecting Licence (EPL) for the Project covers an area of 6 577 km² and falls within the central and northern zones of Namibia's prospective Damara gold belt.

An air quality assessment is required as part of the Environmental Impact Assessment (EIA) for the Project. Airshed Planning Professionals (Pty) Ltd was appointed by Environmental Compliance Consultancy (ECC) to undertake an air quality impact assessment for the proposed Project. The main objective of the investigation is to quantify the potential impacts resulting from the proposed activities on the surrounding environment and human health. As part of the air quality assessment, 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.

The investigation followed the methodology required for a specialist impact assessment report.

1.1 Terms of Work

The baseline assessment includes a study of the receiving environment by referring to:

- A study of legal requirements pertaining to air quality – applicable international legal guidelines and limits and dust control regulations.
- Desktop review of all available project and associated data, including meteorological data, previous air quality assessments, EIAs and technical air quality data and modelled results.
- A study of atmospheric dispersion potential by referring to available on-site weather records for a period of at least one year (required for dispersion modelling), land use and topography data.
    - Details on the physical environment i.e. meteorology (atmospheric dispersion potential), land use and topography.
    - Identification of existing air pollution sources (other mines; industries; commercial operations, etc.).
    - Identification of air quality sensitive receptors (AQSRs), including any nearby residential dwellings and proposed receptors (temporary or permanent workers accommodation site(s)) in the vicinity of the mine.
    - Any freely available ambient air quality data, specifically Particulate Matter (PM).
- An impact assessment, including:
    - Identify all current sources of air pollution in the area (other mines; wildfires; domestic fuel burning; etc.).
    - The compilation of a comprehensive emissions inventory including the identification and quantification of all emissions associated with the proposed mining (open pit, hauling and processing operations).
    - Atmospheric dispersion modelling to simulate ambient air pollutant concentrations and dustfall rates from the project activities.
    - The screening of simulated ambient pollutant concentration levels and dust fallout against ambient air quality guidelines and standards.
- Assessment of the potential air quality impacts on human health and the environment.
- The identification and recommendation of suitable mitigation measures and monitoring requirements.
- The preparation of a comprehensive specialist air quality impact assessment (AQIA) report.

1.2 Project Description

The proposed mine will comprise of opencast mining operations, a processing plant, and waste facilities. Conventional mining methods such as drilling, blasting and excavation are used at two open pit areas: Twin Hills & Bulge and Clouds. Ore and waste will be removed with haul trucks and taken to the Run of Mine (RoM) stockpile area and waste rock dumps (WRDs), respectively. Ore will be crushed at a primary crusher where after it will undergo secondary crushing and milling at the processing plant. The waste from the processing plant will be sent to the tailings storage facility (TSF), which will be a co-disposal of waste rock and tailings material. The mine layout plan is provided in Figure 1.

With the focus of this assessment on air quality impacts from the proposed mining operations on the surrounding environment, the subsequent discussion is intended to provide an indication of the likely source activities associated with the different phases of the mine, and intended to guide planning around the monitoring network (i.e. which pollutants to focus on). Air pollution associated with opencast mining activities include air emissions emitted during the construction-, operational-, closure- and post-closure phases.

The construction phase will include the establishment of required mining infrastructure and associated facilities such as workshops, maintenance areas, stores, wash bays, lay-down areas, batch plant, fuel handling and storage area, offices, change houses, etc. Activities that would result in air pollution during the construction phase are listed Table 1.

Table 1: Construction activities resulting in air pollution

Activity	Associated pollutants
Handling and storage area for construction materials (paints, solvents, oils, grease) and waste	particulate matter (PM)[a] and fumes (Volatile Organic Compounds [VOCs])
Power and water supply infrastructure	sulfur dioxide (SO_2); oxides of nitrogen (NOx); carbon monoxide (CO); carbon dioxide (CO_2)[b]; particulate matter (PM)
Drilling and blasting	SO_2; NOx; CO; PM, CO_2
Clearing and other earth moving activities	mostly PM, gaseous emissions from earth moving equipment (SO_2; NOx; CO; CO_2)
Stockpiling topsoil and sub-soil	mostly PM, gaseous emissions from front-end-loaders (FEL) (SO_2; NOx; CO; CO_2)
Foundation excavations	mostly PM, gaseous emissions from excavators (SO_2; NOx; CO; CO_2)
Opening and backfill of material (specific grade) from borrow pits	mostly PM, gaseous emissions from trucks and equipment (SO_2; NOx; CO; CO_2)
Establishing access and haul roads (scraping and grading)	mostly PM, gaseous emissions from trucks and equipment (SO_2; NOx; CO; CO_2)
Digging of foundations and trenches	mostly PM, gaseous emissions from diggers (SO_2; NOx; CO; CO_2)
Delivery of materials – storage and handling of material such as sand, rock, cement, chemical additives, etc.	mostly PM, gaseous emissions from trucks (SO_2; NOx; CO; CO_2)
General building/construction activities including, amongst others: mixing of concrete; operation of construction vehicles and machinery; refuelling of machinery; civil, mechanical and electrical works; painting; grinding; welding; etc	mostly PM, gaseous emissions from construction vehicles and machinery (SO_2; NOx; CO; CO_2)

Notes: [a] Particulate matter (PM) comprises a mixture of organic and inorganic substances, ranging in size and shape and can be divided into coarse and fine particulate matter. Total Suspended Particulates (TSP) represents the coarse fraction >10μm, with particulate matter with an aerodynamic diameter of less than 10μm (PM_{10}) and particulate matter with an aerodynamic diameter of less than 2.5μm ($PM_{2.5}$) falling into the finer inhalable fraction. TSP is associated with dust fallout (nuisance dust) whereas PM_{10} and $PM_{2.5}$ are considered a health concern.
[b] CO_2 is a greenhouse gas (GHG).

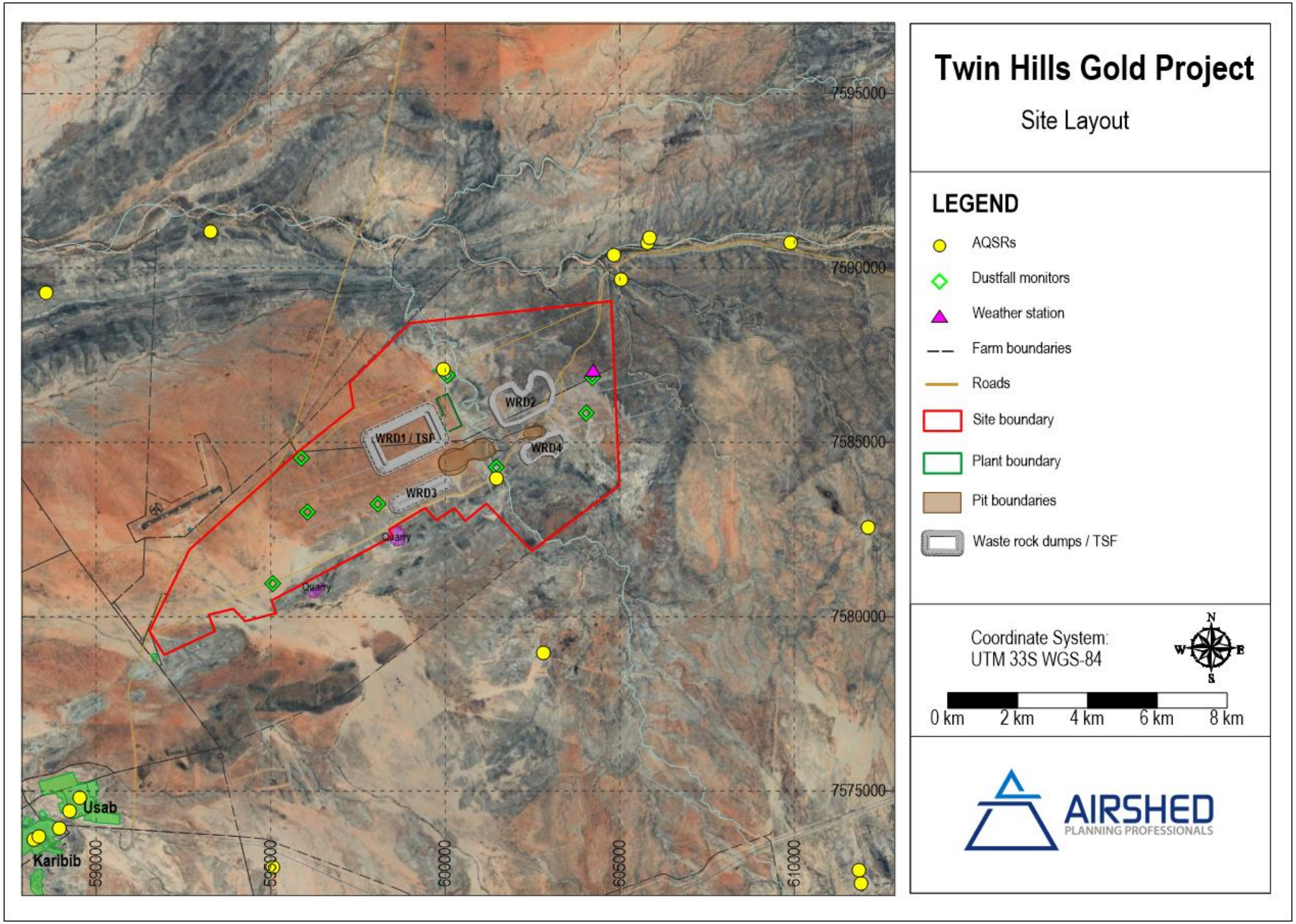

Figure 1: Twin Hills Gold Project layout, monitoring network and identified air quality sensitive receptors

The processing plant at the proposed Project includes several processes (NPI, 2011), which are illustrated in Figure 2 and described as follows:

- ***Comminution*** where the ore is reduced to fine particles through crushing and milling;
- ***Thickening*** reduces the water content of the concentrate slurry;
- ***Carbon-in-Leach (CIL)*** involves the removal of complex gold ions from solution through cyanidation (adding cyanide to the process slurry to promote the dissolution and complexing of the gold) before adsorption onto activated carbon – the Carbon Regeneration Kiln forms part of this circuit (Figure 2);
- ***Elution*** is where the loaded carbon is washed in a hot water, caustic and cyanide solution to remove gold to the washing liquor;
- ***Electrowinning*** where an electric current is applied to the pregnant solution to precipitate gold onto steel wool cathodes;
- ***Roasting/ drying*** to convert any sulfides present to oxides (dissolution of sulfides is suppressed in the pre-aeration process prior to cyanidation); and
- ***Smelting*** where the crude gold is separated from the impurities (called slag) and the molten gold is poured into moulds.

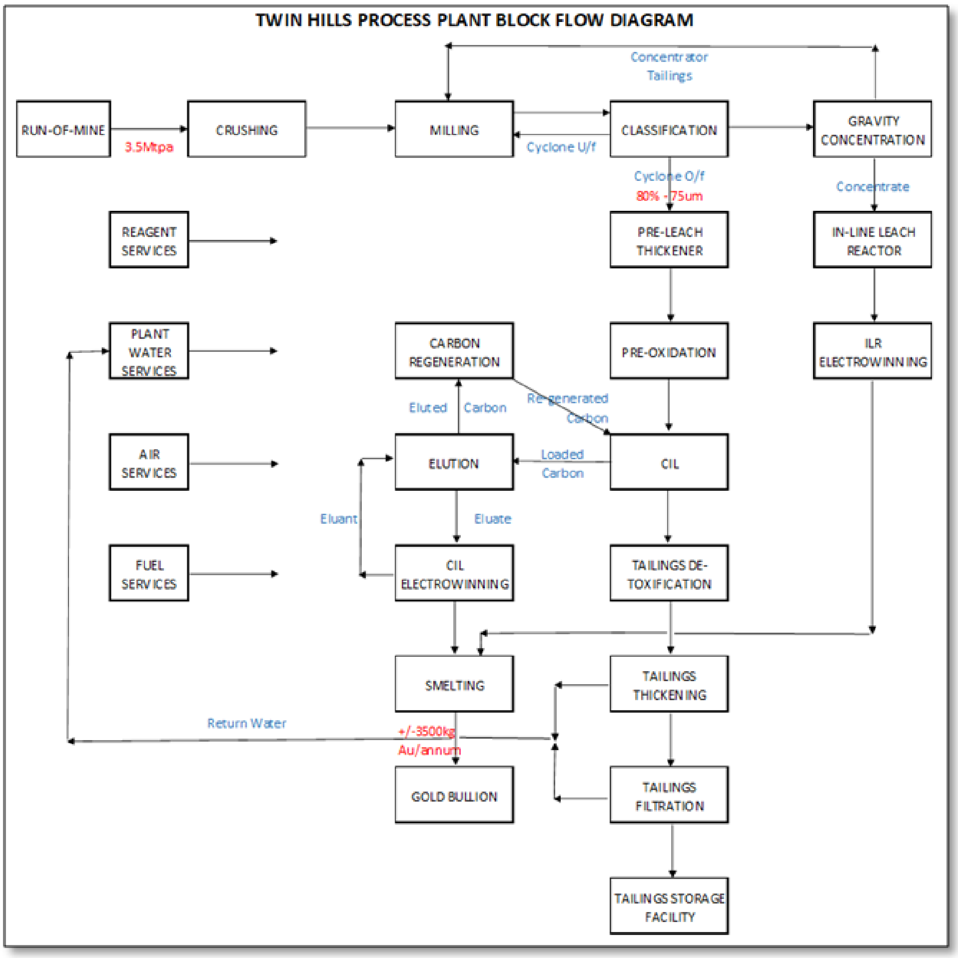

Figure 2: Twin Hills Gold Project Process Plant Flowsheet sing plant (Moeller, 2021)

Support operations may include backup power generators, but this still needs to be confirmed.

Activities at the Project likely to result in pollutants to air are listed in Table 2.

Table 2: Operational activities resulting in air pollution

<table>
<tr><th colspan="2">Activity</th><th>Associated pollutants</th></tr>
<tr><td colspan="2">Open pit mining: drilling and blasting</td><td>PM, SO_2; NOx; CO; CO_2</td></tr>
<tr><td colspan="2">Open pit: excavation of ore and waste rock</td><td>mostly PM, gaseous emissions from mining equipment (PM, SO_2; NOx; CO; CO_2)</td></tr>
<tr><td colspan="2">Haulage of materials (ore and waste rock)</td><td>PM from road surfaces and windblown dust from trucks, gaseous emissions from truck exhaust (PM, SO_2; NOx; CO; CO_2)</td></tr>
<tr><td colspan="2">Waste rock dump(s) (WRDs)</td><td rowspan="2">PM from tipping and windblown dust, gaseous emissions from truck exhaust (PM, SO_2; NOx; CO; CO_2)</td></tr>
<tr><td colspan="2">Waste rock / TSF co-disposal dump</td></tr>
<tr><td colspan="2">Processing of ore (crushing, screening, milling)</td><td>mostly PM, gaseous emissions from machinery (PM, SO_2; NOx; CO; CO_2)</td></tr>
<tr><td rowspan="5">Processing Plant</td><td>comminution</td><td>PM, metals[a]</td></tr>
<tr><td>CIL – leaching (cyanidation); elution; electrowinning</td><td>Acetone, ammonia (NH_3), carbon disulphide (CS_2), cyanide (HCN); hydrochloric acid (HCl); PM, Total Volatile Organic Compounds (TVOC)</td></tr>
<tr><td>carbon regeneration kiln</td><td>CS_2, CO, HCN, NOx, PM, SO_2</td></tr>
<tr><td>roaster/ dryer stack</td><td>PM, metals[a][b], NOx, SO_2, CO, TVOC, polycyclic aromatic hydrocarbons (PAH), toxic equivalent quantities (TEQ)</td></tr>
<tr><td>smelting</td><td>PM, metals[a]; SO_2; SO_2, sulphuric acid (H_2SO_4), TVOC</td></tr>
<tr><td colspan="2">Back-up diesel power generators [c]</td><td>PM, metals[a], NOx, SO_2, CO, TVOC, PAH, TEQ</td></tr>
</table>

Notes: [a] Metals include antimony, arsenic, beryllium, boron, cadmium, chromium(III), chromium(VI), cobalt, copper, fluoride, lead, manganese, mercury, nickel, selenium, zinc.
[b] All metals except antimony, boron, cobalt, fluoride, chromium(VI).
[c] Power is planned to be supplied by NamPower (the national power utility), requirement for back-up generators not confirmed.

Closure and post-closure activities typically include rehabilitation of the site infrastructure – demolition of infrastructure and vegetation of WRDs and waste rock / TSF co-disposal dump (WRD1/TSF). These activities mainly result in PM emissions with gaseous emissions from equipment and trucks.

1.3 Project Approach and Methodology

The approach to, and methodology followed in the completion of tasks completed as part of the scope of work are provided in Table 3.

An information requirements list was sent to ECC at the onset of the project. In response to the request, the following information was supplied:

- Layout maps;
- Process descriptions; and
- Project equipment details.

Documentation reviewed included the following:

- *04_LYC_Twin_Hills_PEA_Mining_OPEX_CAPEX_v08_12052021_fv.xlsx*.
- Osino Resources: Twin Hills Gold Project Preliminary Economic Assessment (PEA) - Mining Study. Report No. LYC/OSI/PEA/2021/018/01. 15 June 2021 (Moeller, 2021).
- 6683_000-FF-004_A Block Flow Diagram_colour.pdf.
- *6683-ELST-001_A-Electrical-Load-List.xlsx*.
- ECC- List of Requirements (1).docx, April 2021.

Table 3: Project Approach and Methodology

Task	Activity	Description	Report Section
Legal Review	A study of legal requirements pertaining to air quality in Namibia – ambient air quality standards and guidelines; dust control regulations and emission limits and guidelines.	Namibian Atmospheric Pollution Prevention Ordinance (No. 11 of 1976) International air quality criteria referenced, include: • World Health Organisation (WHO); • World Bank Group (WBG); • International Finance Corporation (IFC); and • South Africa (SA) air quality legislation.	Section 2
Baseline Assessment	Desktop review of all available project and associated data, including meteorological data, previous air quality assessments, EIAs and technical air quality data and models.	Air Quality Management Plan (AQMP) Report as part of the Strategic Environmental Management Plan (SEMP) for the Uranium and Other Industries in the Erongo Region (Liebenberg-Enslin, et al., 2019)	Section 3
	Physical environmental parameters that influence the dispersion of pollutants in the atmosphere include: • terrain, • land cover, and • meteorology.	On-site meteorological data was available for a 12-month period (23 July 2020 to 22 July 2021) and was used to determine the dispersion potential of the site. Daily rainfall data was provided for the period July 2020 to July 2021.	Section 3.2
	Identification of existing air pollution sources (other mines; agriculture; industries; etc.).	Likely sources of potential air quality pollution include but are not limited to mining and quarry operations, annual “East wind conditions”, biomass burning and wildfires, vehicle emissions and small-scale industrial operations (e.g. boilers, generators, etc.).	Section 3.1
	Identification of air quality-sensitive receptors, including any nearby residential dwellings and proposed receptors (temporary or permanent workers accommodation site(s)) near the mine.	A map of all the potential air quality sensitive receptors (AQSRs) are provided.	Section 3.1
	Analysis of available ambient air quality data for the area – dustfall data from the Twin Hills dustfall monitoring network is assessed.	Dustfall monitoring network was initiated in June 2020 and comprises of eight (8) single dustfall units. Dust deposition rates for the period June 2020 to June 2021 are presented.	Section 3.3
Impact Assessment	The compilation of an emissions inventory incl. the identification and quantification of all emissions associated with the proposed mining operations (open pit mine and processing plant).	Mining will commence in different phases, and for the purpose of the assessment the following scenarios are included: • Scenario 1: Mining year 7 (Ore domain primarily Clouds pit) • Scenario 2: Mining year 10 (Ore domain Twin Hills & Bulge pit)	Section 4.1

		Construction operations will include the development of the mining infrastructure. Pollutants quantified are limited to particulate matter (TSP, PM_{10} and $PM_{2.5}$) and gaseous emissions (SO_2, NO_2 and CO). Use is made of process descriptions, mining rates and infrastructure maps to quantify activity emissions through the application of emissions factors and emission equations as published by the United States Environmental Protection Agency (US EPA) and Australian National Pollutant Inventory (NPI).	
	Atmospheric dispersion simulations of all pollutants (PM_{10}, $PM_{2.5}$ and dust fallout) for the operations reflecting highest daily and annual average concentrations due to routine emissions from the mining operations.	Use was made of the ADMS 5 model (Atmospheric Dispersion Modelling System) developed by the Cambridge Environmental Research Consultants (CERC). This model simulates a wide range of buoyant and passive releases to the atmosphere either individually or in combination. It has been the subject of several inter-model comparisons (CERC, 2004), one conclusion of which is that it tends provide conservative values under unstable atmospheric conditions in that, in comparison to the older regulatory models, it predicts higher concentrations close to the source. The ADMS model was chosen specifically for its capability of modelling flow over complex topography, to account for the local topographical features in the project region.	Section 4.2
	Dispersion modelling results and compliance evaluation for the different scenarios of the Operational phase. Construction, Closure and Decommissioning phases are assessed qualitatively.	Compliance is assessed by comparing modelled ambient PM ($PM_{2.5}$ and PM_{10}) concentrations and dustfall rates to the relevant national and international ambient air quality standards and dustfall regulations. NO_2, SO_2 and CO emission are assessed based on emissions only.	Section 4.3
	Air quality impact assessment	The impact significance is evaluated against the adopted Air Quality Objectives (AQO).	Section 5
	The identification of air quality management and mitigation measures based on the findings of the compliance and impact assessment.	Practical mitigation and optimisation measures that can be implemented effectively to reduce or enhance the significance of impacts were identified.	Section 6

1.4 Assumptions, Exclusions and Limitations

The main assumptions, exclusions and limitations are summarised below:

- Meteorological and Ambient Data:
    - On-site meteorological data was available for a period of 12-months (23 July 2020 to 22 July 2021) and deemed acceptable for use in the dispersion model (US EPA, 2000).
    - Only dust fallout data was available for the site for the period June 2020 to June 2021. A general description of the air quality within the greater Erongo Region was obtained from the AQMP conducted as part of the SEMP. A limitation is that Karibib is located on the eastern boundary of the area assessed as part of the SEMP AQMP.
- Emissions:
    - The quantification of sources of emission was restricted to the Project activities only. Although other background sources were identified, such as emissions from roads and other mines and quarries, these could not be quantified and did not form part of the scope of work.
    - Emissions were based on the process description and mine layout plan as provided and were quantified for two operational years representing the two open pit areas with the highest mining rates (i.e. mining year 7 and 10).
    - Since it is a proposed mine, no site-specific particle size fraction data for the various sources were available and use was made of information obtained from existing gold mines previously studied, as well as uranium mines in the area.
    - Routine emissions for the proposed operations were simulated. Blasting is regarded a non-routine (*upset*) event, occurring only intermittently for short durations. Blasting was not accounted for in the modelling, since it will occur for less than an hour a day, twice a week.
- Impact Assessment:
    - Impacts due to the operational phase were assessed quantitatively, whilst the construction, closure and decommissioning phases were assessed qualitatively due to the limited information available.
    - The impact assessment was limited to airborne particulate (including TSP, PM_{10} and $PM_{2.5}$). Gaseous emissions from vehicle exhaust were quantified, but not modelled since impacts from these sources are usually localized and unlikely to exceed health screening limits outside the proposed mining right area. Emissions from point-source releases (Kiln stack, Roaster/ Dryer stack, and Furnace stack) could not be determined due to insufficient information on the design parameters.
    - Since it is a difficult task to calculate real-life variations in impacts due to the variability of the operation, design maximum mining rates were utilized in the simulations. Though the nature of the mining operations will change over the life of mine, the proposed sources were modelled to reflect the worst-case conditions (i.e. resulting in the highest impacts and/or closest to AQSRs). For this reason, two operational phase scenarios were modelled, with Scenario 1 reflecting the maximum throughput during Year 7 operations, and Scenario 2, the highest production during Year 10.
    - There will always be some degree of uncertainty in any geophysical model, but it is desirable to structure the model in such a way to minimize the total error. A model represents the most likely outcome of an ensemble of experimental results. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere. Nevertheless, dispersion modelling is generally accepted as a necessary and valuable tool in air quality management.

2 LEGAL OVERVIEW

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. Air quality guidelines and standards are based on benchmark concentrations that normally indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Benchmark concentrations could therefore be based on health effects, such as SO_2 or carcinogenic consequences, such as benzene.

Air quality guidelines and standards are normally given for specific averaging or exposure periods and are evaluated as the observed air concentration expressed as a fraction of a benchmark concentration. A standard, as opposed to a benchmark concentration only, is a set of instructions which include a limit value and may contain a set of conditions to meet this limit value. Standards are normally associated with a legal requirement as implemented by the country's relevant authority; however, organisations such as the World Bank Group (WBG) International Finance Corporation (IFC) and private companies also issue standards for internal compliance. The benchmark concentrations issued by the World Health Organisation (WHO), on the other hand, are not standards, but rather guidelines that may be considered for use as limit values in standards.

A common condition included in a standard is the allowable frequency of exceedances of the limit value. The frequency of exceedances recognises the potential for unexpected meteorological conditions coupled with emission variations that may result in outlier air concentrations and would normally be based on a percentile, typically the 99^{th} percentile.

Standards are normally issued for criteria pollutants, i.e. those most commonly emitted by industry including SO_2, NO_2, CO, PM_{10} and $PM_{2.5}$, but may also include secondary pollutants such as O_3. Some countries include other pollutants, specifically when these are considered to be problematic emissions.

In addition to ambient air quality standards or guidelines, emission limits aim to control the amount of pollution from a point source[1]. Emissions to air should be avoided or controlled according to Good International Industry Practice (GIIP) applicable to the specific industry sector (IFC, 2007a).

Namibia does not have air quality guidelines or limits and reference is usually made to international ambient air quality guidelines and standards. The WHO is widely referenced, as well as countries in the region who have air quality standards. As part of the AQMP developed for the SEMP update, ambient guidelines for PM_{10} and $PM_{2.5}$ were determined to provide the necessary performance indicators for mines and industries within the Erongo Region. These guidelines are regarded applicable to the current study and discussed in one of the following sub sections.

2.1 Namibian Legislation

The Atmospheric Pollution Prevention Ordinance (No. 11 of 1976) deals with the following:

Part I	:	Appointment and powers of officers;
Part II	:	Control of noxious or offensive gases;
Part III	:	Atmospheric pollution by smoke;
Part IV	:	Dust control;
Part V	:	Pollution of the atmosphere by gases emitted by vehicles;
Part IV	:	General provisions; and
Schedule 2:		Scheduled processes.

[1] Point sources are discrete, stationary, identifiable sources of emissions that release pollutants to the atmosphere (IFC, 2007).

The Ordinance does not include any ambient air standards with which to comply, but opacity guidelines for smoke are provided under Part III. It is implied that the Director[2] provides air quality guidelines for consideration during the issuing of Registration Certificates, where Registration Certificates may be issued for "Scheduled Processes" which are processes resulting in noxious or offensive gases and typically pertain to point source emissions. To our knowledge no Registration Certificates have been issued in Namibia. However, an Environmental Clearance Certificate is required for any activity entailing a scheduled process as referred to in the Atmospheric Pollution Prevention Ordinance, 1976.

Also, the Ordinance defines a range of pollutants as noxious and offensive gases, but no ambient air quality guidelines or standards or emission limits are provided for Namibia.

Part II of the Ordinance pertains to the regulation of noxious or offensive gases. The Executive Committee may declare any area a *controlled area* for the purpose of this Ordinance by notice in the Official Gazette. Any scheduled process carried out in a *controlled area* must have a current registration certificate authorising that person to carry on that process in or on that premises.

The published Public and Environmental Health Act 1 of 2015 provides "a framework for a structured uniform public and environmental health system in Namibia; and to provide for incidental matters". The act identifies health nuisances, such as chimneys sending out smoke in quantities that can be offensive, injurious, or dangerous to health and liable to be dealt with.

2.1.1 Best Practice Guide for the Mining Sector in Namibia

A Best Practice Guide for the Mining Sector in Namibia was published in July 2020 (NCE, 2020). The document serves as a guiding framework during all mining phases to effectively assess aspects such as environmental and social impacts.

The report lists air quality as an environmental risk. It provides examples of sources and activities that would result in particulate and gaseous emissions and gives guidance on management and control of these source activities. Aspects relevant to the Project can be summarised as follows:

- The benefits of the SEMP for industry are highlighted and the SEMP Environmental Quality Objectives (EQOs) require as a minimum management objective that "any change to the environment must be within acceptable limits, and that pro-active intervention will be triggered by the responsible party to avoid unwanted changes that breach a specific threshold." All mining companies within the region submit reports annually as part of the SEMP annual report which is available in the public domain.
- Section 3 provides requirements for Baseline Studies where air quality is listed as one of the most important aspects where background conditions of dust, gaseous and nuisance emissions and in some cases fumes and odours are required. Dust and gaseous emissions require immediate monitoring, as well as the establishment of a network of meteorological measuring points. Dust requires the monitoring of particulate matter (PM), in PM_{10}–format, but the monitoring program may require simultaneous measurement of TSP or $PM_{2.5}$ as well.
- Applicable ambient air quality guidelines are listed in Section 3 of the report. It states that Namibia does not have ambient air quality standards or guidelines and references the SEMP AQMP (Liebenberg-Enslin, et al., 2019) guidelines which were determined to provide the necessary performance indicators for the region. These are discussed in more detail under Section 2.5.
- Recommendations in Section 3 include: Dust Management Plans for all operational sites (mines, exploration sites and quarries); annual reporting of dust fall levels and PM_{10} concentrations to the authorities; dust suppression at

[2] *Director* means the Director of Health Services of the Administration, and, where applicable, includes any person who, in terms of any authority granted to him under section 2(2) or (3) of the Ordinance.

construction sites (as well as annual reporting on dust mitigation measures); update and improvement of the current emissions inventory; establishing a monitoring regime to enhance source apportionment of PM concentrations and sodium content; and continuation with PM_{10} and meteorological monitoring.

- Section 4 indicates that once mines are operational, an air quality management plan is essential for dealing with issues that can potentially have an adverse impact on operations. In addition to dust, an air quality plan needs to incorporate the management of emissions (release of pollutants and particulates) and fumes as well. All mines must, as a minimum requirement of an air quality management plan, manage dust.
- Requirements for air quality monitoring during the operational phase is provided and reference is made again to the SEMP guidelines as performance indicators for the region. All the uranium mines in Namibia are located in the Erongo Region and all these mines have extensive air quality monitoring programmes in place.
- The report further provides guidance on closure and maintenance where management and monitoring of erosion is one of the essential aspects.

2.2 International Criteria

Typically, when no local ambient air quality criteria exist, or are in the process of being developed, international criteria are referenced. This serves to provide an indication of the severity of the potential impacts from proposed activities. The most widely referenced international air quality criteria are those published by the WBG, the WHO, and the European Community (EC). The South African (SA) National Ambient Air Quality Standards (NAAQS) are also referenced since it is regarded representative indicators for Namibia due to the similar environmental and socio-economic characteristics between the two countries. The PM guidelines selected as part of the SEMP AQMP for the Erongo Region were based on these international guidelines and standards, and the following subsections provide the relevant background.

2.2.1 WHO Air Quality Guidelines

Air Quality Guidelines (AQGs) were published by the WHO in 1987 and revised in 1997. Since the completion of the second edition of the AQGs for Europe, which included new research from low-and middle-income countries where air pollution levels are at their highest, the WHO has undertaken to review the accumulated scientific evidence and to consider its implications for its AQGs. The result of this work is documented in *'Air Quality Guidelines – Global Update 2005'* in the form of revised guideline values for selected criteria air pollutants, which are applicable across all WHO regions (WHO, 2005).

Given that air pollution levels in developing countries frequently far exceed the recommended WHO AQGs, interim target (IT) levels were included in the update. These are more lenient than the WHO AQGs with the purpose to promote steady progress towards meeting the WHO AQGs (WHO, 2005). There are two or three interim targets depending on the pollutant, starting at WHO interim target-1 (IT-1) as the most lenient and IT-2 or IT-3 as more stringent targets before reaching the AQGs. The SA NAAQS are, for instance, in line with IT-1 for SO_2 and IT-3 for PM_{10} and $PM_{2.5}$. It should be noted that the WHO permits a frequency of exceedance of 1% per year (4 days per year) for 24-hour average PM_{10} and $PM_{2.5}$ concentrations. In the absence of interim targets for NO_2, reference is made to the AQG value. These are provided in Table 4 for pollutants considered in this study.

2.2.2 SA National Ambient Air Quality Standards

NAAQSs for SA were determined based on international best practice for SO_2, NO_2, $PM_{2.5}$, PM_{10}, O_3, CO, Pb and benzene. These standards were published in the Government Gazette on 24 of December 2009 and included a margin of tolerance (i.e. frequency of exceedance) and with implementation timelines linked to it. SA NAAQSs for $PM_{2.5}$ were published on 29 July 2012. As mentioned previously, SA NAAQS closely follow WHO interim targets, which are targets for developing countries, for $PM_{2.5}$, PM_{10} and SO_2. The SA NAAQS for ambient NO_2 concentrations is equivalent to the WHO AQG. SA NAAQSs referred to in this study are also given in Table 4.

Table 4: International assessment criteria for criteria pollutants

Pollutant	Averaging Period	WHO Guideline Value (µg/m³)	South Africa NAAQS (µg/m³)
Sulfhur Dioxide (SO_2)	1-year	-	50
	24-hour	125 (IT1) 50 (IT2) (a) 20 (guideline)	125 (b)
	1-hour	-	350 (c)
	10-minute	500 (guideline)	500 (d)
Nitrogen Dioxide (NO_2)	1-year	40 (guideline)	40
	1-hour	200 (guideline)	200 (c)
Particulate Matter (PM_{10})	1-year	70 (IT1) 50 (IT2) 30 (IT3) 20 (guideline)	40 (e) (b)
	24-hour	150 (IT1) 100 (IT2) 75 (IT3) 50 (guideline)	75 (e)
Particulate Matter ($PM_{2.5}$)	1-year	35 (IT1) 25 (IT2) 15 (IT3) 10 (guideline)	25 (f) 20 (g) 15 (h)
	24-hour	75 (IT1) 50 (IT2) 37.5 (IT3) 25 (guideline)	65 (f) 40 (g) 25 (h)

Notes:

(a) Intermediate goal based on controlling motor vehicle emissions; industrial emissions and/or emissions from power production. This would be a reasonable and feasible goal to be achieved within a few years for some developing countries and lead to significant health improvement.
(b) 4 permissible frequencies of exceedance per year
(c) 88 permissible frequencies of exceedance per year
(d) 526 permissible frequencies of exceedance per year
(e) Applicable from 1 January 2015.
(f) Applicable immediately to 31 December 2015.
(g) Applicable 1 January 2016 to 31 December 2029.
(h) Applicable 1 January 2030.

2.2.3 Dustfall Limits

Air quality standards are not defined by all countries for dust deposition, although some countries may make reference to annual average dust fall thresholds above which a 'loss of amenity' may occur. In the southern African context, widespread dust deposition impacts occur as a result of windblown dust from mine tailings and natural sources, from mining operations and other fugitive dust sources.

South Africa has published the National Dust Control Regulations (NDCR) on the 1st of November 2013 (Government Gazette No. 36974). The purpose of the regulations is to prescribe general measures for the control of dust in all areas including residential and light commercial areas. Similarly, Botswana published dust deposition evaluation criteria (BOS 498:2013). According to these limits, an enterprise may submit a request to the authorities to operate within the Band 3 (action band) for a limited period, providing that this is essential in terms of the practical operation of the enterprise (for example the final removal of a tailings deposit) and provided that the best available control technology is applied for the duration. No margin of tolerance will be granted for operations that result in dustfall rates in the Band 4 (alert band). This four-band scale is presented in Table 5.

Table 5: Bands of dustfall rates

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

2.3 International Conventions

The technical reference documents published in the IFC Environmental, Health and Safety (EHS) Guidelines provide general and industry specific examples of Good International Industry Practice (GIIP). The General EHS Guidelines are designed to be used together with the relevant Industry Sector EHS Guidelines (IFC, 2007).

The IFC EHS Guidelines provide a general approach to air quality management for a facility, including the following:

- Identifying possible risks and hazards associated with the project as early on as possible and understanding the magnitude of the risks, based on:
  - the nature of the project activities; and,
  - the potential consequences to workers, communities, or the environment if these hazards are not adequately managed or controlled.
- Preparing project- or activity-specific plans and procedures incorporating technical recommendations relevant to the project or facility;
- Prioritising the risk management strategies with the objective of achieving an overall reduction of risk to human health and the environment, focusing on the prevention of irreversible and / or significant impacts;
- When impact avoidance is not feasible, implementing engineering and management controls to reduce or minimise the possibility and magnitude of undesired consequence; and,

- Continuously improving performance through a combination of ongoing monitoring of facility performance and effective accountability.

Significant impacts to air quality should be prevented or minimised by ensuring that:

- Emissions to air do not result in pollutant concentrations exceeding the relevant ambient air quality guidelines or standards. These guidelines or standards can be national guidelines or standards or in their absence WHO AQGs or any other international recognised sources.
- Emissions do not contribute significantly to the relevant ambient air quality guidelines or standards. It is recommended that 25% of the applicable air quality standards are allowed to enable future development in a given airshed. Thus, any new development should not result in ground level concentrations exceeding 25% of the guideline value.
- The EHS recognises the use of dispersion models to assess potential ground level concentrations. The models used should be internationally recognised or comparable.

2.3.1 Degraded Airsheds or Ecological Sensitive Areas

The IFC provides further guidance on projects located in degraded airsheds (IFC, 2007), i.e. areas where the national/ WHO/ other recognised international Air Quality Guidelines are significantly exceeded or where the project is located next to areas regarded as ecological sensitive such as national parks. The Project is not located in an ecologically sensitive area, and the airshed is not regarded to be degraded.

2.3.2 Fugitive Source Emissions

According to the IFC (IFC, 2007), fugitive source emissions refer to emissions that are distributed spatially over a wide area and confined to a specific discharge point. These sources have the potential to result in more significant ground level impacts per unit release than point sources. It is therefore necessary to assess this through ambient quality assessment and monitoring practices.

2.4 Air Emission Standards

An ambient standard is a never-exceed level for a pollutant in the ambient environment, whereas emission standards are never-exceed levels applied directly to the quantities of emissions coming from pollution sources.

None of the processes at the proposed Project such as gold processing fall under the list of “Scheduled Process” in the Ordinance. To the author’s knowledge, no registration certificate has been issued for any “Scheduled Process” in Namibia.

Since Namibia does not have any emission limits or guidelines, the international IFC and SA Minimum Emission Standards (MES) are referenced.

2.4.1 IFC Emission Guidelines and Standards

The IFC EHS guidelines refer to projects, which generate emissions to the air at any stage of a project life cycle. The purpose of the guidelines is to minimize the impact to human health, safety and the environment from emissions to air. The IFC guidelines on air emissions for Nickel, Copper, Lead, Zinc and Aluminium Smelting and Refining, but not for Gold. These emission limits, listed in Table 6, are based on performance levels and measures considered achievable by new technology and to be used as general guidelines on the emissions from the gold processing.

All emission limit values are given as daily averages based on continuous monitoring and standard conditions at a temperature of 273.15 K (0°C), a pressure of 101.3 kPa, measured oxygen content and dry gas without dilution of the gases with air.

Table 6: IFC Guidelines for Base Metal Smelting and Refining

Pollutant	Process[(a)]	Guideline value
NO_x	Primary and secondary fire refining, electric slag cleaning and melting	100 – 300 mg/Nm³[(b)]
SO_2	Primary smelting and converting	>99.1% conversion efficiency (for ~ 1– 4 percent SO_2 off gas) >99.7% conversion efficiency (for >5 percent SO_2 off gas)
	Primary and secondary fire refining, electric slag cleaning and melting	<50 – 200 mg/Nm³[(c)]
Dust	Primary and secondary fire refining, electric slag cleaning and melting, and drying	1 – 5 mg/Nm³[(d)]
VOC / solvents	Hydrometallurgical and electro-winning processes	5 – 15 mg/Nm³[(e)]
Acid Mists / gasses	Hydrometallurgical and electro-winning processes	50 mg/Nm³[(f)]
TOC	Primary and secondary fire refining, electric slag cleaning and melting	5 – 50 mg/Nm³[(g)]
Dioxins	Primary and secondary fire refining, electric slag cleaning and melting, and drying	0.1 – 0.5 ng TEQ/m³[(h)]
Mercury	All types of metals / smelting processes	0.02 mg/Nm³

Notes: [(a)] Primary smelting process refers to the smelting of ore, whereas secondary smelting is the smelting of scrap metal.

[(b)] Achievable by Low NOx burner; Oxy-fuel burner and Oxidizing scrubber.

[(c)] Alkali scrubber (semi -dry and fabric filter, wet scrubber or double alkali using lime, magnesium hydroxide, sodium hydroxide), or combinations of sodium or alumina/aluminium sulphate in combination with lime, or a fabric filter with lime injection (SO_2 emission concentration of 500 mg/m³ can be achieved)

[(d)] Fabric filter or temperature control.

[(e)] Containment, condenser, carbon and bio -filter.

[(f)] Alkali scrubber (semi -dry and fabric filter, wet scrubber or double alkali using lime, magnesium hydroxide, sodium hydroxide) or De-mister.

[(g)] Afterburner or optimized combustion.

[(h)] Fabric filter with lime injection, or afterburner followed by quenching, or adsorption by activated carbon, or oxidation catalyst.

2.4.2 South Africa Minimum Emission Standards

The South African Department of Forestry, Fisheries and Environment (DFFE, previously Department of Environmental Affairs [DEA]) established a list of the minimum emissions standards[4] in 2010, with an amended list published in 2013. Since South Africa is a neighbouring country to Namibia, with similar environmental and socio-economic conditions, the emission limits applicable to Drying (Sub-category 4.1: Drying and Calcining) and precious metals (Sub-category 4.17: Precious and Base Metal Production and Refining) are considered achievable and regarded as GIIP. Drying applies to the drying of mineral solids including ore for facilities with a production capacity of more than 100 tons per month (tpm). Gold production at Project less than 100 tpm. Precious and base metal production and refining, however, applies to all installations, with emission limits provided in Table 7.

All emission limit values are for standard conditions at a temperature of 298.15 K (25°C), and a pressure of 101.3 kPa.

[3] Degraded Air shed (national air quality standards are not complied with or in their absence WHO AQGs are exceeded significantly)

[4] Air Quality Act (39/2004) – List of activities which result in atmospheric emissions which have or may have a significant detrimental effect on the environment, including health, social, economic, ecological conditions

Table 7: SA Minimum Emission Standards for Precious and Base Metal Production and Refining

Pollutant	Unit	Stack emission limits under normal conditions of 273 K and 101.3 kPa
NO_x	mg/Nm³	300
SO_2	mg/Nm³	400
Particulate matter	mg/Nm³	50
Chlorine	mg/Nm³	50
Hydrogen chloride	mg/Nm³	30
Hydrogen fluoride	mg/Nm³	30
Ammonia	mg/Nm³	100

2.5 Recommended Guidelines and Objectives

The IFC references the WHO guidelines but indicates that any other internationally recognized criteria can be used such as the United States (US) Environmental Protection agency (EPA) or the EC. It was, however, found that merely adopting the WHO guidelines would result in exceedances of these guidelines in many areas due to the arid environment in the country, and specifically in Namibia. The WHO states that these AQG and interim targets should be used to guide standard-setting processes and should aim to achieve the lowest concentrations possible in the context of local constraints, capabilities, and public health priorities. These guidelines are also aimed at urban environments within developed countries (WHO, 2005). For this reason, the South African NAAQS are also referenced since these were developed after a thorough review of all international criteria and selected based on the socio, economic and ecological conditions of the country.

In the absence of guidelines on ambient air concentrations for Namibia, reference is made to the Air Quality Objectives (AQO) recommended as part of the SEMP AQMP (Liebenberg-Enslin, et al., 2019). These objectives are based on the WHO interim targets and SA NAAQS (Table 4). The criteria were selected on the following basis:

- The WHO IT3 was selected for particulates since these limits are in line with the SA NAAQSs, and the latter are regarded feasible limits for the arid environment of Namibia.
- Even though $PM_{2.5}$ emissions are mainly associated with combustion sources and mainly a concern in urban environments, it is regarded good practice to include as health screening criteria given the acute adverse health effects associated with this fine fraction. Also, studies found that desert dust with an aerodynamic diameter 2.5 µm cause premature mortality.
- For SO_2, there is no IT3, and the IT2 was selected since the WHO states: “This would be a reasonable and feasible goal for some developing countries (it could be achieved within a few years) which would lead to significant health improvements that, in turn, would justify further improvements (such as aiming for the AQG value)”.
- The WHO provides no interim targets for NOx. The AQGs are in line with the SA NAAQSs and therefore regarded as achievable limits.
- The Botswana and South African criteria for dust fallout are the same and with limited international criteria for dust fallout, these were regarded applicable.

The proposed Air Quality Objectives (AQOs) as set out in Table 8 are intended to be used as indicators during the impact assessment.

Table 8: Proposed Air Quality Objectives for the Project

Pollutant	Averaging Period	Criteria	Reference
NO_2	1-hour average (µg/m³)	200[a]	WHO AQG & EC & SA NAAQS
	Annual average (µg/m³)	40	WHO AQG & EC & SA NAAQS
SO_2	1-hour average (µg/m³)	350[a]	EC Limit & SA NAAQS (no WHO guideline)
	24-hour average (µg/m³)	50[b]	WHO IT2 (seen as a per 40% of the SA and EC limits)
	Annual average (µg/m³)	50	SA NAAQS (no WHO guideline)
Particulate matter (PM_{10})	24-hour average (µg/m³)	75[b]	WHO IT3 & SA NAAQS (as per SEMP AQMP)
	Annual average (µg/m³)	40	SA NAAQS (as per SEMP AQMP)
Particulate matter ($PM_{2.5}$)	24-hour average (µg/m³)	37.5[b]	WHO IT3 (as per SEMP AQMP)
	Annual average (µg/m³)	15	WHO IT3 & SA NAAQS (as per SEMP AQMP)
Dustfall	30-day average (mg/m²/day)	600[c]	SA NDCR & Botswana residential limit
		1 200[c]	SA NDCR & Botswana industrial limit
		2 400	Botswana Alert Threshold

Notes: [a] Not to be exceeded more than 88 hours per year (SA)
[b] Not to be exceeded more than 4 times per year (SA)
[c] Not to be exceeded more than 3 times per year or 2 consecutive months

With the SA MES based on international nest practice whilst considering that it is a developing country and growing economy, the MES for Precious and base metal production and refining, as provided in Table 7, should suffice.

3 DESCRIPTION OF THE BASELINE ENVIRONMENT

3.1 Site Description and Sensitive Receptors

The proposed Project is located just outside of Karibib (approximately 5 km), in the eastern part of the Erongo Region of Namibia. This region is characterised by low rainfall, extreme temperature ranges and unique climatic factors influencing the natural environment and biodiversity (Goudie, 2009). Episodic dust storms associated with strong easterly winds occur during the autumn and winter months, giving rise to dust emissions from natural and anthropogenic sources under conditions of high wind speeds (MME, 2010).

The Project covers an area with dimensions of about 25 km northeast-southwest and 11 km north-south. The terrain is hilly, with a ridge to the north and northwest, and a ridge on the southern side. The topography of the Project site is shown in Figure 3.

Air Quality Sensitive (AQSRs) primarily relate to where people reside. There are no villages or homesteads near the project, with the closest settlement – farmhouses – directly to the south of Twin Hills pit, and one at the proposed Processing Plant (this one is assumed to be relocated). The town of Karibib (and Usab suburb) is located about 3.5 km to the southwest from the site boundary. Other settlements in the vicinity include scattered homesteads to the north of the mine boundary, along the Khan River. All identified AQSRs are shown in Figure 1 providing the spatial context for the closest AQSRs. These will be included as sensitive receptors during the air quality impact assessment.

Main (national) roads in close proximity to the Project are the B2 to the south of the project and the C33 to the west.

3.2 Atmospheric Dispersion Potential

Meteorological mechanisms govern the dispersion, transformation and eventual removal of pollutants from the atmosphere. 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 stability of the atmosphere and the depth of the surface-mixing layer define the vertical component. 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. Pollution concentration levels therefore fluctuate in response to changes in atmospheric stability, to concurrent variations in the mixing depth, and to shifts in the wind field.

A description of the wind field, temperature, precipitation, and atmospheric stability is provided in the following section. Twin Hills operates a weather station on-site (21°49'2.17"S; 16°0'30.89"E) recording wind speed (km/hr), wind direction (degrees), temperature (°C), humidity (%), barometric pressure (Pa) and rainfall (mm). Weather data is available since 23 July 2020, when the station was installed. Data availability for the period is provided in Table 9.

Table 9: Data availability of meteorological parameters measured at the Twin Hills Weather Station

Data Period	Wind Speed (m/s)	Wind Direction (deg)	Temperature (°C)	Humidity (%)	Barometric Pressure (Pa)
23 Jul 2020 – 22 Jul 2021	99%	99%	100%	100%	100%

Note: Data availability was assessed based on the period data was recorded for.

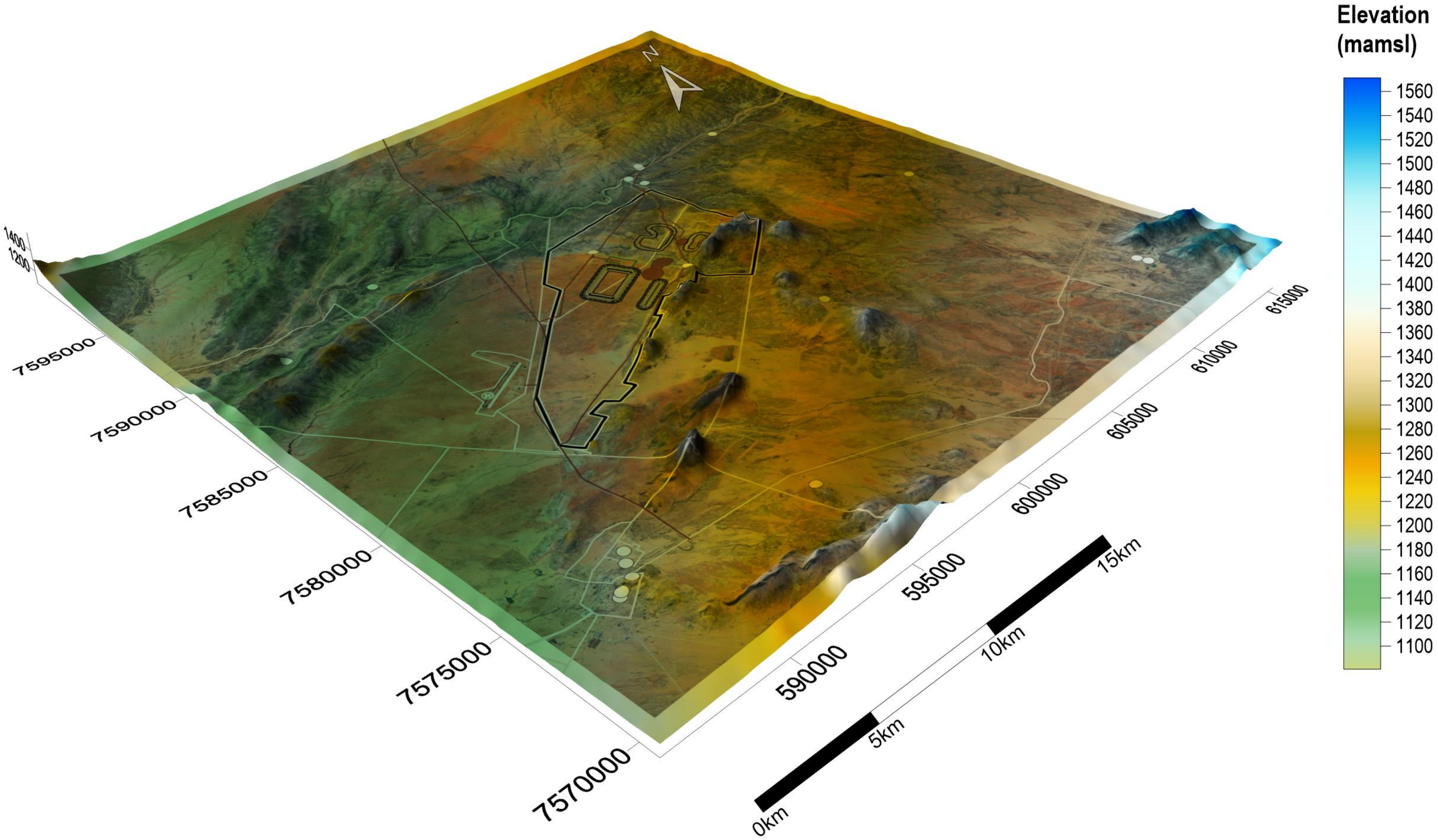

Figure 3: Topography of the proposed Twin Hills Gold Project

3.2.1 Surface Wind Field

The wind direction, and the variability in wind direction, determines the general path that air pollutants will follow, and the extent of crosswind spreading. Wind roses comprise 16 spokes, which represent the directions from which winds blew during the period. The colours used in the wind roses below, reflect the different categories of wind speeds; the red area, for example, representing winds between higher than 5 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. The frequency with which calms occurred refers to periods during which the wind speed was below 1 m/s.

Period, daytime and night-time wind roses for the study area, based on the Twin Hills meteorological data for 12-month period: 23 Jul 2020 to 22 Jul 2021 are depicted in Figure 4, with monthly wind roses for the same period shown in Figure 5.

The wind field is dominated by winds from the southwest and the east to southeast, with the strongest winds from the southwest. Calm conditions prevailed 7.5% of the time with a period average wind speed of 2.3 m/s. During the day, easterly winds prevailed with strong but less frequent winds from the southwest, and calm conditions for 3.7%. At night, the wind field shifted to more frequent south-westerly winds with winds at lower wind speeds less frequently from the east to southeast (Figure 4). The highest winds speed recoded during the 23 Jul 2020 to 22 Jul 2021 period was 8.9 m/s.

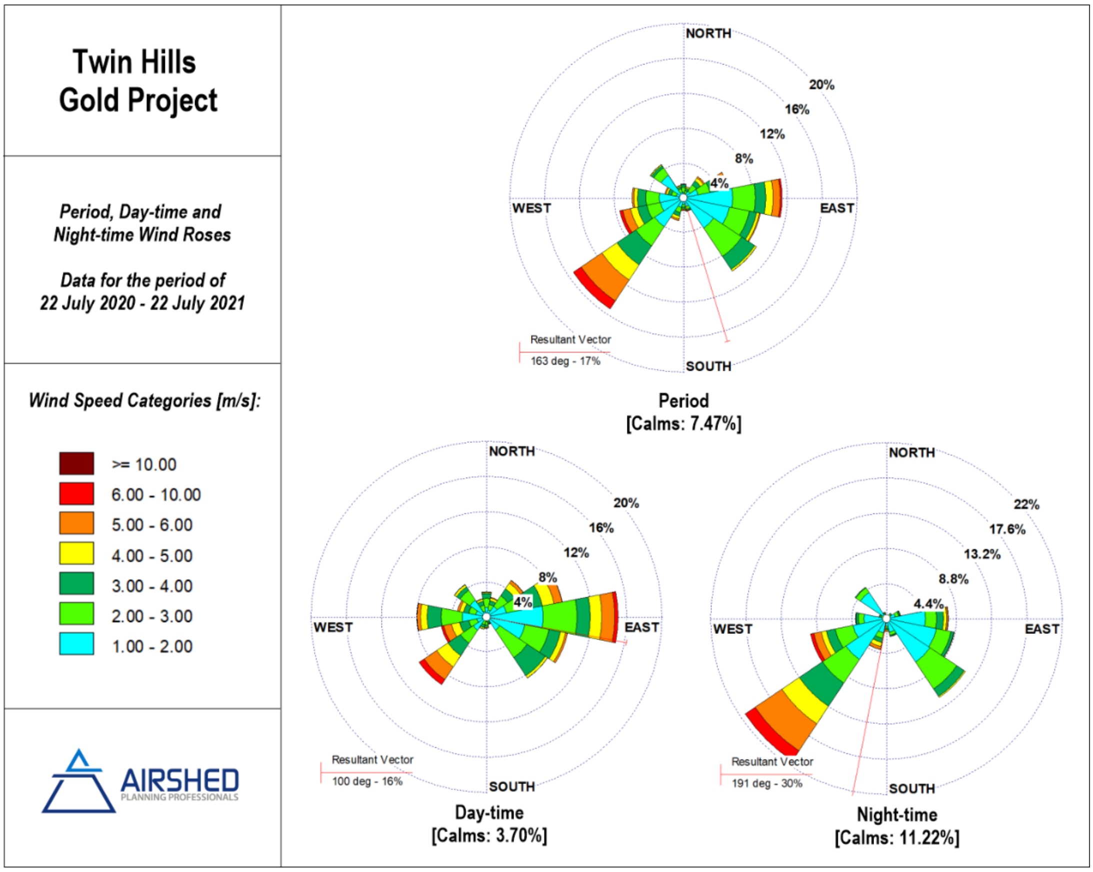

Figure 4: Period, day- and night-time wind roses based on Twin Hills on-site weather data (23 July 2020 – 22 July 2021)

Monthly variation in the wind field is shown in Figure 5. During the summer months November to February, the south-westerly winds dominate with infrequent weak winds from the east. In March the wind field changes to dominant easterly winds and less frequent south-westerly winds. During April the wind field shifts slightly to the southeast, but with strong, although less frequent easterly winds are associated with the so called "East wind conditions". The south-easterly winds prevail during the months of May to July. In August winds from the northwest dominates followed by strong easterly winds, whereafter the wind field shifts to strong south-westerly winds and frequent, but weaker, easterly winds in September.

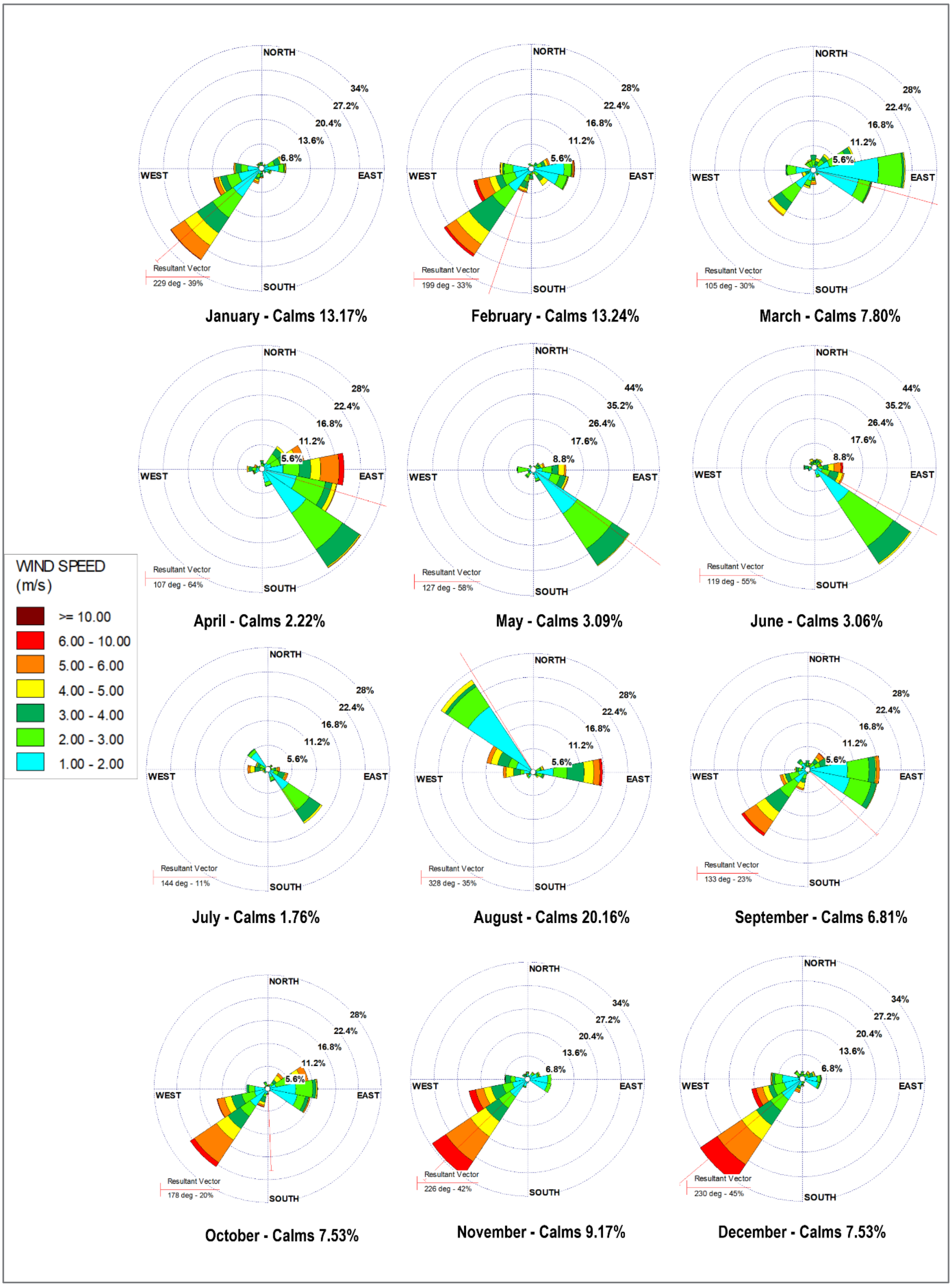

Figure 5: Monthly wind roses based on Twin Hills on-site weather data (23 July 2020 – 22 July 2021)

According to the Beaufort wind force scale (https://www.metoffice.gov.uk/guide/weather/marine/beaufort-scale), wind speeds between 6-8 m/s equate to a moderate breeze, with wind speeds between 14-17 m/s near gale force winds. Based on the available data for the period Jul 2020 – Jul 2021, wind speeds fell mostly in the 1-2 m/s category with winds exceeding 8 m/s only for 0.05% (Figure 6). Winds exceeding 5 m/s occurred for 7.5% of the time, with a maximum wind speed of 8.9 m/s. The average wind speed over the period was 2.3 m/s. Calm conditions (wind speeds <1 m/s) occurred for 7.5% of the time (Figure 6). The likelihood for wind erosion to occur from open and exposed surfaces, with loose fine material, but taking into account that the natural surfaces are crusted, was estimated when the wind speed exceeds 10 m/s (Liebenberg-Enslin, et al., 2019), whereas the estimated wind speed threshold for gold tailings is 8.8 m/s (Liebenberg-Enslin, 2014). Wind speeds exceeding 10 m/s occurred for 0% over the period, and 0.01% of the time above 8.8 m/s.

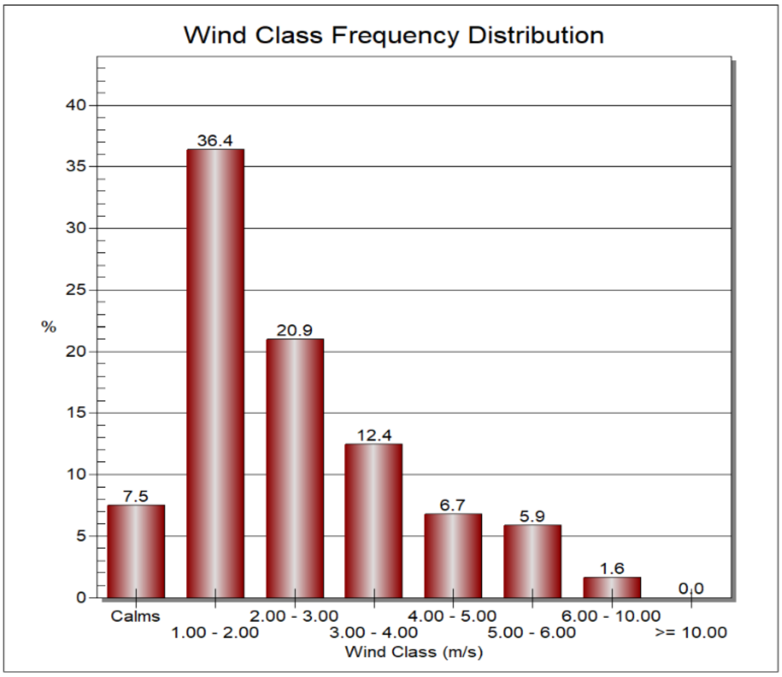

Figure 6: Wind speed categories based Twin Hills meteorological data (23 July 2020 – 22 July 2021)

3.2.2 Temperature

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

Minimum, average, and maximum temperatures for the study area are given as -3°C, 23°C and 42°C respectively, based on Twin Hills weather data for the period Jul 2020 – Jul 2021 (Figure 7).

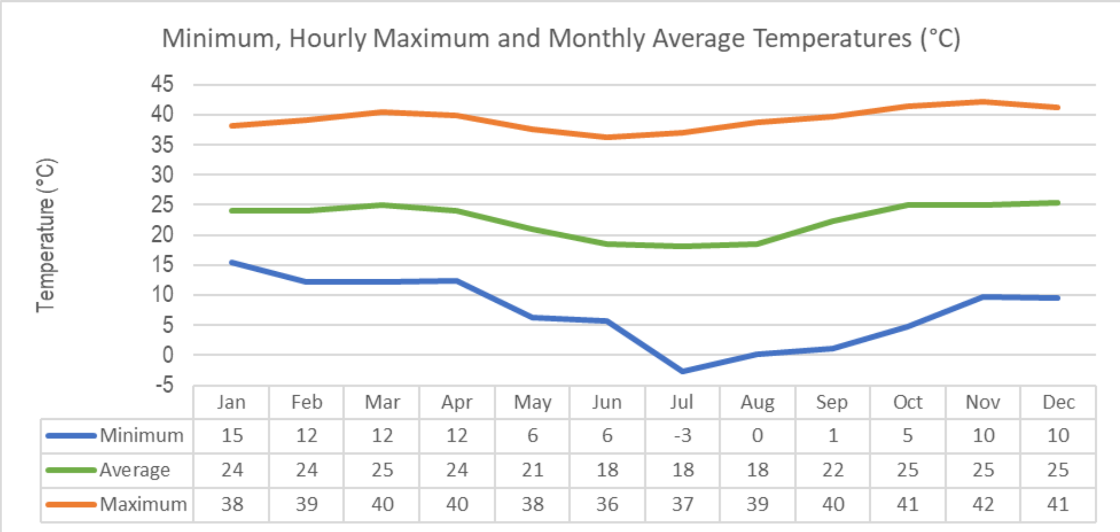

Figure 7: Daily minimum, average, and maximum temperatures based on Twin Hills meteorological data (23 July 2020 – 22 July 2021)

3.2.3 Precipitation

Precipitation is important to air pollution studies since it represents an effective removal mechanism for atmospheric pollutants and inhibits dust generation potentials. Monthly average rainfall figures obtained from the Twin Hills weather station data are illustrated in Figure 8. Annual rainfall for July 2020 to June 2021 is 254 mm, with the highest rainfall of 115 mm in January 2021.

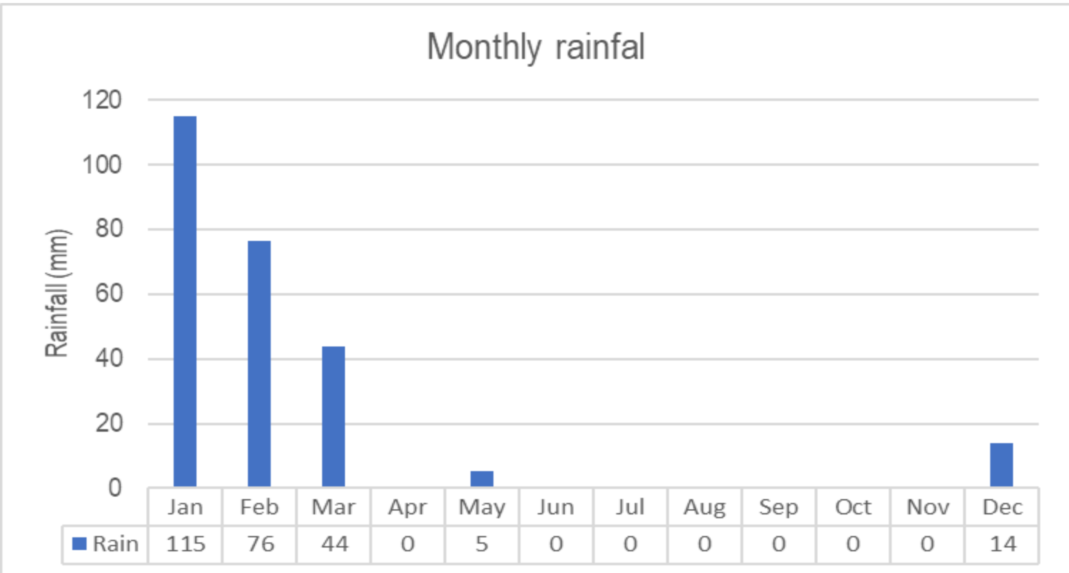

Figure 8: Average rainfall based on Twin Hills meteorological data (23 July 2020 – 22 July 2021)

3.2.4 Atmospheric Stability

The new generation air dispersion models differ from the models traditionally used in several 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. 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 the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface and the predominance of an unstable layer. In unstable conditions, ground level pollution is readily dispersed thereby reducing ground level concentrations. Elevated emissions, however, such as those released from a chimney, are returned more readily to ground level, leading to higher ground level concentrations.

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 less dilution potential. During windy and/or cloudy conditions, the atmosphere is normally neutral (which causes sound scattering in the presence of mechanical turbulence). For low level releases, the highest ground level concentrations would occur during weak wind speeds and stable (night-time) atmospheric conditions.

Atmospheric stability is frequently categorised into one of six stability classes – these are briefly described in Table 10 with the percentage time each class occurred during the 12 months. For low level releases, such as mining operations, the highest ground level concentrations would occur during weak wind speeds and stable (night-time) atmospheric conditions (Category E), which relates to on average 7% of the time at the proposed Project site. However, windblown dust is likely to occur under high winds (neutral conditions – Category D) which accounted for 5% of the time, on average. Stack releases, such as from the power generators and smelter stacks, unstable conditions (Category C – 22%) can result in very high concentrations of poorly diluted emissions close to the stack. Neutral conditions disperse the plume equally in both the vertical and horizontal planes and the plume shape is referred to as coning. Stable conditions (Category E) prevent the plume from mixing vertically, although it can still spread horizontally and is called fanning (Tiwary & Colls, 2010).

Table 10: Atmospheric stability classes: Frequency of occurrence for the period 23 July 2020 – 22 July 2021

Designation	Stability Class	Atmospheric Condition	Frequency of occurrence
A	Very unstable	calm wind, clear skies, hot daytime conditions	12%
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	5%
E	Stable	moderate wind, slightly overcast night-time conditions	7%
F	Very stable	low winds, clear skies, cold night-time conditions	42%

3.3 Current Ambient Air Quality

3.3.1 Existing Sources of Atmospheric Emissions in the Area

The Project falls within the eastern part of the Erongo Region. The main air pollution sources within the region, as identified during the 2019 air quality study as part of the SEMP AQMP (Liebenberg-Enslin, et al., 2019), include current mining and quarry operations, exploration activities, public roads (paved, unpaved and salt/treated), and natural exposed areas prone to wind erosion. In addition, there are several other sources emitting particulate matter (PM) such as small boilers and incinerators, commercial activities, charcoal packaging, construction activities (roads, buildings, etc.), and marine aerosols (sea salts and organic matter originating from the Atlantic Ocean).

The main pollutant of concern would be particulate matter (TSP; PM_{10} and $PM_{2.5}$) resulting from vehicle entrainment on the roads (paved, unpaved, and treated surfaces), windblown dust, and mining and exploration activities. Gaseous pollutants such as SO_2, NOx, CO and CO_2 would result from vehicles and combustion sources, but these are expected to be at low concentrations due to the few combustion sources in the region.

3.3.1.1 Vehicle entrainment from roads

Particulate emissions from roads occur when the force of the wheels on the road surface grinds the surface material into finer particles which are then lifted by the rolling wheels and kept in suspension due to the turbulent wake behind the vehicle (U.S. EPA, 2011). Dust emissions from paved and unpaved roads varies linearly with the volume of traffic. In addition, a number of parameters influence the surface condition of a particular road, such as average vehicle speed, mean vehicle weight, silt content of road material, and road surface moisture, and these will thus impact on dust emissions (U.S. EPA, 2006).

The national road to the south (B2) of the Project is a paved road and one of the main routes from Windhoek to Swakopmund, resulting in one of the road sections with the highest traffic in the region. During the SEMP AQMP, the emissions from these roads were quantified based on vehicle estimated annual average daily traffic (EAADT) figures, as provided by the Namibian Roads Authority (RA) for the year 2016. The vehicle kilometres travelled per day (VKT/day) on the paved B2 were calculated to be 224,722. Vehicle entrainment from the B2 was calculated to be a significant contributor at 29% to the regional paved road $PM_{2.5}$ and PM_{10} emissions. The C33, is a paved road connecting the Karibib Airport to the B2 and will be used to connect the mine to the B2. This road was not accounted for in the SEMP study but is assumed to have very low traffic counts[5].

Dispersion modelling was conducted to identify the main contributing sources to the measured PM_{10} and $PM_{2.5}$ concentrations. Modelled results indicated that vehicle entrainment from roads (paved, unpaved, and salt/treated surfaces) are the main contributing sources of PM_{10} and $PM_{2.5}$ emissions, but mostly affecting receptors close to the roads. Vehicle entrained emissions from the paved B2 are likely to be a significant background source of PM_{10} and $PM_{2.5}$ concentrations at the Project.

3.3.1.2 Windblown dust

Windblown particulates from natural exposed surfaces, mine waste facilities, and product stockpiles can result in significant dust emissions with high particulate concentrations near the source locations, potentially affecting both the environment and human health.

Wind erosion is a complex process, including three different phases of particle entrainment, transport, and deposition. 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

[5] This will be confirmed with the Traffic Specialist to include in the impact assessment phase.

influence the removal potential. For a natural environment such as the gravel plains of the Erongo Region, the threshold friction velocity was estimated to be 10 m/s and above due to the crusting effect of the soil surface.

In the quantification of windblown fugitive PM, use was made of the Airshed inhouse ADDAS model taking into account the particle size distribution (PSD); moisture content; particle density and friction threshold velocity. Windblown dust from natural exposed areas within the entire Erongo Region regarded to be prone to wind erosion (16,170 km²), resulted in high emissions ranging between 11 g/m²/year for $PM_{2.5}$ and 15 g/m²/year for PM_{10}. When reported as a soil (PM) loss per square metre (m²), the erosion losses seem reasonable when compared to other reported soil/PM_{10} losses due to wind erosion (Pi et al., 2018; Schepanski, 2018). The percentage hours where emission rates occurred ranged between 0.1% and 2.1%, which is in line with wind speeds exceeding 10 m/s. Wind speeds at the Twin Hills weather station exceeded 10 m/s for 0% of the time over the 12 months of available data. Windblown dust from natural exposed surfaces at and around the Project is regarded to be an insignificant source of particulate matter.

3.3.1.3 Mines and Exploration operations

Pollutants typically emitted from mining and quarrying activities are particulates, with smaller quantities associated with vehicle exhaust emissions. Mining and quarrying activities, especially open-cast mining methods, as well as exploration activities, emit pollutants near ground-level over (potentially) large areas. Source activities resulting in significant dust emissions include: drilling and blasting; materials handling (loading, unloading, and tipping); crushing and screening; windblown dust (from the sources as described above); access roads; and plant stack emissions.

Mines in proximity to the proposed Project are Navachab Gold Mine located west-southwest of Karibib, approximately 20 km from Twin Hills Gold Project, and a number of marble quarries – Capra Hill, Dreamland and Savanna Marble.

Emissions quantified for the various mines in the region as part of the SEMP AQMP (Liebenberg-Enslin, et al., 2019), indicated vehicle entrained dust from on-site haul roads and access roads (combination of paved and unpaved road surfaces) to be the main contributing source to PM_{10} emissions. The largest source of $PM_{2.5}$ emissions was windblown dust mainly derived from the mining TSFs. Crushing and screening operations were identified as the third largest source of PM emissions followed by materials handling.

From the regional dispersion model, mining and quarry operations were the second highest dust sources. The impact range of these sources were a few kilometres from the mining operations, primarily within an east-west (or east-northeast and west-southwest) direction, not affecting the coastal towns but the nearby settlements.

3.3.1.4 Regional transportation of pollutants

Another source of air pollution is aerosols as a result of regional-scale transport of mineral dust and ozone (due to vegetation burning) from the north of Namibia (http://www.fao.org/docrep/005/x9751e/x9751e06.htm). Biomass burning is an incomplete combustion process (Cachier, 1992), with carbon monoxide, methane and nitrogen dioxide gasses 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. Formenti et al., (2018) attributed the recording of black carbon at Henties Bay to contributions from biomass burning and even from the SA highveld's coal fired power stations.

Evaporation of sea spray are also sources of airborne particles, whereas pollen grains, mould spores and plant and insect parts all contribute to the atmospheric particulate load. Marine aerosols may include sea salt as well as organic matter (O'Dowd and De Leew, 2007). Sea salt is a major atmospheric aerosol component on a global scale, with a significant impact on PM concentrations (O'Dowd and De Leew, 2007; Athanasopoulou et al., 2008; Kelly et al., 2010; Karaguliun et al., 2015). Aside from the primary contribution from sea salt, recent interest is on its role in chemical reactions (with gaseous emission) and on climate change (O'Dowd and De Leew, 2007; Kelly *et al.*, 2010). One of the findings from the SEMP AQMP was the contribution from the ocean (westerly sector) to PM_{10} concentrations at Swakopmund and Walvis Bay. The contribution from sea salts in the PM_{10} filters was confirmed through chemical analyses (Liebenberg-Enslin, et al., 2019). How far these sea salts can be transported inland is not known.

3.3.2 Existing Ambient Air Pollutant Concentrations in the Project Area

There is a dustfall monitoring network in place at the Project, but no ambient PM (PM_{10} and $PM_{2.5}$) monitoring network.

PM concentrations measured as part of the SEMP AQMP monitoring network were limited to the coastal towns of Swakopmund, Walvis Bay and Henties Bay with a station in the central western part of the region on the farm Jakalswater. None of these locations are representative of the air quality in the Karibib area.

3.3.3 Dustfall monitoring data for the Project

The dustfall monitoring network was initiated in June 2020 and comprises of eight (8) single dustfall units (Figure 1).

Dustfall deposition rates from the Twin Hills monitoring network for the period June 2020 to June 2021 are presented in Figure 9. Dustfall rates are generally low for the sampling period and well within the dustfall limit of 600 mg/m²/day (adopted limit for residential areas) and 1 200 mg/m²/day (adopted limit for non-residential areas). Dustfall rates were the lowest during the months of June to September 2020 and might have been influenced by the regional lockdown due to COVID-19. It should be noted that no exchanges were made as a result of this in August, hence the reason for the combined Aug/Sep period. The highest dustfall was collected at AQ-02 during October 2020 (422 mg/m²/day) and March 2021 (520 mg/m²/day), followed by AQ-07 in January 2021 (502 mg/m²/day) and AQ-03 in April 2021 (403 mg/m²/day).

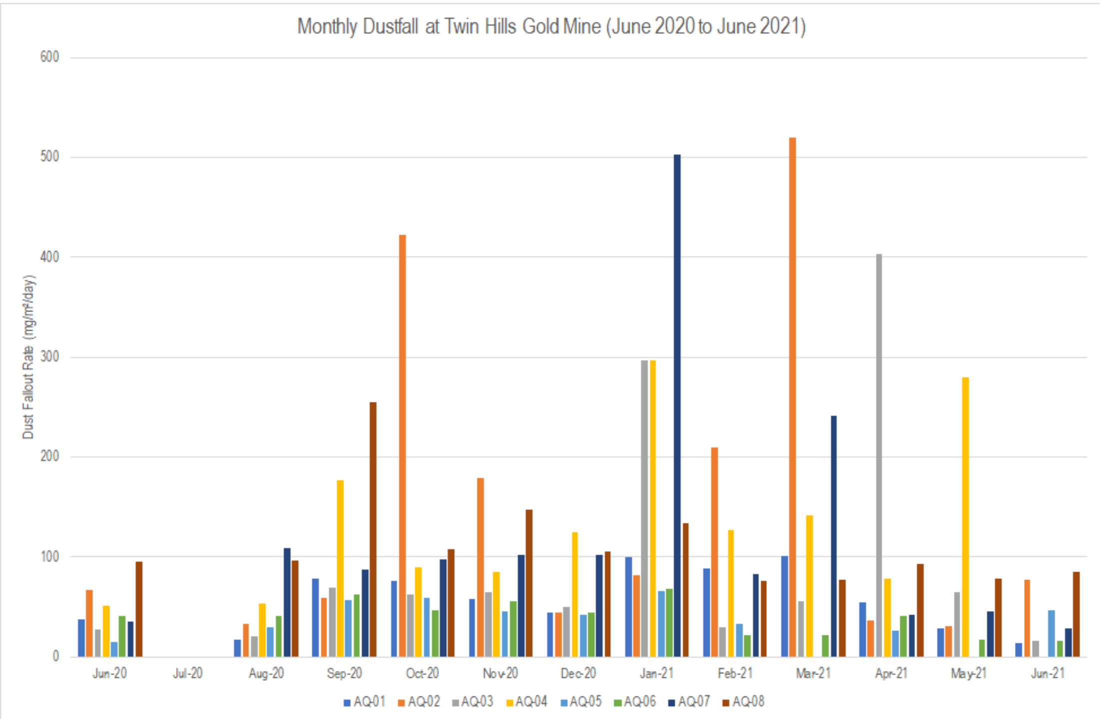

Figure 9: Dustfall rates for Project monitoring (Jun 2020 – Jul 2021)

The dustfall rates show slight spatial and temporal variation across the site as shown in Figure 10. The dustfall rates are presented as a daily average over the 12-month period (June 2020 – June 2021), with no clear spatial trend visible. AQ-01, AQ-03, AQ-05 and AQ-06 had the lowest average dustfall over the period with the rest slightly higher.

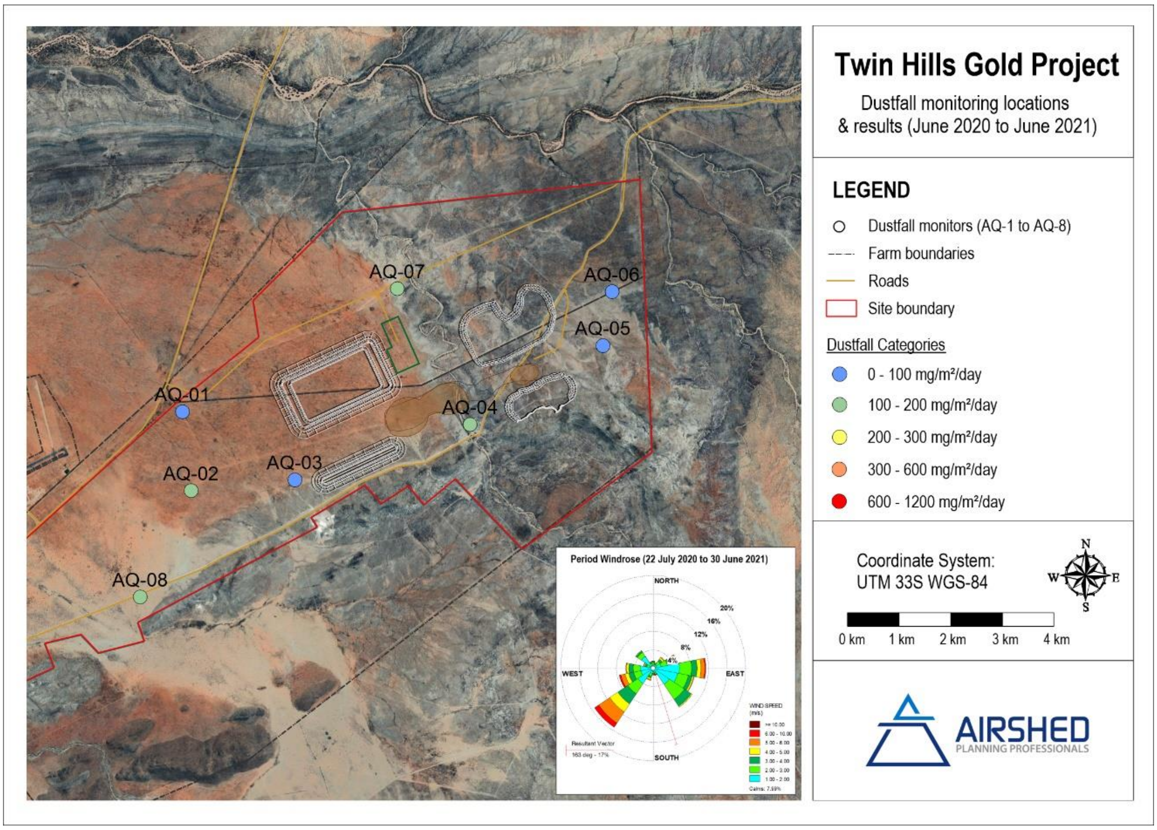

Figure 10: Spatial representation of the dustfall rates at Project, with dustfall as a daily average over the period Jun 2020 – Jul 2021

4 IMPACT ASSESSMENT

The emissions inventory, dispersion modelling and results are discussed in Section 4.1, 4.2 and Section 4.3 respectively.

4.1 Atmospheric Emissions

4.1.1 Construction Phase

Construction normally comprises a series of different operations including land clearing, topsoil removal, material loading and hauling, stockpiling, grading, bulldozing, compaction, etc. Most of the infrastructure such as surface haul roads and stockpiles required for the Life of Mine (LOM) will be constructed during the first year of mining. WRDs will progress over time with haul trucks tipping the waste on the top elevation of the dumps with the dozers pushing the waste material down. These actions will cause the WRDs to progress horizontally over time. The WRDs are located as close to the pit exits as possible in order to optimise productivity and minimise waste mining costs. ROM pad stockpiles will be constructed in close vicinity to the primary crusher tipping point in order to minimise the reclamation costs. Other infrastructure will include a power line connection to the 220 kV national grid through the Khan-Marble 66 kV line, and a water pipeline connection from the NamWater Karibib Regional State Water Scheme (Moeller, 2021).

The main pollutant of concern from 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.

All operations associated with the construction phase are listed in Table 1. Each of the operations has their own duration and potential for dust generation. It is therefore 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 due to their temporary nature and duration, and the likelihood that these activities will not occur concurrently at all portions of the site; dispersion simulation was not undertaken for construction emissions.

The US EPA documents emission factors which aim to provide a general rule-of-thumb as to the magnitude of emissions which may be anticipated from construction operations (US EPA, 2006). The quantity of dust emissions is assumed to be proportional to the area of land being worked and the level of construction activity. The approximate emission factors for general construction activity operations are given as:

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

The PM_{10} fraction is given as ~39% of the US EPA total suspended particulate factor. These emission factors are most applicable to construction operations with (i) medium activity levels, (ii) moderate silt contents, and (iii) semiarid climates. The emission factor for TSP considers 42 hours of work per week of construction activity. Test data were not sufficient to derive the specific dependence of dust emissions on correction parameters, and because the above emission factor is referenced to TSP, use of this factor to estimate PM_{10} emissions will result in conservatively high estimates. Also, because derivation of the factor assumes that construction activity occurs 30 days per month, the above estimate is somewhat conservatively high for TSP as well.

Areas assumed to be cleared of vegetation for infrastructure development and mining preparation are listed in Table 11. Assuming all areas to be developed simultaneously, the resulting emission estimates are 27 782 tpa for TSP, 10 835 tpa for PM_{10} and 5 417 tpa for $PM_{2.5}$.

Table 11: Construction areas

Mining Area	Area (m^2)	Area (ha)
Processing Plant Area	410 000.00	41.00
Surface road construction	277 020.03	27.70
Twin Hills & Bulge (Pit clearing)	1 003 604.82	100.36
Clouds (Pit clearing)	168 202.75	16.82
WRDs	6 747 645.63	674.76
Total	**8 606 473.24**	**860.65**

4.1.2 Operational Phase

Quantification of emissions from the proposed Project are restricted to fugitive releases (non-point releases) as listed in Table 2. Particulates are the main pollutant of concern from mining operations. Gaseous emissions (i.e. SO_2, NO_x, CO and VOCs) will primarily result from diesel combustion, both from mobile and stationary sources. Point-source releases will be limited to the Kiln stack, Roaster/ Dryer stack, and Furnace stack, with the resulting emissions only qualitatively assessment and not quantified or modelled since no design parameters (stack height, stack diameter, exit temperature, volumetric flow rates, etc.) were available. These sources are intermittent sources, not operating continuously, and are therefore expected not to result in significant impacts.

Mining will commence at two open pit areas: Twin Hills & Bulge and Clouds. Ore production is estimated at 3.5 million tons per annum (mtpa), realising a total production of 50.39 million tons over the life of mine (LOM) which is estimated at 15 years.

Two mining scenarios were selected to be assessed in an attempt to determine the worst-case impacts, based on the mining rates as well as hauling distances from the open pits to the ROM pad and WRDs. The two scenarios assessed are:

- **Operational Year 7** (Scenario 1) – representative of maximum throughput from Clouds pit of 1.85 mtpa of ore, and 0.32 mtpa from Twin Hills & Bulge, and a total of 22.89 mtpa of waste rock.
- **Operational Year 10** (Scenario 2) – representative of maximum throughput from Twin Hills & Bulge pits of 4.25 mtpa of ore and 20.75 mtpa of waste.

The emission equations used to quantify emissions from the proposed activities are shown in Table 12.

For each scenario, both unmitigated and mitigated activities were assessed. The estimated control efficiencies as obtained from literature (NPI, 2012) for the various mining activities are given in Table 13.

A summary of estimated particulate emissions from the proposed Project operations is provided in Table 14 for Scenario 1 and in Table 15 for Scenario 2, with the gaseous emissions provided in Table 16.

Table 12: Emission equations used to quantify fugitive dust emissions from the proposed Project

<table>
<tr><th>Activity</th><th>Emission Equation</th><th>Source</th><th>Information assumed/provided</th></tr>
<tr><td>Drilling</td><td>Emission factors
<table><tr><th>TSP</th><th>PM_{10}</th><th>$PM_{2.5(}$</th><th>Unit</th></tr><tr><td>0.59</td><td>0.31</td><td>0.31</td><td>kg/hole drilled</td></tr></table></td><td>NPI Section: Mining (NPI, 2012)</td><td>Total number of drill holes per year:
Year 7: 8 785 (ore) and 95 351 (waste)
Year 10: 17 157 (ore) and 86 427 (waste)
201 holes for ore and 1 808 holes for waste rock
Drill hole sizes:<table><tr><td>Length (m)</td><td>Hole diameter (mm)</td><td>Spacing (m)</td><td>Bench height (m)</td></tr><tr><td>10.7</td><td>102</td><td>3.2</td><td>10</td></tr></table>Hours of operation were given as 24 hours per day, 7 days a week, 360 days per year.</td></tr>
<tr><td>Blasting</td><td>$$E = 0.00022 \cdot (A)^{1.5}$$Where,
E = Emission factor (kg dust / t transferred)
A = Blast area (m^2)

The $PM_{2.5}$, PM_{10} and TSP fraction of the emission factor is 5.3%, 35% and 74% respectively.</td><td>NPI Section: Mining (NPI, 2012)</td><td>Blast areas were calculated accounting for the drill hole length; spacing; hole diameter; and total number of holes. Total blast area over a year:
Year 7: 135 091 m^2
Year 10: 122 448 m^2
2 blasts per week, 103 blast per year.
This was assumed to be the same for Scenario 1 and Scenario 2
Since blasting is an intermittent source, lasting for a couple of minutes, this is not included in the dispersion model.</td></tr>
<tr><td>Materials handling</td><td>$$E = 0.0016 \frac{\left(U/_{2.2}\right)^{1.3}}{\left(M/_{2}\right)^{1.4}}$$Where,
E = Emission factor (kg dust / t transferred)
U = Mean wind speed (m/s)
M = Material moisture content (%)

The $PM_{2.5}$, PM_{10} and TSP fraction of the emission factor is 5.3%, 35% and 74% respectively.</td><td>US-EPA AP42 Section 13.2.4 (US EPA, 2006)</td><td>The moisture content of materials are as follows:
Ore: 3% (provided)
Waste: 3% (provided)
The respective throughput of materials during the operational phase was calculated as:<table><tr><th>Scenario</th><th>Pit</th><th>Ore (tpa)</th><th>Waste (tpa)</th><th>Total (tpa)</th></tr><tr><td rowspan="3">1 (Year 7)</td><td>Pit 1: Twin Hills & Bulge</td><td>322 334.78</td><td>3 390 706.20</td><td>3 713 040.98</td></tr><tr><td>Pit 2: Clouds</td><td>1 854 116.36</td><td>19 503 833.31</td><td>21 357 949.67</td></tr><tr><td>ROM Pad Ore Piles [(a)]</td><td>9 546 711.92</td><td></td><td></td></tr><tr><td rowspan="2">2 (Year 10)</td><td>Pit 1: Twin Hills & Bulge</td><td>4 250 639.68</td><td>20 751 852.49</td><td>25 002 492.18</td></tr><tr><td>ROM Pad Ore Piles [(a)]</td><td>6 335 290.01</td><td></td><td></td></tr></table>Notes: [(a)] ROM stockpiles will be classified according to marginal-, low-, medium 1-, medium 2- and high-grade bins.

Operational hours: 8 646 hours per year (360.25 days, 24 hours per day)</td></tr>
</table>

<table>
<tr><th>Activity</th><th>Emission Equation</th><th>Source</th><th>Information assumed/provided</th></tr>
<tr><td></td><td></td><td></td><td>Average wind speed of 2.3 m/s, from on-site weather data (period 23 Jul 2020 to 22 Jul 2021).</td></tr>
<tr><td>Front-end-loader (FEL)</td><td>Emission factors
<table>
<tr><th>TSP</th><th>PM_{10}</th><th>$PM_{2.5}$ [(a)]</th><th>Unit</th></tr>
<tr><td>0.47</td><td>0.026</td><td>0.004</td><td>kg/tonne</td></tr>
</table>
Notes: [(a)] Fraction assumed to be the same fraction as for Materials Handling</td><td>NPI Section: Mining (NPI, 2012)</td><td>The location of operation and handling rates are:
<table>
<tr><th>Scenario</th><th>Description</th><th>Handling rate (tph)</th></tr>
<tr><td rowspan="3">1 (Year 7)</td><td>FEL - ore in Pit 1</td><td>37.28</td></tr>
<tr><td>FEL - ore in Pit 2</td><td>214.45</td></tr>
<tr><td>FEL - ore ROM pad stockpiles</td><td>1 104.18</td></tr>
<tr><td rowspan="2">2 (Year 10)</td><td>FEL - ore in Pit 1</td><td>491.63</td></tr>
<tr><td>FEL - ore ROM pad stockpiles</td><td>732.74</td></tr>
</table>
.</td></tr>
<tr><td>Bulldozing</td><td>$$E = k \cdot (s)^{a} / (M)^{b}$$
Where,
E = Emission factor (kg/hr/vehicle)
s = Material silt content (%)
M = Material moisture content (%)
<table>
<tr><th></th><th>k</th><th>a</th><th>b</th></tr>
<tr><td>TSP</td><td>2.6</td><td>1.2</td><td>1.3</td></tr>
<tr><td>PM_{10}</td><td>0.34</td><td>1.5</td><td>1.4</td></tr>
</table></td><td>NPI Section: Mining (NPI, 2012)</td><td>The location of operation and number of dozers are:
<table>
<tr><th>Scenario</th><th>Description</th><th>Areas</th><th>No of Dozers</th></tr>
<tr><td rowspan="2">1 (Year 7)</td><td>Track Dozer - dumps & loading area</td><td>WRD 2, WRD3 & WRD4</td><td>2.33</td></tr>
<tr><td>Wheel Dozer - loading area & ramp cleaning</td><td>ROM pad Stockpiles</td><td>3.00</td></tr>
<tr><td rowspan="2">2 (Year 10)</td><td>Track Dozer - dumps & loading area</td><td>WRD 1, WRD 2 & WRD3</td><td>2.33</td></tr>
<tr><td>Wheel Dozer - loading area & ramp cleaning</td><td>ROM pad Stockpiles</td><td>3.00</td></tr>
</table>
The moisture content of materials are as follows:
Ore: 3% (provided)
Waste: 3% (provided)
The silt content of materials are as follows:
In pit: 25.2% (assumed same as in pit roads)
WRDs: 13% (assumed same as surface haul roads)</td></tr>
<tr><td>Graders</td><td>$$E = 0.0034 \cdot (S)^{a}$$
Where,
E = Emission factor (kg/VKT)
s = Material silt content (%)
M = Material moisture content (%)
<table>
<tr><th></th><th>TSP</th><th>PM_{10}</th></tr>
<tr><td>a</td><td>2.5</td><td>2.0</td></tr>
</table></td><td>NPI Section: Mining (NPI, 2012)</td><td>The location of operation and VKT/year are:
<table>
<tr><th>Scenario</th><th>Description</th><th>VKT/year</th></tr>
<tr><td rowspan="2">1 (Year 7)</td><td>Grader in Pit 1</td><td>66 442.02</td></tr>
<tr><td>Grader in Pit 2</td><td>66 442.02</td></tr>
<tr><td>2 (Year 10)</td><td>Grader in Pit 1</td><td>132 884.03</td></tr>
</table>
Grader speed was taken as 22 km/hr</td></tr>
</table>

Activity	Emission Equation	Source	Information assumed/provided
Vehicle entrainment on unpaved surfaces (mine roads)	$E = k\left(\frac{s}{12}\right)^{a}\left(\frac{W}{3}\right)^{b}\cdot 281.9$ Where, E = particulate emission factor in grams per vehicle km travelled (g/VKT) k = basic emission factor for particle size range and units of interest s = road surface silt content (%) W = average weight (tonnes) of the vehicles travelling the road The particle size multiplier (k) is given as 0.15 for $PM_{2.5}$ and 1.5 for PM_{10}, and as 4.9 for TSP The empirical constant (a) is given as 0.9 for $PM_{2.5}$ and PM_{10}, and 4.9 for TSP The empirical constant (b) is given as 0.45 for $PM_{2.5}$, PM_{10} and TSP	US-EPA AP42 Section 13.2.2 (U.S. EPA, 2006)	Truck/ vehicle information:

Information	Unit	Year 7	Year 7 & 10	Year 10
		Haul Truck	Water Tanker	Haul Truck
No. of Trucks		22	2	25
Onsite truck Payload	ton	86.45	36	86.45
Average weight	ton	115	48	115
Average weight on road [(a)]	ton	**20.33**		**23.30**
Average speed [(b)]	km/hr	40	20	40

Notes: [(a)] equation requires average weight of all vehicles on road section.
[(b)] assumed

Vehicle kilometre travelled (VKT) were calculated from road lengths, truck capacities and the number of trips required for transporting materials.

Scenario 1 (Year 7)

Road Description	Material	Length (m)	Trips/hour		VKT/hour
			Haul Truck	Water Tanker	
Pit 1 in-pit road	ore + waste	983.52	5.26	2.03	7.18
Pit 1 to WRD 3	waste	2 009.02	4.81	1.00	11.66
Pit 1 to ROM Sp	ore	1 102.65	0.46	1.81	2.50
Pit 2 in-pit road	ore + waste	980.39	30.28	2.04	31.69
Pit 2 to WRD 2b	waste	961.59	13.83	2.08	15.30
Pit 2 to WRD 4	waste	514.86	13.83	3.88	9.12
Pit 2 to ROM Sp	ore	2 581.11	2.63	0.77	8.79

Scenario 2 (Year 10)

Road Description	Material	Length (m)	Trips/hour		VKT/hour
			Haul Truck	Water Tanker	
Pit 1 in-pit road	ore + waste	983.52	35.45	2.03	36.87
Pit 1 to WRD 1	waste	2 038.53	29.42	0.98	61.98
Pit 1 to WRD 2a	waste	961.59	29.42	2.08	30.29
Pit 1 to WRD 3	waste	2 009.02	29.42	1.00	61.11
Pit 1 to ROM Sp	ore + waste	1 102.65	6.03	1.81	8.65

Activity	Emission Equation	Source	Information assumed/provided
			Hours of operation: 24 hours (three 8-hour shifts hrs per day), 7 days per week Silt content (taken from Navachab Mine data): • In-pit roads: 25.2% (29.5% silt loading but US EPA cut-off at 25.2%) • Surface haul roads: 13% Layout of the roads between pits and ROM pad and WRDS were assumed – shortest distances were taken.
Vehicle entrainment on paved surfaces (access roads)	$EF = k \cdot (sL)^{0.91} \cdot (W)^{1.02}$ Where EF is the emission factor in g/vehicle kilometre travelled (VKT) k is the particle size multiplier (k_{TSP} – 3.23, k_{PM10} – 0.62, $k_{PM2.5}$ – 0.15) sL is the road surface material silt loading in g/m² W is the average weight vehicles in tonnes	US-EPA AP42 Section 13.2.1 (U.S. EPA, 2011)	Transport activities include the transport of consumables, product, and staff on the: • C33 tarred road, connecting the mine to the B2 at Karibib • Mine access road (from the C33) Truck/ vehicle information: (see table below) The road surface silt loading: • Access road: 9.7 g/m² (US EPA Table 13.2.1-4 Iron & Steel production) • Public road: 7.0 g/m² (US EPA Table 13.2.1-2 Baseline conditions for public roads).

Truck/ vehicle information:

Information	Unit	Year 7 & 10	
		Diesel Tanker	Busses
No. of Trucks		2	3
Onsite truck Payload	ton	28	0.98
Average weight [(b)]	ton	37.5	3.6
Average weight on road [(a)]	ton	**17.184**	
Operational Hours	hours/year	3 523	4 500

Notes: [(a)] equation requires average weight of all vehicles on road section.
[(b)] assumed

Road Description	Length (m)	Trips/hour	VKT/hour
Access road to plant	5 765.58	0.93	5.35
Public paved road (C33)	12 803.28	0.93	11.88

<table>
<tr><th>Activity</th><th>Emission Equation</th><th>Source</th><th>Information assumed/provided</th></tr>
<tr>
<td>Crushing and screening</td>
<td>Emission factors
<table>
<tr><th>Crushing</th><th>TSP</th><th>PM_{10}</th><th>$PM_{2.5}$[(a)]</th><th>Unit</th></tr>
<tr><td>Primary</td><td>0.2</td><td>0.02</td><td>0.01</td><td>kg/tonne</td></tr>
<tr><td>Secondary</td><td>0.6</td><td>0.04</td><td>0.02</td><td>kg/tonne</td></tr>
<tr><td>Tertiary</td><td>1.4</td><td>0.08</td><td>0.04</td><td>kg/tonne</td></tr>
</table>
Notes: [(a)] Fraction of $PM_{2.5}$ taken from US-EPA crushed stone emission factor ratio for tertiary crushing.

Where,
E = Default emission factor for low moisture content ore (moisture < 4%)</td>
<td>NPI Section: Mining (NPI, 2012)</td>
<td>The throughput of the ROM material was provided as 3 500 000 tpa for all operational years.

Hours of operation were given as 24 hrs per day, 7 days per week.

ROM moisture: 3%

3-stage crushing and ball milling.

Primary crushing assumed to be located near ROM pad.

Secondary assumed to be between the ROM pad and the plant.

Tertiary crushing assumed to be at the plant.</td>
</tr>
<tr>
<td>Wind Erosion</td>
<td>$$E(i) = G(i)10^{(0.134(\%clay)-6)}$$
For
$$G(i) = 0.261\left[\frac{P_a}{g}\right]u^{*3}(1+R)(1-R^2)$$
And
$$R = \frac{u_t^*}{u^*}$$
where,
$E_{(i)}$ = emission rate (g/m²/s) for particle size class i
P_a = air density (g/cm³)
G = gravitational acceleration (cm/s³)
u^*_t = threshold friction velocity (m/s) for particle size i
u^* = friction velocity (m/s)</td>
<td>(Marticorena & Bergametti, 1995)</td>
<td>Layout of WRDs, WRD/TSF and ROM stockpiles was provided, with areas, moisture content and particle density provided:
<table>
<tr><th>Dump/ Stockpile</th><th>Area (m²)</th><th>Moisture content (%)</th><th>Particle density (kg/m³)</th></tr>
<tr><td>WRD/TSF</td><td>3 190 572.08</td><td>3</td><td>2 690 [(a)]</td></tr>
<tr><td>WRD2</td><td>1 917 742.25</td><td>3</td><td>2 630</td></tr>
<tr><td>WRD3</td><td>831 116.22</td><td>3</td><td>2 630</td></tr>
<tr><td>WRD4</td><td>808 215.09</td><td>3</td><td>2 630</td></tr>
<tr><td>ROM Pad</td><td>40 000.00</td><td>3</td><td>2 750</td></tr>
</table>
Notes: [(a)] average assumed between ore and waste.

The moisture content and particle density were provided for waste material and ore.

Waste rock, ROM ore and tailings particle size distribution was obtained from similar processes (see Table 25).

Hourly emission rate file was calculated and simulated.

Threshold friction velocity (u^*) for the TSF was estimated at 7 m/s, and at 9.8 m/s for the WRDs and ROM stockpile.</td>
</tr>
</table>

<table>
<tr><th>Activity</th><th>Emission Equation</th><th>Source</th><th>Information assumed/provided</th></tr>
<tr><td>Gaseous Emissions from vehicle Exhausts</td><td>NPI single valued emission factors - Miscellaneous Industrial Vehicles
<table>
<tr><th>PM_{10}</th><th>$PM_{2.5}$</th><th>NOx</th><th>Unit</th></tr>
<tr><td>0.0012</td><td>0.0011</td><td>0.015</td><td>kg/kWh</td></tr>
<tr><td>1.27E-02</td><td>1.16E-02</td><td>1.59E-01</td><td>kg/L</td></tr>
<tr><th>CO</th><th>SO_2</th><th>VOC</th><th>Unit</th></tr>
<tr><td>0.0062</td><td>0.000008</td><td>0.0014</td><td>kg/kWh</td></tr>
<tr><td>6.56E-02</td><td>8.47E-05</td><td>1.48E-02</td><td>kg/L</td></tr>
</table></td><td>NPI single valued emission factors (NPI, 2008)</td><td>Hours of operation: 24 hours per day, 7 days per week.
Fuel (diesel) consumption supplied for equipment (Source: email W Moeller, 23/07/2021).
<table>
<tr><th>Diesel consumption sources</th><th>Unit</th><th>Year 7</th><th>Year 10</th></tr>
<tr><td>Hauling</td><td>litres</td><td>6 972 523</td><td>8 351 592</td></tr>
<tr><td>Loading</td><td>litres</td><td>3 123 366</td><td>3 098 726</td></tr>
<tr><td>Drilling</td><td>litres</td><td>3 021 501</td><td>2 738 720</td></tr>
<tr><td>Secondary [(a)]</td><td>litres</td><td>2 230 114</td><td>2 230 114</td></tr>
<tr><td>Tertiary [(b)]</td><td>litres</td><td>423 561</td><td>423 561</td></tr>
<tr><td>Total</td><td>litres</td><td>15 771 065</td><td>16 842 714</td></tr>
</table>
Notes: [(a)] FEL, dozers, diesel tanker, water tanker, grader.
[(b)] Other trucks, rock breaker, crane, forklift, busses, light delivery vehicles, etc.</td></tr>
</table>

Table 13: Estimated control efficiencies provided for mitigation measures applied to various mining operations (NPI, 2012)

Operation/Activity	Control method and emission reduction
Drilling	70% CE for water sprays
Blasting	No control
Unpaved surface haul roads	90% CE for water sprays with chemical suppressants
Unpaved in pit haul roads	50% CE for water sprays, level 1 watering (2 litres/m²/hr)
Paved public road	No control
Materials handling (loading and unloading)	50% CE for water sprays
FEL, Bulldozer and Grader in-pit	50% CE for water sprays
Crushing and screening	50% CE for water sprays keeping ore wet
Windblown dust from WRDs and stockpiles	No control

Note: CE is Control Efficiency

Table 14: Scenario 1 – Calculated emission rates from unmitigated and mitigated mining operations during Year 7

Activity/ Area of operation	Unmitigated			Mitigated		
	TSP (tpa)	PM_{10} (tpa)	$PM_{2.5}$ (tpa)	TSP (tpa)	PM_{10} (tpa)	$PM_{2.5}$ (tpa)
Drilling	61.44	32.28	16.96	30.72	30.67	16.88
Blasting	1 136.05	590.74	34.08	284.01	280.60	16.96
Materials Handling	40.90	19.34	2.93	20.45	9.67	1.46
Crushing & Screening	7 700.00	490.00	245.00	3 850.00	245.00	122.50
Unpaved Roads	3 077.35	1 033.94	103.39	1 204.80	413.11	41.31
Paved Roads	0.0066	0.0013	0.0003	0.0066	0.0013	0.0003
FEL	2 754.94	289.56	45.92	1 377.47	144.78	22.96
Dozer	1 170.21	295.96	44.82	585.10	147.98	22.41
Grader	512.84	207.74	32.95	256.42	103.87	16.47
WE (WRDs & Stockpiles)	11.28	2.88	0.80	11.28	2.88	0.80
Total	**16 465.01**	**2 962.45**	**526.86**	**7 620.26**	**1 378.56**	**261.76**

Table 15: Scenario 2 – Calculated emission rates from unmitigated and mitigated mining operations during Year 10

Activity/ Area of operation	Unmitigated			Mitigated		
	TSP (tpa)	PM_{10} (tpa)	$PM_{2.5}$ (tpa)	TSP (tpa)	PM_{10} (tpa)	$PM_{2.5}$ (tpa)
Drilling	61.11	32.11	16.87	30.56	30.51	16.79
Blasting	980.36	509.78	29.41	245.09	242.15	14.63
Materials Handling	37.04	17.52	2.65	18.52	8.76	1.33
Crushing & Screening	7 700.00	490.00	245.00	3 850.00	245.00	122.50
Unpaved Roads	6 613.81	2 134.64	213.46	2 092.57	689.59	68.96
Paved Roads	0.0066	0.0013	0.0003	0.0066	0.0013	0.0003
FEL	2 487.69	261.47	41.47	1 243.85	130.74	20.73
Dozer	1 170.21	295.96	44.82	585.10	147.98	22.41
Grader	512.84	207.74	32.95	256.42	103.87	16.47
WE (WRDs & SP)	11.28	2.88	0.80	11.28	2.88	0.80
Total	**19 574.35**	**3 952.11**	**627.44**	**8 333.40**	**1 601.47**	**284.63**

Scenario 2 (Year 10) would result in total higher emission rates for TSP, PM_{10} and $PM_{2.5}$ compared to Scenario 1 (Year 7). This is due to almost double the ore to be mined during Year 10 compared to Year 7, resulting in more truck trips from the pit to the ROM pad, hence doubling the emissions from haul roads. Other activities such as drilling and blasting, materials

handling and FEL operations are slightly lower for Scenario 2, with all other activities remaining the same. With the proposed mitigation measures in place, PM emissions would reduce by between 54% and 59%.

Table 16: Calculated emission rates from all mobile combustion sources for Year 7 and Year 10

Mobile fuel usage	PM_{10} (tpa)	$PM_{2.5}$ (tpa)	NOx (tpa)	CO (tpa)	SO_2 (tpa)	VOC (tpa)
Scenario 1 (Year 7)	200.29	183.60	2 503.66	1 034.85	1.34	233.67
Scenario 1 (Year 10	213.90	196.08	2 673.78	1 105.16	1.43	249.55

The main pollutant of concern from mobile combustion is NOx (Table 16).

4.1.3 Closure and Decommissioning Phase

It is assumed that all the operations will have ceased by the closure phase of the project. The potential for impacts during this phase will depend on the extent of rehabilitation efforts during closure. Aspects and activities associated with the closure phase of the proposed operations are listed in Table 17. Simulations of the closure and decommissioning phases were not included in the current study due to its temporary impacting nature.

Table 17: Activities and aspects identified for the closure and decommissioning phase

Impact	Source	Activity
PM emissions	WRDs, Stockpiles and mine pits	Dust generated during rehabilitation activities
PM emissions	Plant and infrastructure	Demolition of the process plant and infrastructure
Gas emissions	Vehicles	Tailpipe emissions from vehicles utilised during the closure phase

4.2 Atmospheric Dispersion Modelling

The impact assessment of the project’s operations on the environment is discussed in this section. To assess impact on human health and the environment the following important aspects need to be considered:

- The criteria against which impacts are assessed (Section 2.5);
- The potential of the atmosphere to disperse and dilute pollutants emitted by the project (Section 3.2); and
- The AQSRs in the vicinity of the proposed mine (Section 3.1).

The impact of proposed operations on the atmospheric environment was determined through the simulation of ambient pollutant concentrations. Dispersion models simulate 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 of various sources. Increasing reliance has been placed on concentration estimates from models as the primary basis for environmental and health impact assessments, risk assessments and emission control requirements. It is therefore important to carefully select a dispersion model for the purpose.

4.2.1 Dispersion Model Selection

For the purpose of the current study, it was decided to use the Atmospheric Dispersion Modelling System (ADMS) developed by the Cambridge Environmental Research Consultants (CERC). CERC was established in 1986, with the aim of making use of new developments in environmental research from Cambridge University and elsewhere for practical purposes. CERC's leading position in environment software development and associated consultancy has been achieved by encapsulating advanced scientific research into a number of computer models which include ADMS 5. This model simulates a wide range of buoyant and passive releases to the atmosphere either individually or in combination. It has been the subject of a number of inter-model comparisons (CERC, 2004), one conclusion of which is that it tends provide conservative values under unstable atmospheric conditions in that it predicts higher concentrations than the older models close to the source.

ADMS 5 is a new generation air dispersion model which differs from the regulatory models traditionally used in a number of aspects, the most important of which are the description of atmospheric stability as a continuum rather than discrete classes (the atmospheric boundary layer properties are described by two parameters; the boundary layer depth and the Monin-Obukhov length, rather than in terms of the single parameter Pasquill Class) and in allowing more realistic asymmetric plume behaviour under unstable atmospheric conditions. Dispersion under convective meteorological conditions uses a skewed Gaussian concentration distribution (shown by validation studies to be a better representation than a symmetric Gaussian expression).

ADMS 5 is currently used in many countries worldwide and users of the model include Environmental Agencies in the UK and Wales, the Scottish Environmental Protection Agency (SEPA) and regulatory authorities including the UK Health and Safety Executive (HSE). Concentration and deposition distributions for various averaging periods may be calculated. It has generally been found that the accuracy of off-the-shelf dispersion models improve with increased averaging periods. The accurate prediction of instantaneous peaks is the most difficult and are normally performed with more complicated dispersion models specifically fine-tuned and validated for the location. For the purposes of this report, the shortest time period modelled is one hour.

4.2.2 Meteorological Requirements

Hourly meteorological data for the period 23 July 2020 to 22 July 2021 from the Twin Hills on-site weather station was utilised for the dispersion simulations.

4.2.3 Source Data Requirements

ADMS 5 model is able to model point, jet, area, line and volume sources. Sources were modelled as follows:

- Paved and unpaved roads – modelled as area sources;
- Wind erosion – modelled as area sources;
- Materials handling and crushing and screening – modelled as volume sources;
- In-pit (including all activities within the pit i.e. drilling, material handling, in pit roads, FEL, dozers and graders) – modelled as area sources; and

4.2.4 Modelling Domain

The dispersion of pollutants expected to arise from proposed activities was modelled for an area covering 25 km (east-west) by 25 km (north-south). The area was divided into a grid matrix with a resolution of 250 m by 250 m, with the project located centrally. ADMS 5 calculates ground-level (1.5 m above ground level) concentrations and dustfall rates at each grid and discrete receptor point. All AQSRs shown in Figure 1 were included in the model.

4.3 Dispersion Modelling Results

Dispersion modelling was undertaken to determine highest daily and annual average ground level concentrations (GLCs). Averaging periods were selected to facilitate the comparison of predicted pollutant concentrations to relevant ambient air quality and inhalation health criteria as well as dustfall regulations.

Pollutants with the potential to result in human health impacts which are assessed in this study include $PM_{2.5}$ and PM_{10}. Dustfall is assessed for its nuisance potential. Results are primarily provided in form of isopleths to present areas of exceedance of assessment criteria. Ground level concentration or dustfall isopleths presented in this section depict interpolated values from the concentrations simulated by ADMS 5 for each of the receptor grid points specified.

Isopleth plots reflect the incremental GLCs for $PM_{2.5}$ and PM_{10} where exceedances of the relevant Air Quality Objectives (AQOs) (Table 8) were simulated.

It should also be noted that ambient air quality criteria apply to areas where the Occupational Health and Safety regulations do not apply, thus outside the property or lease area. Ambient air quality criteria are therefore not occupational health indicators but applicable to areas where the general public has access i.e. off-site.

4.3.1 Scenario 1 – Operational Year 7

4.3.1.1 PM_{10}

The simulated exceedances of highest daily and annual average PM_{10} AQOs for unmitigated and mitigated operations are provided in Figure 11 and Figure 12 respectively, with the GLCs at the nearest AQSRs provided in Table 18.

The area over which the 24-hour AQO (WHO IT-3 and SA NAAQS) is exceeded, falls mainly within the site boundary with the only exceedances outside the site boundary on the north-western and south-eastern boundaries (Figure 11). With proposed mitigation in place, there are no exceedances outside the site boundary as shown in Figure 12. The annual average PM_{10} GLCs are well within the AQO outside the site boundary, both for unmitigated and mitigated activities.

AQSRs affected by PM_{10} GLCs from the mining operations are the two farmhouses located within the site boundary (Table 18). It is however assumed that these homesteads will be relocated since these falls within the mining operations. With mitigation measures in place, only farmhouse #1 will be affected by the mining operations.

Table 18: Simulated PM_{10} ground level concentrations (in µg/m³) at selected AQSRs for Year 7 (non-compliance is highlighted)

AQSR	Unmitigated			Mitigated		
	Annual Average	**Highest Day**	**FOE**	**Annual Average**	**Highest Day**	**FOE**
AQO	40 µg/m³	75 µg/m³	<4 days/year	40 µg/m³	75 µg/m³	<4 days/year
1	24.17	243.01	36	12.45	118.98	14
2	17.76	131.95	10	8.65	68.79	0
3	0.49	4.54	0	0.28	2.50	0
4	0.45	4.88	0	0.24	2.45	0
5	0.48	4.95	0	0.26	2.46	0
6	0.44	4.75	0	0.23	2.24	0
7	0.43	4.31	0	0.23	2.27	0
8	2.83	13.50	0	1.47	7.24	0
9	2.37	11.46	0	1.34	7.08	0
10	8.85	37.80	0	4.49	18.86	0
11	7.34	31.86	0	3.69	15.59	0
12	7.00	32.12	0	3.52	15.82	0
13	6.78	31.25	0	3.41	15.34	0
14	3.21	14.72	0	1.63	8.14	0
15	0.68	10.22	0	0.36	5.23	0
16	0.96	11.29	0	0.51	6.32	0
17	1.14	15.68	0	0.61	8.46	0
18	1.02	13.96	0	0.55	7.46	0
19	0.22	4.79	0	0.12	2.44	0

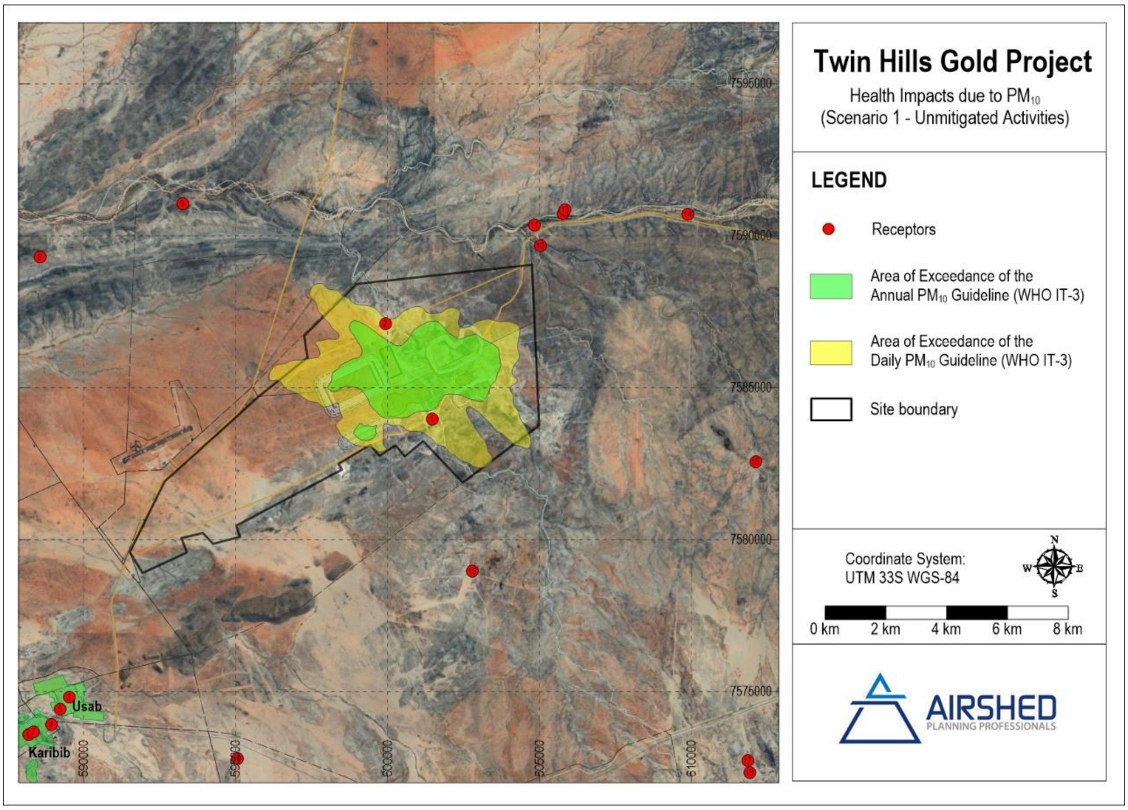

Figure 11: Area of non-compliance of daily and annual PM_{10} AQO for unmitigated Year 7 operations

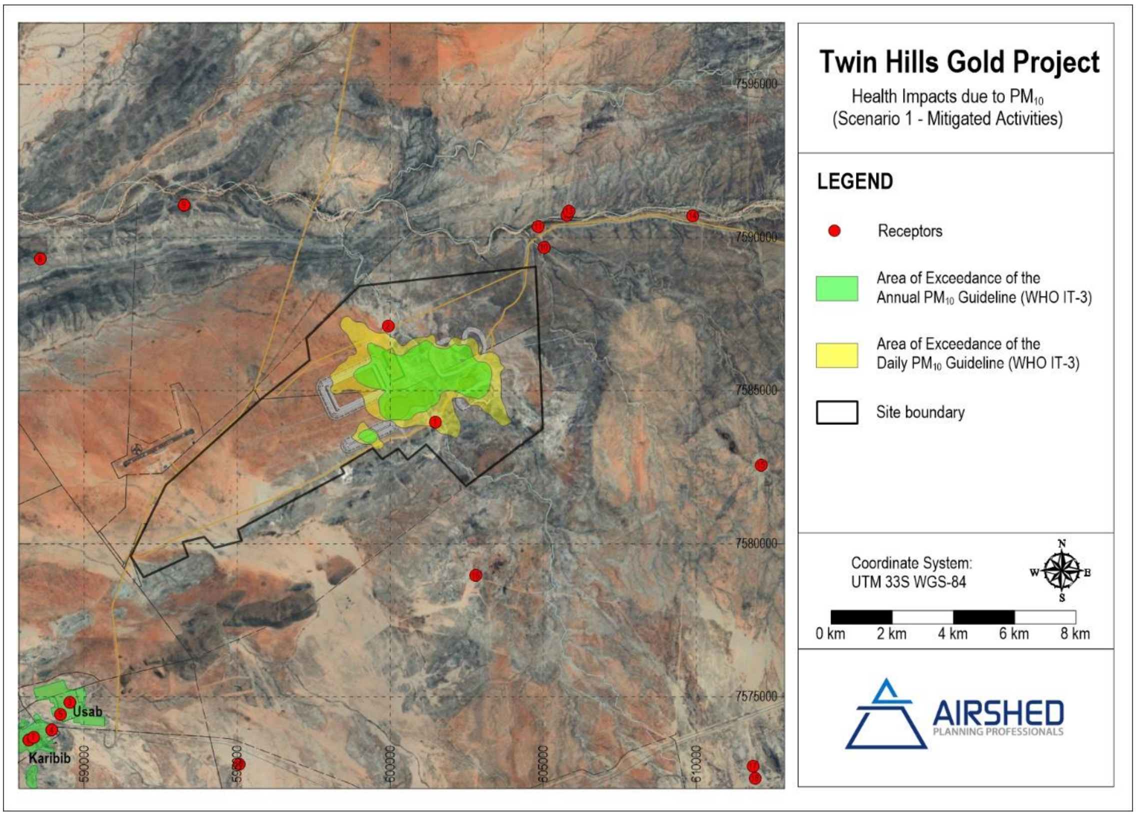

Figure 12: Area of non-compliance of daily and annual PM_{10} AQO for mitigated Year 7 operations

4.3.1.2 *$PM_{2.5}$*

The simulated exceedances of highest daily and annual average $PM_{2.5}$ AQO for unmitigated and mitigated operations are provided in Figure 13 to Figure 14 respectively, with the GLCs at the nearest AQSRs provided in Table 19.

For daily $PM_{2.5}$, the area of unmitigated GLCs exceedance is a small area on the north-western boundary, with no exceedances outside the site boundary when mitigation is applied (Figure 13 and Figure 14 respectively). Unmitigated and mitigated annual average $PM_{2.5}$ concentrations are within the AQO outside the site boundary.

Only the one AQSR located to the south of Twin Hills & Bulge Pit are impacted on by unmitigated $PM_{2.5}$ concentrations, with no exceedances of the daily AQO when mitigation measures are applied. There are no annual exceedances of the $PM_{2.5}$ AQO at any of the AQSRs, without and with mitigation in place.

Table 19: Simulated $PM_{2.5}$ ground level concentrations (in µg/m³) at selected AQSRs for Year 7 (non-compliance is highlighted)

AQSR	Unmitigated			Mitigated		
	Annual Average	**Highest Day**	**FOE (37.5 µg/m³)**	**Annual Average**	**Highest Day**	**FOE (37.5 µg/m³)**
AQO	15 µg/m³	37.5 µg/m³	<4 days/year	15 µg/m³	37.5 µg/m³	<4 days/year
1	6.64	70.71	22	3.92	38.87	1
2	4.78	43.56	2	2.65	24.29	0
3	0.13	1.23	0	0.09	0.77	0
4	0.12	1.18	0	0.07	0.76	0
5	0.13	1.56	0	0.08	0.76	0
6	0.12	1.53	0	0.07	0.69	0
7	0.12	1.13	0	0.07	0.70	0
8	0.81	4.23	0	0.46	2.36	0
9	0.65	3.36	0	0.42	2.30	0
10	2.49	10.37	0	1.42	5.85	0
11	2.22	9.60	0	1.21	5.07	0
12	2.02	9.07	0	1.13	4.97	0
13	1.97	8.90	0	1.09	4.85	0
14	0.80	3.75	0	0.48	2.51	0
15	0.17	2.47	0	0.11	1.54	0
16	0.25	3.52	0	0.15	2.16	0
17	0.32	4.46	0	0.20	2.70	0
18	0.29	3.96	0	0.17	2.37	0
19	0.06	1.32	0	0.04	0.76	0

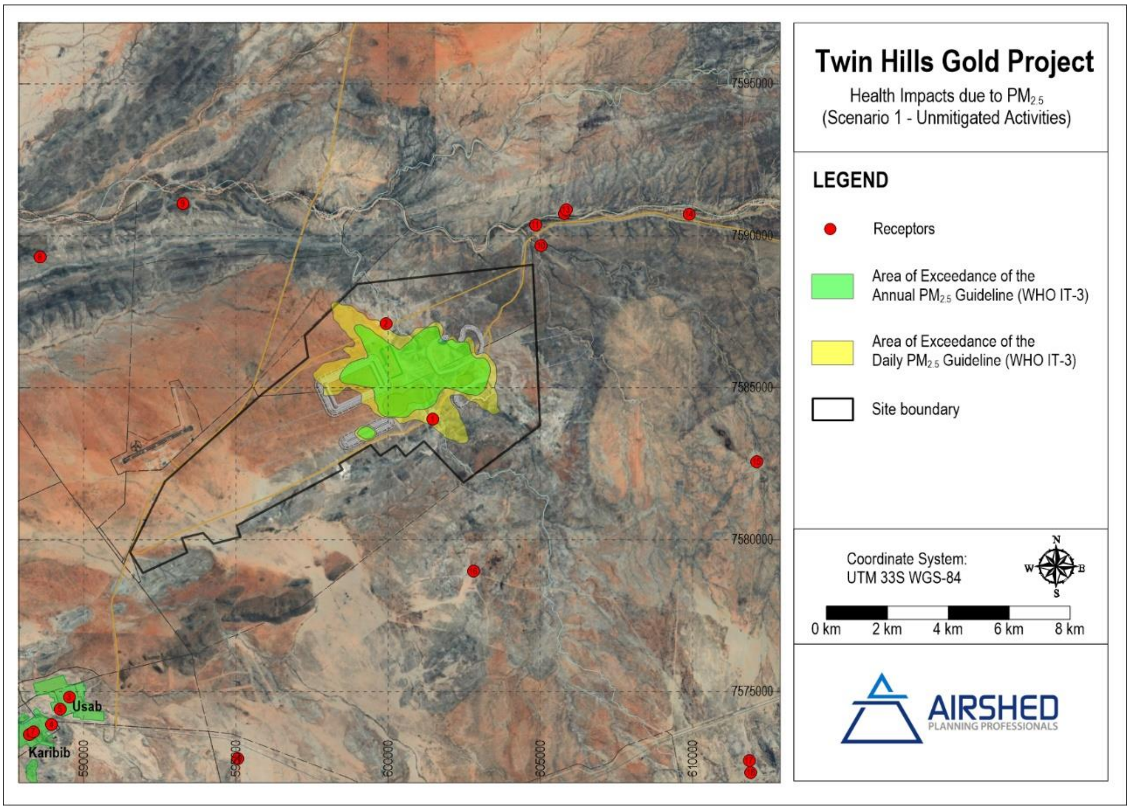

Figure 13: Area of non-compliance of daily and annual $PM_{2.5}$ AQO for unmitigated Year 7 operations

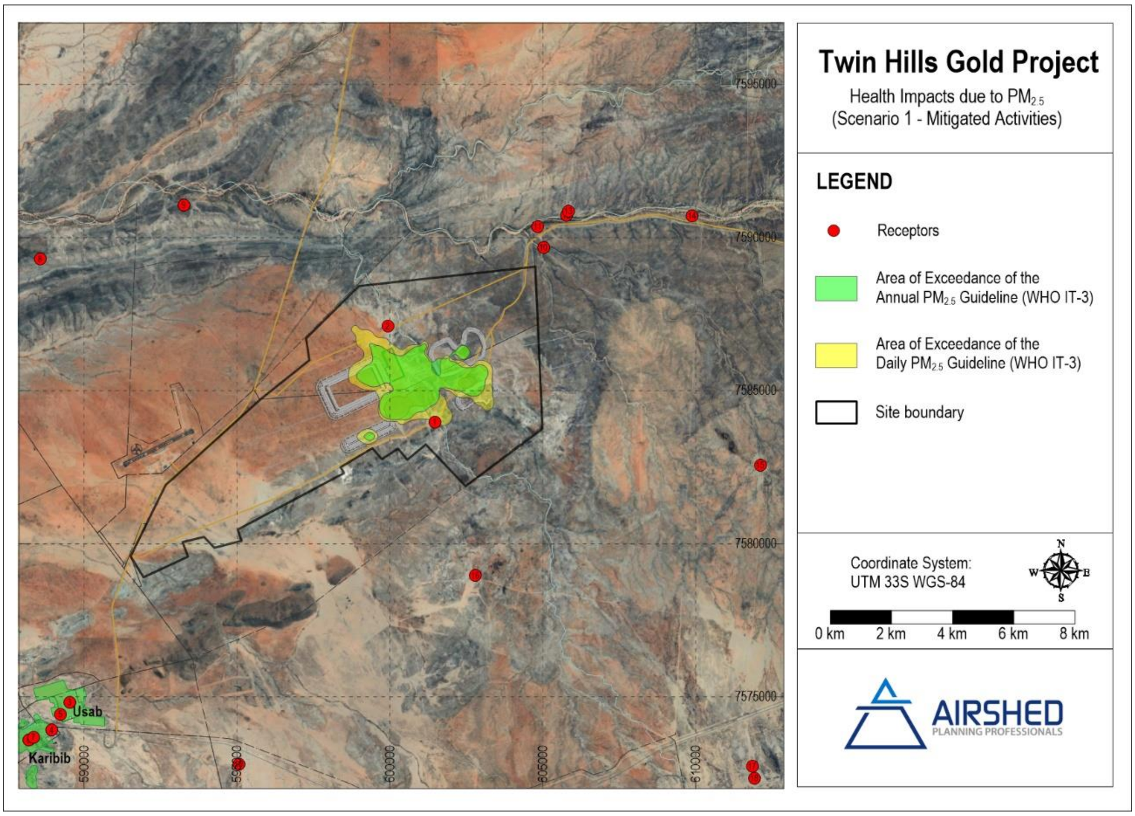

Figure 14: Area of non-compliance of daily and annual $PM_{2.5}$ AQO for mitigated Year 7 operations

4.3.1.3 Dust Fallout

The simulated maximum daily dustfall rates for unmitigated and mitigated activities are provided in Figure 15 and Figure 16 respectively, with the values at each of the AQSRs provided in Table 20.

Maximum daily dustfall rates, for both unmitigated and mitigated activities, do not exceed the AQO (SA NDCR residential limit of 600 mg/m²/day) at any of the AQSRs or outside the site boundary.

Table 20: Simulated dustfall rates (in mg/m²/day) at selected AQSRs for Year 7

AQSR	Unmitigated	Mitigated
	Highest 30-day average	Highest 30-day average
AQO	600 mg/m²/day	600 mg/m²/day
1	19.28	6.72
2	19.74	6.70
3	0.31	0.21
4	0.27	0.18
5	0.29	0.19
6	0.25	0.17
7	0.26	0.17
8	1.20	0.43
9	2.12	0.70
10	6.03	2.72
11	5.19	2.23
12	4.36	1.90
13	4.20	1.83
14	1.34	0.71
15	0.43	0.20
16	0.64	0.24
17	0.30	0.10
18	0.28	0.09
19	0.17	0.07

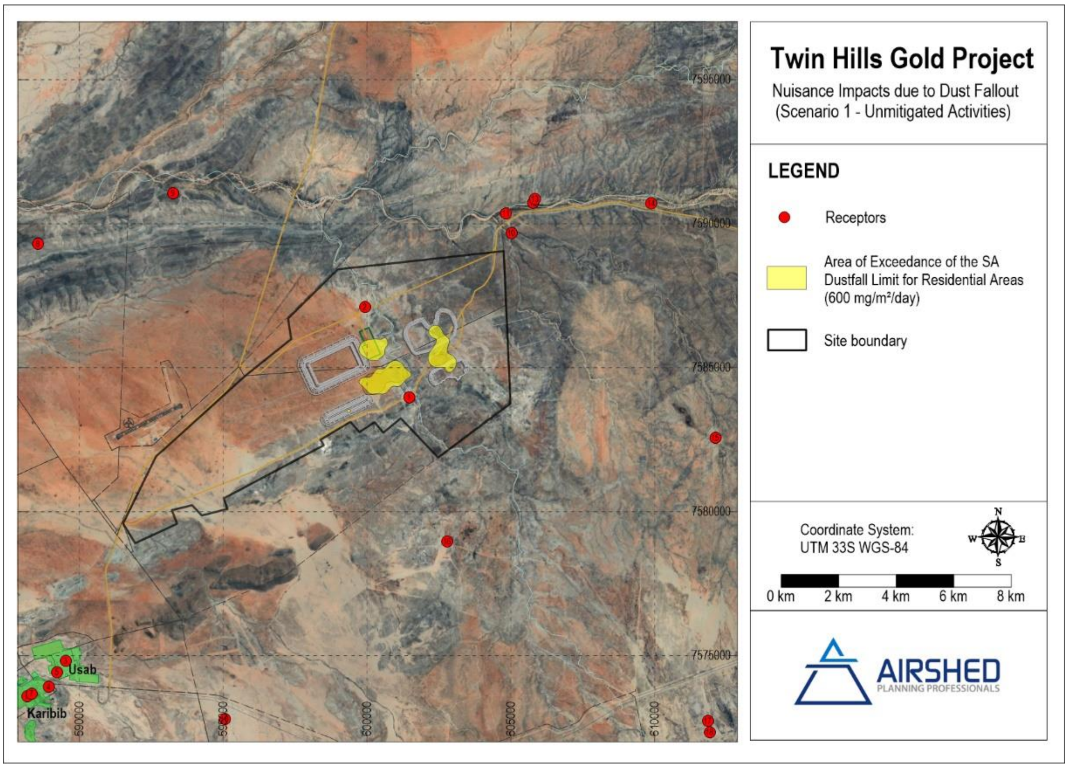

Figure 15: Area of non-compliance of dustfall limit values for unmitigated Year 7 operations

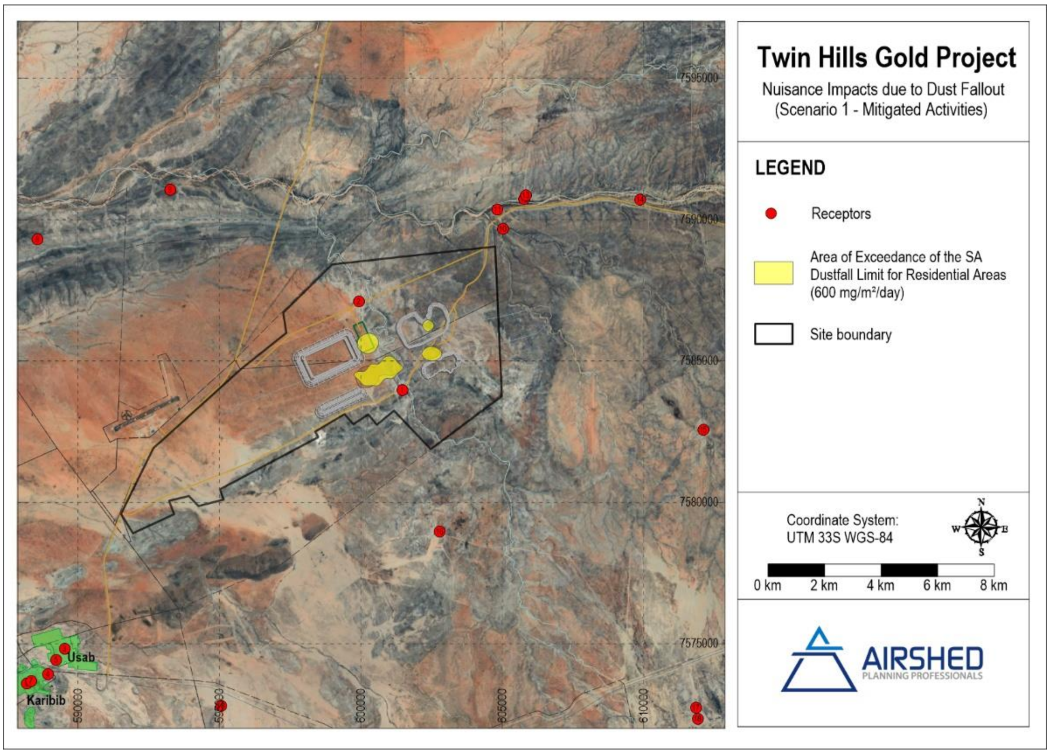

Figure 16: Area of non-compliance of dustfall limit values for mitigated Year 7 operations

4.3.2 Scenario 2 – Operational Year 10

4.3.2.1 PM_{10}

The simulated exceedances of highest daily and annual average PM_{10} AQOs for unmitigated and mitigated operations are provided in Figure 17 and Figure 18 respectively, with the GLCs at the nearest AQSRs provided in Table 21Table 18: Simulated PM_{10} ground level concentrations (in µg/m³) at selected AQSRs.

The daily PM_{10} AQO (WHO IT-3 and SA NAAQS) is exceeded towards the north, northwest, west and southeast of the site boundary with no mitigation in place (Figure 17). With mitigation in place, the impact area reduces with only smaller areas in exceedance of the AQO to the northwest, west and southeast (Figure 18). Over an annual average, the PM_{10} AQO is exceeded for a small area on the north-western boundary (Figure 17), but with mitigation in place the impact is well within site boundary (Figure 18).

AQSRs affected by PM_{10} GLCs from Year 10 mining operations are the two farmhouses located within the site boundary (Table 21). With no mitigation on place, the daily and annual average AQOs are exceeded at AQSR#1, with daily exceedances at AQSR#2. With mitigation measures in place, the concentrations are lower, but still with exceedances of the daily AQO at both receptors.

Table 21: Simulated PM_{10} ground level concentrations (in µg/m³) at selected AQSRs for Year 10 (non-compliance is highlighted)

AQSR	Unmitigated			Mitigated		
	Annual Average	**Highest Day**	**FOE**	**Annual Average**	**Highest Day**	**FOE**
AQO	40 µg/m³	75 µg/m³	<4 days/year	40 µg/m³	75 µg/m³	<4 days/year
1	67.07	693.96	66	39.41	411.31	44
2	25.89	217.21	33	12.99	120.87	9
3	1.09	11.26	0	0.57	5.42	0
4	0.97	10.77	0	0.51	5.29	0
5	1.04	11.05	0	0.55	5.35	0
6	0.95	10.19	0	0.49	4.89	0
7	0.95	10.30	0	0.50	4.97	0
8	5.65	29.77	0	2.87	15.20	0
9	6.28	29.53	0	3.14	15.07	0
10	19.86	83.55	5	9.91	41.22	0
11	14.79	65.92	0	7.06	30.37	0
12	15.26	65.69	0	7.51	31.70	0
13	14.69	61.70	0	7.21	30.13	0
14	5.53	25.24	0	2.62	13.10	0
15	1.43	15.92	0	0.75	7.71	0
16	2.23	31.89	0	1.13	16.92	0
17	2.86	40.04	0	1.46	20.70	0
18	2.61	36.34	0	1.33	18.80	0
19	2.61	36.34	0	1.33	18.80	0

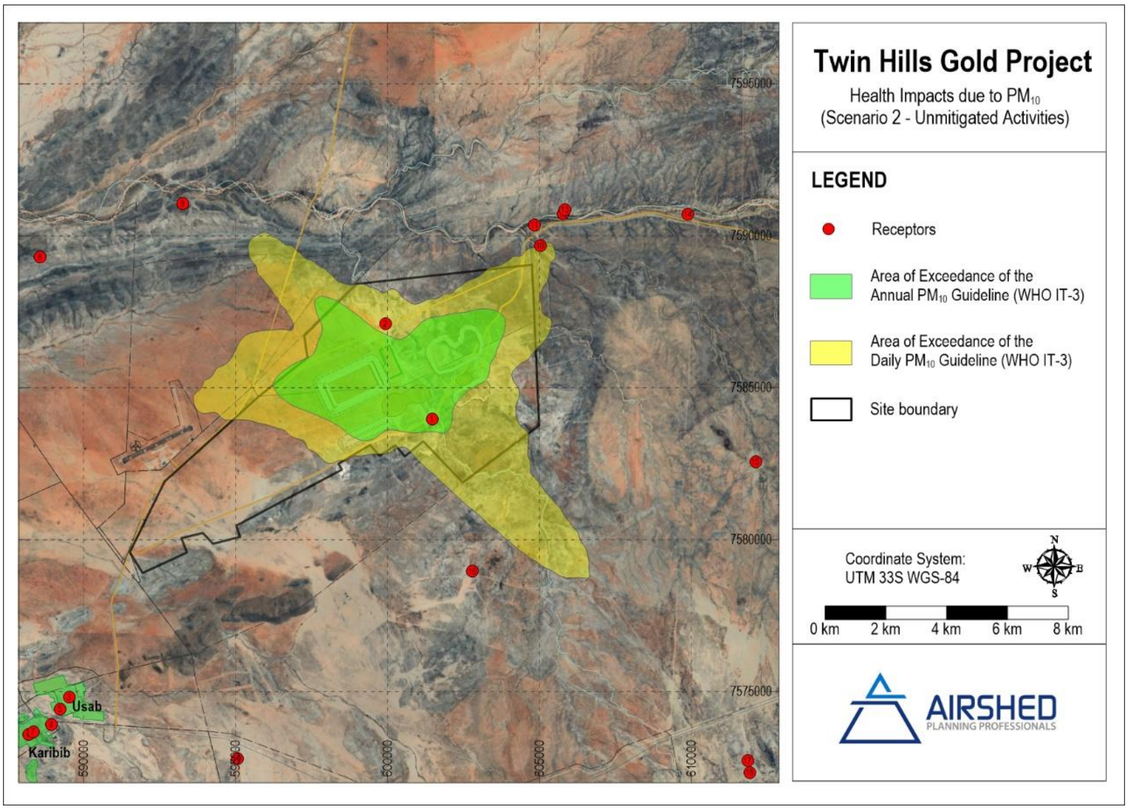

Figure 17: Area of non-compliance of daily and annual PM_{10} AQO for unmitigated Year 10 operations

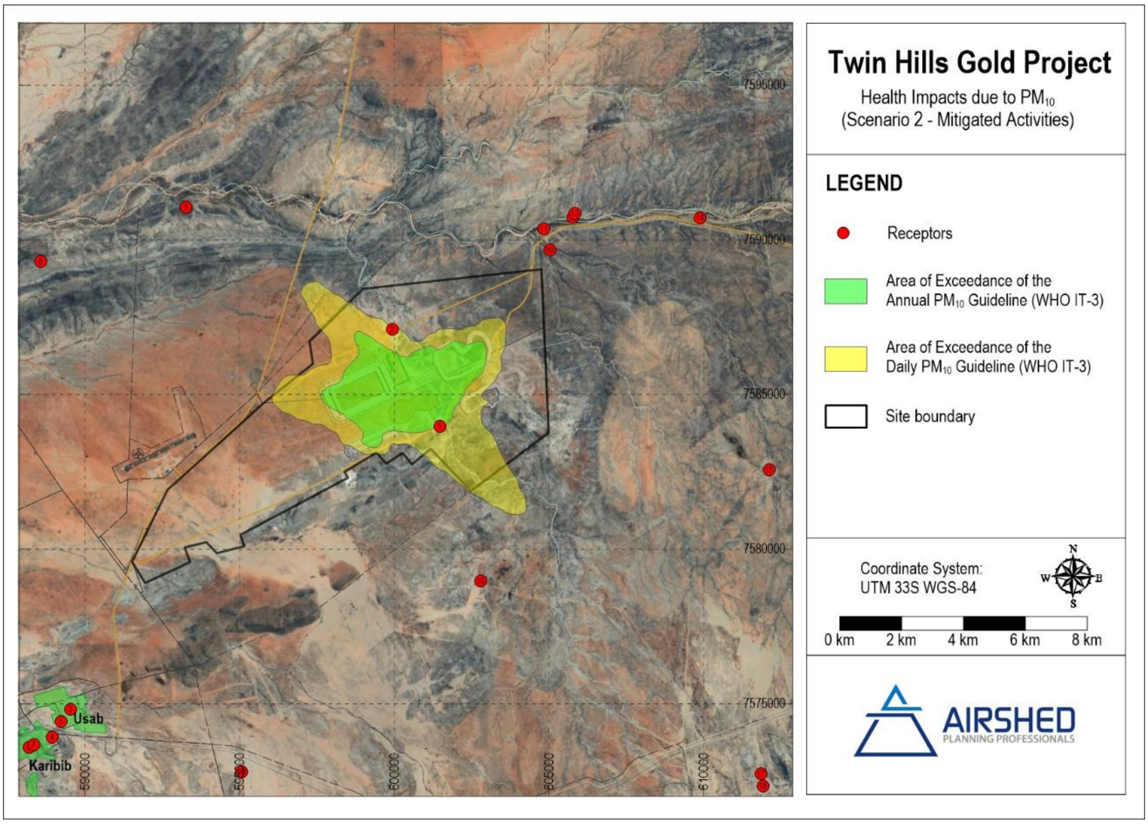

Figure 18: Area of non-compliance of daily and annual PM_{10} AQO for mitigated Year 10 operations

4.3.2.2 $PM_{2.5}$

The simulated exceedances of highest daily and annual average $PM_{2.5}$ AQO for unmitigated and mitigated operations are provided in Figure 19 and Figure 20 respectively, with the GLCs at the nearest AQSRs provided in Table 22.

Unmitigated and mitigated $PM_{2.5}$ GLCs are in exceedance of the daily AQO towards the west, northwest and southeast of the site boundary, but for much smaller areas when mitigation is applied (Figure 19 and Figure 20). Over an annual average, there are no off-site exceedances for either unmitigated or mitigated operations.

AQSRs affected by $PM_{2.5}$ GLCs are the two farmhouses located within the site boundary (Table 21). With no mitigation on place, the daily and annual average AQOs are exceeded at AQSR#1, with daily exceedances at AQSR#2. With mitigation measures in place, the concentrations are lower, but still exceeding the daily AQO at AQSR#1.

Table 22: Simulated $PM_{2.5}$ ground level concentrations (in µg/m³) at selected AQSRs for Year 10

AQSR	Unmitigated			Mitigated		
	Annual Average	Highest Day	FOE (37.5 µg/m³)	Annual Average	Highest Day	FOE (37.5 µg/m³)
AQO	15 µg/m³	37.5 µg/m³	<4 days/year	15 µg/m³	37.5 µg/m³	<4 days/year
1	17.71	187.73	41	13.72	144.89	36
2	6.70	67.76	9	4.23	44.08	2
3	0.27	2.58	0	0.19	1.73	0
4	0.24	2.52	0	0.17	1.66	0
5	0.25	2.55	0	0.18	1.67	0
6	0.23	2.34	0	0.16	1.51	0
7	0.23	2.36	0	0.16	1.54	0
8	1.39	7.24	0	0.92	4.92	0
9	1.49	7.26	0	1.00	4.95	0
10	4.79	19.91	0	3.17	13.06	0
11	3.62	15.69	0	2.24	9.37	0
12	3.70	15.79	0	2.39	9.97	0
13	3.56	15.13	0	2.30	9.57	0
14	1.25	6.08	0	0.80	4.27	0
15	0.34	3.70	0	0.24	2.40	0
16	0.51	8.22	0	0.35	5.72	0
17	0.69	9.76	0	0.47	6.75	0
18	0.63	8.80	0	0.43	6.11	0
19	0.12	2.69	0	0.08	1.80	0

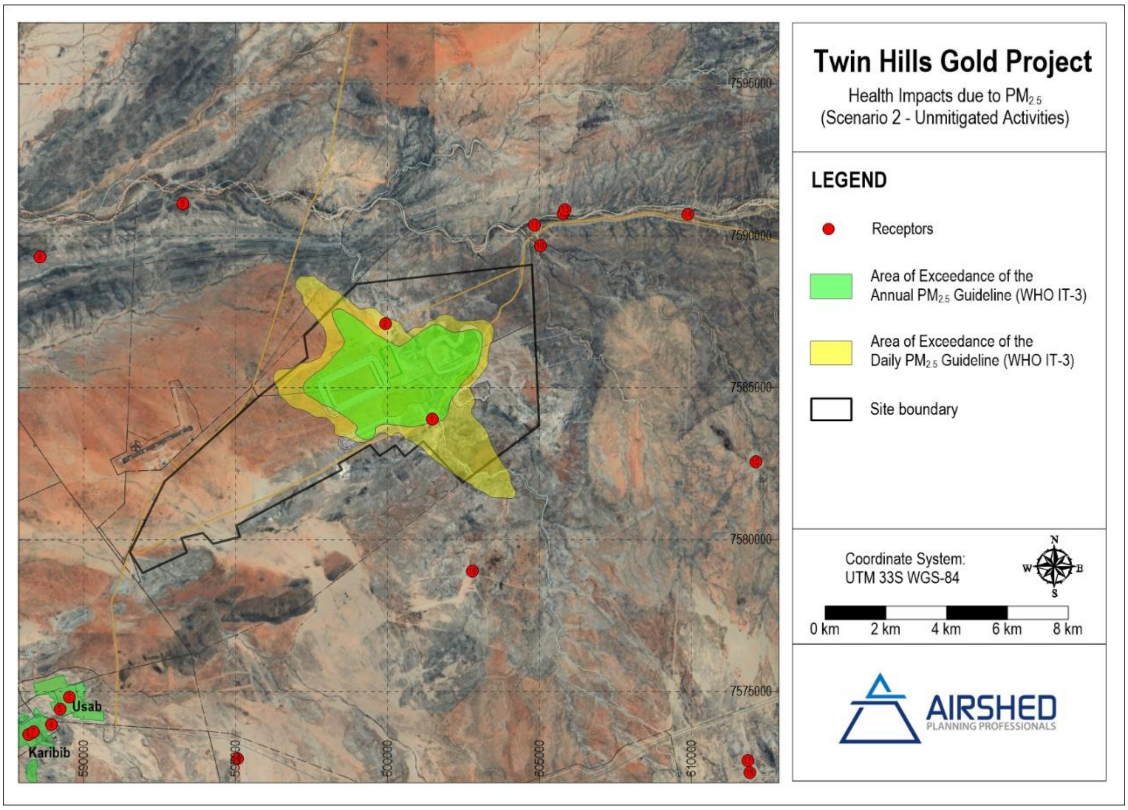

Figure 19: Area of non-compliance of daily and annual $PM_{2.5}$ AQO for unmitigated Year 10 operations

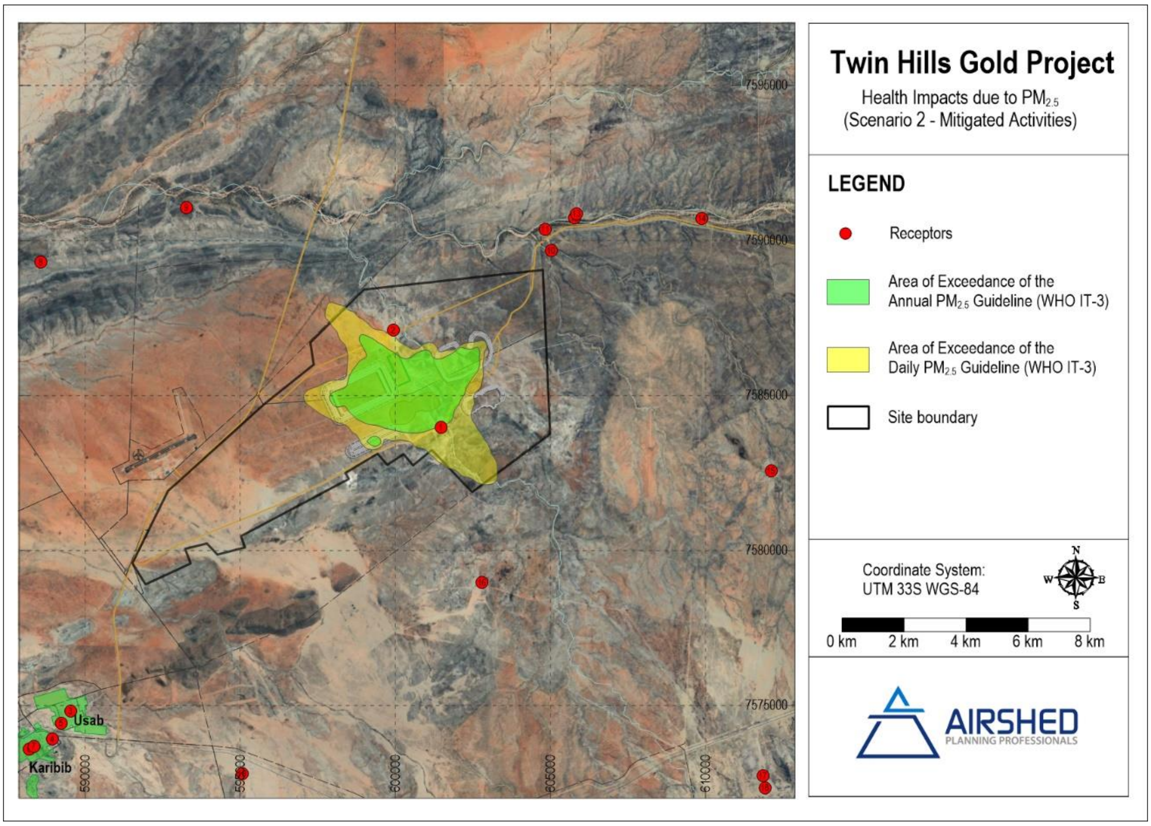

Figure 20: Area of non-compliance of daily and annual $PM_{2.5}$ AQO for mitigated Year 10 operations

4.3.2.3 Dust Fallout

The simulated maximum daily dustfall rates for mitigated and unmitigated activities are provided in Figure 21 and Figure 22 respectively, with the values at each of the AQSRs provided in Table 23.

Maximum daily dustfall rates, for both unmitigated and mitigated activities, are within the AQO (SA NDCR residential limit of 600 mg/m²/day) at all of the AQSRs and outside the site boundary.

Table 23: Simulated dustfall rates (in mg/m²/day) at selected AQSRs for Year 10

AQSR	Unmitigated	Mitigated
	Highest 30-day average	**Highest 30-day average**
AQO	600 mg/m²/day	600 mg/m²/day
1	99.87	32.00
2	38.18	12.63
3	0.75	0.29
4	0.67	0.26
5	0.71	0.28
6	0.61	0.23
7	0.62	0.24
8	3.13	1.20
9	6.92	2.50
10	17.44	6.05
11	12.75	4.53
12	11.74	4.19
13	11.17	4.00
14	2.44	0.90
15	1.05	0.39
16	2.16	0.72
17	0.75	0.29
18	0.71	0.28
19	0.43	0.16

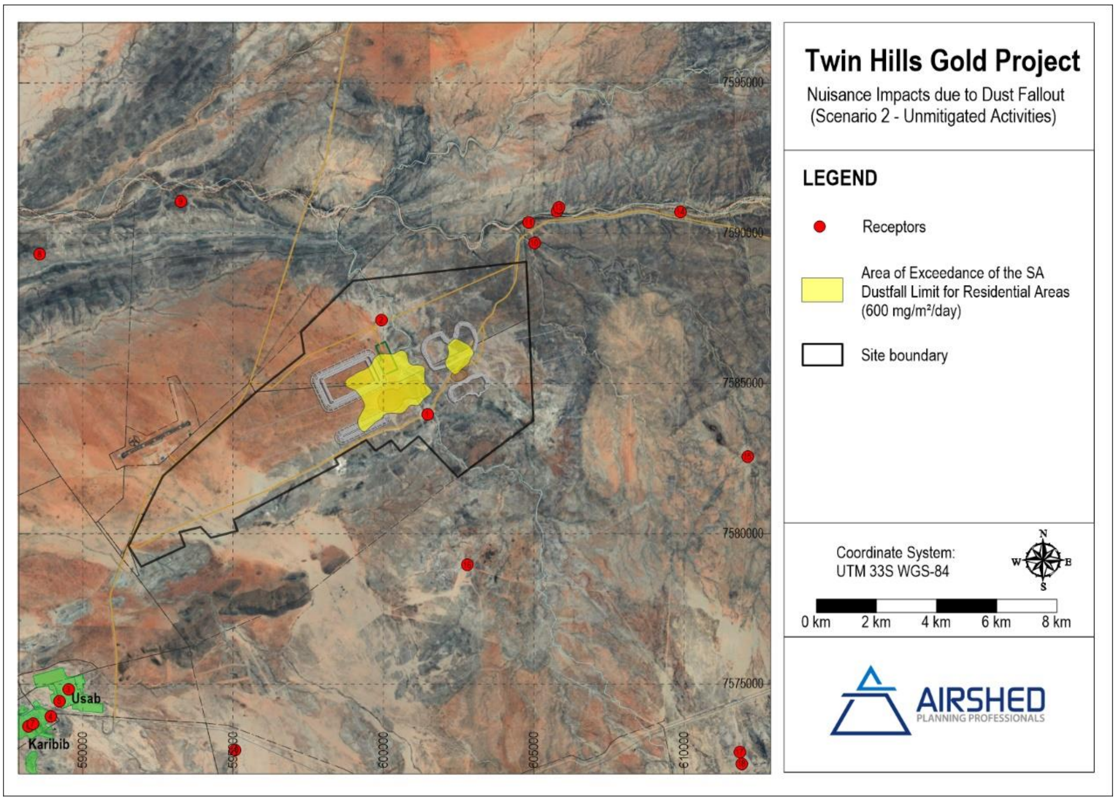

Figure 21: Area of non-compliance of dustfall limit values for unmitigated Year 10 operations

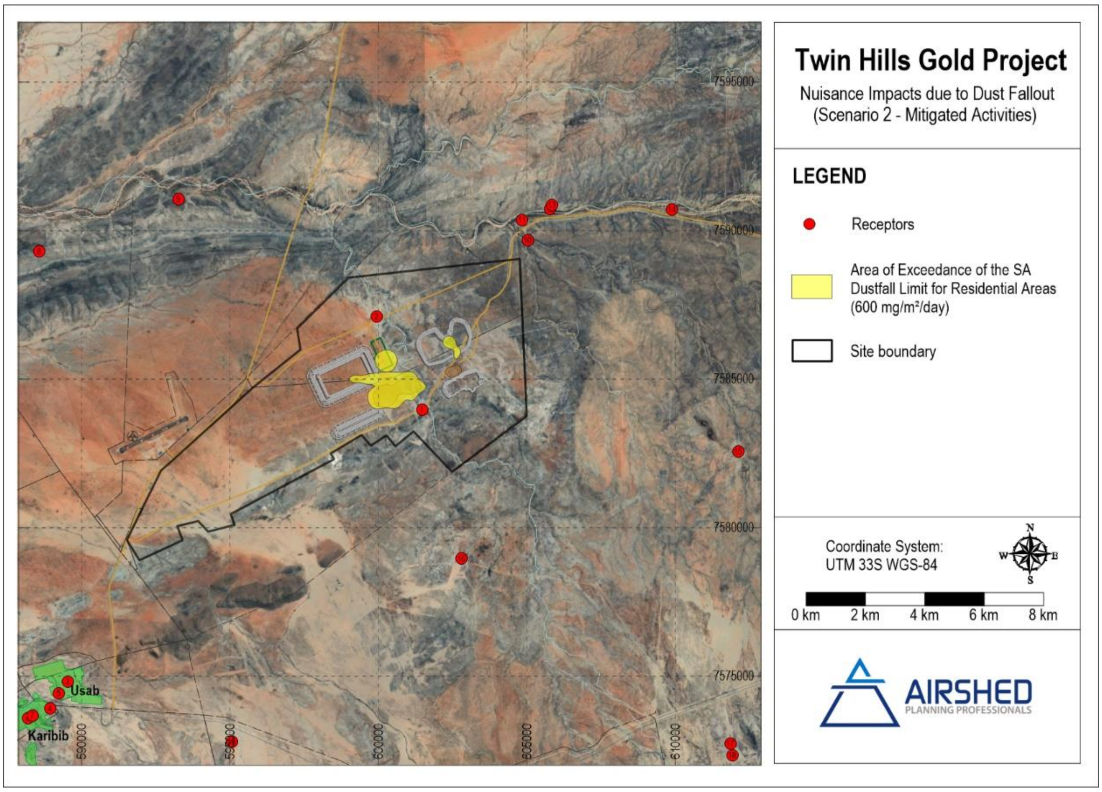

Figure 22: Area of non-compliance of dustfall limit values for mitigated Year 10 operations

5 AIR QUALITY MANAGEMENT MEASURES

In the light of potentially high impacts from the proposed mining operations, specifically from PM_{10} and $PM_{2.5}$ concentrations, it is recommended that the project proponent commit to adequate air quality management planning throughout the life of the proposed project. An air quality management plan provides options on the control of particulate matter at the main sources, while the monitoring network is designed to track the effectiveness of the mitigation measures.

Based on the findings of the impact assessment, the following mitigation, management, and monitoring recommendations are proposed following a hierarchy of: **Avoidance > Minimisation > Rehabilitation > Offset**.

5.1 Air Quality Management Objectives

The main objective of the proposed air quality management measures for the project is to ensure that operations result in ambient air concentrations (specifically $PM_{2.5}$ and PM_{10}) and dustfall rates that are within the selected AQOs (Section 2.5) outside the mine site boundary and at the relevant AQSRs. In order to define site specific management objectives, the main sources of pollution need to be identified. Once the main sources have been identified, target control efficiencies for each source can be defined to **minimise** dust emissions and ensure acceptable cumulative ground level concentrations.

5.1.1 Ranking of Sources

The ranking of sources serves to confirm the current understanding of the significance of specific sources, and to evaluate the emission reduction potentials required for each. Sources ranking can be established on:

- Emissions ranking: based on the comprehensive emissions inventory established for the operations (Section 4.1.2); and
- Impact ranking; based on the simulated pollutant GLCs (Section 4.3).

The sources ranked according to the unmitigated and mitigated emission contribution is provided in Table 24. The mitigation measured applied are summarised in Table 13 and based on mitigation obtained from literature.

The main contribution **emission** sources can be summarised as follows:

- For Scenarios 1 and 2, the main contributing emission sources are similar.
- Vehicle entrainment from unpaved haul roads are the most significant contributing sources to PM_{10} emissions, and the second highest to $PM_{2.5}$ and TSP for both Scenario 1 and Scenario 2 without mitigation. With mitigation applied, it remains the main source of emission to PM_{10}, the second highest to $PM_{2.5}$ and the third highest to TSP.
- Crushing and Screening (primary; secondary and tertiary) operations are the first highest contributing source group to TSP and $PM_{2.5}$ for both Scenario 1 and 2, unmitigated and with mitigation measures in place, and the third highest for PM_{10}.
- Emissions from blasting is the third highest contributor to PM_{10} emissions, with the operations of FEL the third highest contributor to TSP and $PM_{2.5}$ emissions.

Table 24: Sources ranked on emission contribution for Scenario 1 and 2

Sources of Emission	Scenario 1 (Year 7)						Scenario 1 (Year 10)					
	Unmitigated			Mitigated			Unmitigated			Mitigated		
	TSP	PM_{10}	$PM_{2.5}$	TSP	PM_{10}	$PM_{2.5}$	TSP	PM_{10}	$PM_{2.5}$	TSP	PM_{10}	$PM_{2.5}$
Drilling	7	7	7	7	7	6	7	7	7	7	7	5
Blasting	5	2	5	5	2	5	5	2	6	6	3	7
Materials Handling	8	8	8	8	8	8	8	8	8	8	8	8
Crushing & Screening	1	3	1	1	3	1	1	3	1	1	2	1
Unpaved Roads	2	1	2	3	1	2	2	1	2	2	1	2
Paved Roads	10	10	10	10	10	10	10	10	10	10	10	10
FEL	3	5	3	2	5	3	3	5	4	3	5	4
Dozer	4	4	4	4	4	4	4	4	3	4	4	3
Grader	6	6	6	6	6	7	6	6	5	5	6	6
Wind Erosion (WRDs & Stockpiles)	9	9	9	9	9	9	9	9	9	9	9	9

Based on **impacts**, the main contributing source of unmitigated PM_{10} for Scenario 1 is the in-pit activities (drilling, hauling, materials handling and FEL, dozers and graders) at AQSR#1 and crushing and screening at AQSR#2, followed by materials handling operations and vehicle entrainment on roads. With mitigation applied, the in-pit activities remain the main contributing source at the nearby AQSRs followed by materials handling and crushing and screening. For Scenario 2, unmitigated, the main contributing impact sources are the in-pit activities followed by vehicle entrainment from the surface haul roads. With mitigation in place, the in-pit activities remain the main source group, but vehicle entrainment reduces with crushing and screening and materials handling the second and third most significant sources.

For construction the main contributing sources would likely be dust generation from scraping and grading (land clearing) and vehicle entrained dust on-site, with drilling and digging and vehicle entrainment the main sources of dust generation during the power line and pipeline construction.

Closure and Post-closure activities likely to result in dust impacts are the demolition and removal of infrastructure, topsoil recovered from stockpiles for rehabilitation and re-vegetation of surroundings, and vehicle entrainment on unpaved road surfaces during rehabilitation. Once that is done, vehicle activity associated with the mining operations should cease.

5.2 Proposed Mitigation and Management Measures

5.2.1 Proposed Mitigation Measures and/or Target Control Efficiencies

The main sources resulting in PM emissions and impacts from the proposed Project will be in-pit operations (drilling, hauling, materials handling and FEL, dozers and graders), vehicle entrainment from surface haul roads, materials handling and crushing and screening. The haul road distances are the greatest during operational year 10 (Scenario 2) when mining is at Twin Hills & Bulge pits.

Mitigation measures used for the mitigation scenarios were provided to include the following:

5.2.1.1 Construction and closure phase:

- Air quality impacts during construction would be minimised through basic control measures such as limiting the speed of haul trucks; limit unnecessary travelling of vehicles on untreated roads; reducing the area of construction where it is close to receptors; and to apply water sprays on regularly travelled, unpaved sections.

- During closure and post-closure, the open exposed areas prone to wind erosion should be either covered with surface material and rehabilitated (vegetated or compacted) to ensure the surfaces form a hard crust and/or gladded with waste rock.

5.2.1.2 *Operational phases (the control efficiencies are from NPI, 2012):*

- For the control of vehicle entrained dust the following is recommended to minimise impacts:
    - In-pit haul roads – apply water (at an application rate >2 litre/m^2/hour) to ensure a minimum control efficiency of 50%, as indicated achievable by literature. Due to the changing nature of the in-pit roads, the application of chemical suppressants is not regarded feasible.
    - Surface haul roads (to the WRDs and ROM SP) – use chemical suppressants such as *dust-a-side* to ensure a control efficiency of 90%, as indicated by literature to be achievable. The application frequency of the chemical suppressants would depend on the road conditions which in turn is affected by traffic and climate. The road conditions should therefore be closely monitored to determine the frequency of the application to ensure minimal dust generation from the unpaved road surfaces.
- In minimising dust from crushing and screening operations, water sprays to keep the ore wet should ensure a 50% CE, whereas windbreaks around the crushers could achieve 30%. According to literature hooding with cyclones would achieve 65% CE, whereas scrubbers will achieve 75% and fabric filters would result in 83% CE. Enclosure or underground would result in up to 100% CE.
- Minimising dust from materials transfer points, excluding the dried concentrate, could be done using water sprays at the tip points. This should result in a 50% CE.
- In minimising windblown dust from stockpile areas, water sprays should be used to keep surface material moist. A mitigation efficiency of 50% is anticipated.

5.2.2 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.

Except for vehicle/equipment emission testing, source monitoring at mining activities can be challenging due to the fugitive and wind-dependant 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.

5.2.3 Ambient Air Quality Monitoring

Ambient air quality monitoring can serve to meet various objectives, such as:

- Compliance monitoring;
- Validate dispersion model results;

- Use as input for health risk assessment;
- Assist in source apportionment;
- Temporal and spatial trend analysis;
- Source quantification; and,
- Tracking progress made by control measures.

It is recommended that the current dustfall monitoring network, comprising of eight (8) single dustfall units, be maintained and the monthly dustfall results used as indicators to tract the effectiveness of the applied mitigation measures. Dustfall collection should follow the ASTM method.

The dustfall monitoring network should follow the American Society for Testing and Materials standard method for collection and analysis of dustfall (ASTM D1739-98). 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.

5.2.4 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, 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.

5.2.5 Liaison Strategy for Communication with 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 close proximity of the mine to seventeen villages, it is recommended that such meetings be scheduled and held at least on a bi-annual basis. A complaints register must be kept at all times.

5.2.6 Financial Provision

The budget should provide a clear indication of the capital and annual maintenance costs associated with dust control measures, dust monitoring plans and rehabilitation. 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 Interested and Affected Parties 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 FINDINGS AND RECOMMENDATIONS

A quantitative air quality impact assessment was conducted for the operational phase activities of the proposed Project. Construction, closure, and post-closure activities were assessed qualitatively. The assessment included an estimation of atmospheric emissions, the simulation of pollutant concentrations and determination of the significance of impacts. The main concern is the potential air quality impacts from the proposed Project on the receiving environment and human health.

6.1 Main Findings

6.1.1 Baseline Assessment

The main findings from the baseline assessment can be summarised as follows:

- The Project is located approximately 5 km northeast of the town of Karibib, in the eastern part of the Erongo Region of Namibia and the Project covers an area with dimensions of about 25 km northeast-southwest and 11 km northsouth.
- The terrain is hilly, with a ridge to the north and northwest, and a ridge on the southern side.
- There are no villages or homesteads near the project, with the closest settlement – farmhouses – directly to the south of Twin Hills & Bulge pit, and one at the proposed Processing Plant (this one is assumed to be relocated). The town of Karibib (and Usab suburb) is located about 3.5 km to the southwest from the site boundary. Other settlements in the vicinity include scattered homesteads to the north of the mine boundary, along the Khan River.
- The on-site weather data available for the period 23 July 2020 – 22 July 2021. The wind field is dominated by winds from the southwest and the east to south-east, with the strongest winds from the southwest. During the day, easterly winds prevailed with strong but less frequent winds from the southwest, and at night the wind field shifted to the southwest. Calm conditions were recorded for 7.5% of the time with a period average wind speed of 2.3 m/s. Higher wind speeds occurred during the night, with the strongest winds recorded from the southwest. A maximum wind speed of 8.9 m/s were recorded.
- Monthly variation in the wind field showed more frequent south-westerly winds during the summer months and a shift to easterly winds in May, and then to the southeast in April until July – the so called "east-winds". Winds from the northwest prevailed during August, whereafter it shifted to the southwest in September with a remaining easterly component.
- Maximum, minimum, and mean temperatures were given as 42°C, -3°C and 23°C respectively from the Twin Hills weather station for the period 23 July 2020 – 22 July 2021.
- Rainfall over the 12-month period totalled 254 mm, with the highest rainfall month January 2021 (115 mm).
- The main pollutant of concern in the region is particulate matter (TSP; PM_{10} and $PM_{2.5}$) resulting from vehicle entrainment on the roads (paved, unpaved and treated surfaces), windblown dust, and mining and exploration activities. Gaseous pollutants such as SO_2, NOx, CO and CO_2 would result from vehicles and combustion sources, but these are expected to be at low concentrations due to the few sources in the region.
- Sources of atmospheric emissions in the vicinity of the proposed Project include:
    - Vehicle entrainment from roads: The national road to the south (B2) of the Project is the main road between Windhoek and Swakopmund, and one of the roads in the region with the highest traffic counts. paved road with vehicle entrainment calculated to be a significant contributor to the regional paved road $PM_{2.5}$ and PM_{10} emissions. The C33, is a paved road connecting the Karibib Airport to the B2, and although

no information was available for this road, it is expected to have very low traffic counts and low $PM_{2.5}$ and PM_{10} emissions.

  - Windblown dust: Windblown particulates from natural exposed surfaces, mine waste facilities, and product stockpiles can result in significant dust emissions with high particulate concentrations near the source locations, potentially affecting both the environment and human health. Windblown dust from natural exposed surfaces in and at the Project is only likely to result in particulate matter emissions under high wind speed conditions (>10 m/s), and since recorded wind speeds did not exceed 10 m/s, this source is likely to be of low significance.
  - Mines and Exploration operations: Pollutants typically emitted from mining and quarrying activities are particulates, with smaller quantities associated with vehicle exhaust emissions. Mining and quarrying activities, especially open-cast mining methods, emit pollutants near ground-level over (potentially) large areas. Mines in proximity to the proposed Project are Navachab Gold Mine located west-southwest of Karibib, approximately 20 km from the Twin Hills Gold Project, and a number of marble quarries – Capra Hill, Dreamland and Savanna Marble.
  - Regional transport of pollutants: regional-scale transport of mineral dust and ozone (due to vegetation burning) from the north of Namibia is a significant contributing source to background PM concentrations.

- A dustfall monitoring network comprising of eight (8) single dustfall units are in place at the Project, with dustfall data available for the period June 2020 to June 2021. Dustfall rates were generally low for the sampling period and well within the dustfall limit of 600 mg/m²/day (adopted limit for residential areas) and 1 200 mg/m²/day (adopted limit for non-residential areas). Dustfall rates were the lowest during the months of June to September 2020 and might have been influenced by the regional lockdown due to COVID-19. The highest dustfall of 520 mg/m²/day was collected at AQ-02 in March 2021. The dustfall results show no clear spatial trend.

6.1.2 Impact Assessment

The findings from the impact assessment can be summarised as follows:

Construction normally comprises a series of different operations including land clearing, topsoil removal, road grading, material loading and hauling, stockpiling, grading, bulldozing, compaction, etc., with particulate matter the main pollutants of concern from these activities. 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, and how close these activities are to AQSRs. Due to the intermittent nature of construction operations, the impacts are expected to have a small but potentially harmful impact at the nearby AQSRs (#1 and #2) depending on the level of activity. With mitigation measures in place these impacts are expected to be low.

Operational Phase:

- Two mining scenarios were assessed to determine the worst-case impacts, based on the mining rates as well as hauling distances from the open pits to the ROM pad and WRDs. The two scenarios assessed are:
  - Operational Year 7 (Scenario 1) – representative of maximum throughput from Clouds pit of 1.85 mtpa of ore, and 0.32 mtpa from Twin Hills & Bulge, and a total of 22.89 mtpa of waste rock.
  - Operational Year 10 (Scenario 2) – representative of maximum throughput from Twin Hills & Bulge pits of 4.25 mtpa of ore and 20.75 mtpa of waste.
- Emissions quantified for the proposed Project were restricted to fugitive releases (non-point releases) with particulates the main pollutant of concern. Gaseous emissions (i.e. SO_2, NOx, CO and VOCs) will primarily result from diesel combustion, both from mobile and stationary sources, with point-source releases limited to the Kiln stack,

Roaster/ Dryer stack, and Furnace stack. Emissions were quantified based on provided information on mining rates, mine layout plan and estimated fuel consumption.

- Quantified PM (TSP, PM_{10} and $PM_{2.5}$) emissions were higher for Scenario 2 (Year 10) compared to Scenario 1 (Year 7) due to almost double the ore to be mined during Year 10 compared to Year 7, thus resulting in more truck trips and higher emissions. Other activities such as drilling and blasting, materials handling and FEL operations are slightly lower for Scenario 2, with all other activities remaining the same. With the proposed mitigation measures in place, PM emissions would reduce by between 54% and 59%.
- The main sources of $PM_{2.5}$, PM_{10} and TSP emissions are vehicle entrainment from unpaved haul roads, crushing and screening and a combination of in-pit activities (drilling, materials handling, hauling, etc.).
- Gaseous emissions were quantified for all mobile combustion sources based on diesel fuel use, with NOx the main gaseous pollutant of concern. Emissions from the point sources could not be quantified due to insufficient stack parameter information.

- For each of the two scenarios, unmitigated and mitigated options were modelling. Mitigation was applied was based on design mitigation measures provided, which included the following:
  - in-pit operations including haul roads, FEL, Bulldozers and Graders: water sprays assuming 50% CE;
  - drilling: water sprays assuming 70% CE;
  - surface haul roads: water sprays combined with chemical suppressant on resulting in 90% CE;
  - materials handling (loading and unloading ROM and waste rock): water sprays at tip points resulting in 50% CE; and
  - crushing and screening of ROM (primary; secondary and tertiary): resulting in 50% CE from water sprays to keep ore wet.
- Dispersion modelling results for Scenario 1 (Year 7):
  - PM_{10} daily GLCs, for unmitigated activities, exceed the 24-hour AQO (WHO IT-3 and SA NAAQS) at the two AQSRs within the site boundary. For mitigated activities, PM_{10} daily GLCs only exceed the AQO at the AQSR located on the southern side of Twin Hills & Bulge Pit. PM_{10} annual GLCs, for both unmitigated and mitigated activities, are within the AQO outside the site boundary.
  - $PM_{2.5}$ daily GLCs, for unmitigated activities, exceed the AQO (WHO IT-3) only at one AQSR located to the south of Twin Hills & Bulge Pit and for a small area on the north-western boundary. For mitigated activities, there are no exceedances outside the site boundary or at any of the AQSRs. There are no exceedances of the annual $PM_{2.5}$ AQO, without and with mitigation in place.
  - Maximum daily dustfall rates, for both unmitigated and mitigated activities, do not exceed the AQO (SA NDCR residential limit of 600 mg/m²/day) at any of the AQSRs or outside the site boundary.
- Dispersion modelling results for Scenario 2 (Year 10):
  - The daily PM_{10} AQO (WHO IT-3 and SA NAAQS) is exceeded towards the north, northwest, west and southeast of the site boundary with no mitigation in place but reduce to smaller areas of exceedance when mitigation is applied. Over an annual average only the unmitigated operations result in exceedances outside the site boundary. Unmitigated PM_{10} GLCs result in exceedances at the two AQSRs located within the site boundary and remains to exceed the daily AQO with mitigation in place, however with fewer exceedances.
  - Unmitigated and mitigated $PM_{2.5}$ GLCs are in exceedance of the daily AQO towards the west, northwest and southeast of the site boundary, but for much smaller areas when mitigation is applied and with no exceedances of the annual AQO. With no mitigation on place, the daily and annual average AQOs are exceeded at AQSR#1, with daily exceedances at AQSR#2. With mitigation measures in place, the concentrations are lower, but still exceeding the daily AQO at AQSR#1.

    - Maximum daily dustfall rates, for both unmitigated and mitigated activities, are within the AQO (SA NDCR residential limit of 600 mg/m²/day) at all of the AQSRs and outside the site boundary.

- Cumulative air quality impacts could not be assessed since no background PM_{10} and $PM_{2.5}$ data are available. The localised PM_{10} and $PM_{2.5}$ impacts from the proposed Project modelling results indicate the potential for low regional cumulative impacts, and only high cumulative impacts in the immediate vicinity of the mine. Off-site impacts are likely to be managed with proper mitigation measures in place.

Closure operations are likely to include demolishing existing structures, scraping and moving surface material to cover the remaining exposed surfaces (WRDs and WRD/TSF) and contouring of the surface areas. The impacts are expected to be similar to that of construction operations – potentially small but harmful impacts at nearby AQSRs (#1 and #2), depending on the level of activity but low impacts with mitigation measures in place. **Post-closure** operations, likely to include vegetation cover maintenance, would result in very low air quality related impacts.

6.2 Conclusion

The proposed Project is likely result in $PM_{2.5}$ and PM_{10} ground level concentrations in exceedance of the selected AQOs in the immediate vicinity of the mine, with no mitigation on place but can be reduced to compliance levels with mitigation measures in place. Dustfall rates are likely to be low throughout the life of mine, with gaseous concentrations (SO_2, NO_2 and CO) also expected to result in low air quality impacts. The two AQSRs (farmhouses) located within the mine boundary are likely to be negatively affected by the mining operations, irrespective of mitigation measures applied, and should be relocated.

It is the specialist's opinion that the proposed project could be authorised provided strict enforcement of mitigation measures and the tracking of the effectiveness of these measures to ensure the lowest possible off-site impacts.

6.3 Recommendations

Based on the findings from the air quality impact assessment for the Project following recommendations are included:

- Construction and closure phases:
    - 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 applying dust-a-side 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.
    - The access road to the Project site also needs to be kept clean to minimise carry-through of mud on to public roads.
- Operational phases:
    - For the control of vehicle entrained dust a control efficiency (CE) of 90% on unpaved surface roads through the application of chemical surfactants is recommended, with water sprays on the in-pit haul roads to ensure a 50% CE.
    - Drilling operations should be controlled through the application of water sprays at the drill holes ensuring 70% CE.
    - In controlling dust from crushing and screening operations, it is recommended that water sprays be applied to keep the ore wet, to achieve a control efficiency of up to 50%.
    - Mitigation of materials transfer points should be done using water sprays at the tip points. This should result in a 50% control efficiency. Regular clean-up at loading points is recommended.
- Air Quality Monitoring:

- The current dustfall monitoring network, comprising of eight (8) single dustfall units, should be maintained and the monthly dustfall results used as indicators to tract the effectiveness of the applied mitigation measures. Dustfall collection should follow the ASTM method.

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8 APPENDIX A – SPECIALIST CURRICULUM VITAE

CURRICULUM VITAE	HANLIE LIEBENBERG-ENSLIN

FULL CURRICULUM VITAE

Name of Firm	Airshed Planning Professionals (Pty) Ltd
Name of Staff	Hanlie Liebenberg-Enslin
Profession	Managing Director / Air Quality Scientist
Date of Birth	09 January 1971
Years with Firm/ entity	21 years
Nationalities	South African

MEMBERSHIP OF PROFESSIONAL SOCIETIES

- International Union of Air Pollution Prevention and Environmental Protection Associations (IUAPPA) – President 2010–2013, Board member 2013-present
- Member of the National Association for Clean Air (NACA) - President 2008-2010, NACA Council member 2010 –2014

KEY QUALIFICATIONS

Hanlie Liebenberg-Enslin started her professional career in Air Quality Management in 2000 when she joined Environmental Management Services (EMS) after completing her Master's Degree at the University of Johannesburg (then Rand Afrikaans University) 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 May 2013 when she was appointed as Managing Director. She has extensive experience on the various components of air quality management including emissions quantification for a range of source types, simulations using a range of dispersion models, impacts assessment and health risk screening assessments. She has worked all over Africa and has an inclusive knowledge base of international legislation and requirements pertaining to air quality.

She has developed technical and specialist skills in various modelling packages including the industrial source complex models (ISCST3 and SCREEN3), EPA Regulatory Models (AERMOD and AERMET), UK Gaussian plume model (ADMS), EPA Regulatory puff based model (CALPUFF and CALMET), puff based HAWK model and line based models such as CALINE. Her experience with emission models includes Tanks 4.0 (for the quantification of tank emissions) and GasSim (for the quantification of landfill emissions).

Having worked on projects throughout Africa (i.e. South Africa, Mozambique, Botswana, Namibia, Malawi, Kenya, Mali, Democratic Republic of Congo, Tanzania, Madagascar, Guinea and Mauritania) Hanlie has developed a broad experience base. She has a good understanding of the laws and regulations associated with ambient air quality and emission limits in South Africa and various other African countries, as well as the World Bank Guidelines, European Community Limits and World Health Organisation.

Being an avid student, she received her PhD in 2014, specialising in Aeolian dust transport. Hanlie is also actively involved in the National Association for Clean Air and is their representative at the International Union of Air Pollution Prevention and Environmental Protection Associations.

RELEVANT EXPERIENCE

Air Quality Management Plans and Strategies

Vaal Triangle Airshed Priority Area Draft Second Generation Air Quality Management Plan (AQMP)(Aug 2017 – Jun 2020); Advanced Air Quality Management for the Strategic Environmental Management Plan for the Uranium and Other Industries in the Erongo Region (May 2016 – Feb 2019); City of Johannesburg AQMP (2016-2019); Air Quality Monitoring and Management for the Al Madinah Al Munawarah Development Authority (MDA) in Saudi Arabia (2016-2017). Provincial Air Quality Management Plan for the Limpopo Province (March 2013); Mauritius Road Development Agency Proposed Road Decongestion Programme (July 2013); Transport Air Quality Management Plan for the Gauteng Province (February 2012); Gauteng Green Strategy (2011); Air Quality and Radiation Assessment for the Erongo Region Namibia as part of a Strategic Environmental Assessment (June, 2010); Vaal Triangle Airshed Priority Area AQMP (March, 2009); Gauteng Provincial AQMP (January 2009); North West Province AQMP (2008); City of Tshwane AQMP (April 2006); North West Environment Outlook 2008 (December 2007); Ambient Monitoring Network for the North West Province (February 2007); Spatial Development Framework Review for the City of uMhlathuze (August 2006); Ambient Particulate Pollution Management System (Anglo Platinum Rustenburg).

Hanlie has also been the Project Director on all the listed Air Quality Management plan developments.

Mining and Ore Handling

Hanlie has undertaken numerous air quality impact assessments and management plans for coal, platinum, uranium, copper, cobalt, chromium, fluorspar, bauxite and mineral sands mines. These include air quality impact assessments for: Namibia – Husab Uranium Mine, Trekkopje Uranium Mine; Bannerman Uranium Project; Langer Heinrich Uranium Mine, Valencia Uranium Mine, Rössing Uranium Mine; and B2Gold Otjikoto Gold Mine. South Africa – Sishen Iron Ore Mine; Tshipi Borwa Manganese Mine; Mamatwan Manganese Mine; Kolomela Iron Ore Mine; Thabazimbi Iron ore Mine; UKM Manganese Mine; Everest Platinum Mine; Impala Platinum Mine; Anglo Platinum Mines; Abglo Gold Ashanti MWS, Vaal River and West Wits complexes, Harmony Gold, Glencore Coal Mines, South32 and Anglo Coal; Tselentis Coal mine (Breyeton); Lime Quarries (De Hoek, Dwaalboom, Slurry); Beesting Colliery (Ogies); Anglo Coal Opencast Coal Mine (Heidelberg); Klippan Colliery (Belfast); Beesting Colliery (Ogies); Xstrata Coal Tweefontein Mine (Witbank); Xstrata Coal Spitskop Mine (Hendrina); Middelburg Colliery (Middelburg); Klipspruit Project (Ogies); Rustenburg Platinum Mine (Rustenburg); Impala Platinum (Rustenburg); Buffelsfontein Gold Mine (Stilfontein); Kroondal Platinum Mine (Kroondal); Lonmin Platinum Mine (Mooinooi); Rhovan Vanadium (Brits); Macauvlei Colliery (Vereeniging); Voorspoed Gold Mine (Kroonstad); Pilanesberg Platinum Mine (Pilanesberg); Kao Diamond Mine (Lesotho); Modder East Gold Mine (Brakpan); Modderfontein Mines (Brakpan); Zimbiwa Crusher Plant (Brakpan); RBM Zulti South Titanium mining (Richards Bay); Premier Diamond Mine (Cullinan). Botswana – Jwaneng Diamond Mine and Debswana Mining Company. Zimbabwe – Murowa Diamond Mine. Other mining projects include Sadiola Gold Mine (Mali); North Mara Gold Mine (Tanzania); Bulyanhulu North Mara Gold Mine (Tanzania).

Metal Recovery

Air quality impact assessments have been carried out for Smelterco Operations (Kitwe, Zimbia); Waterval Smelter (Amplats, Rustenburg); Hernic Ferrochroime Smelter (Brits); Rhovan Ferrovanadium (Brits); Impala Platinum (Rustenburg); Impala Platinum (Springs); Transvaal Ferrochrome (now IFM, Mooinooi), Lonmin Platinum (Mooinooi); Xstrata Ferrochrome Project Lion (Steelpoort); ArcelorMittal South Africa (Vandebijlpark, Vereeniging, Pretoria, Newcastle, Saldanha); Hexavalent Chrome Xstrata (Rustenburg); Portland Cement Plant (DeHoek, Slurry, Dwaalboom, Hercules, Port Eelizabeth); Vantech Plant (Steelpoort); Bulyanhulu Gold Smelter (Tanzania), Sadiola Gold Recovery Plant (Mali); RBM Smelter Complex (Richards Bay); Chibuto Heavy Minerals Smelter (Mozambique); Moma Heavy Minerals Smelter (Mozambique); Boguchansky Aluminium Plant (Russia); Xstrata Chrome CMI Plant (Lydenburg); SCAW Metals (Germiston).

Chemical Industry

Comprehensive air quality impact assessments have been completed for AECI (Pty) Ltd Operations (Modderfontein); Kynoch Fertilizer (Potchefstroom), Foskor (Richards Bay) and Omnia (Rustenburg).

Petrochemical Industry

Numerous air quality impact assessments have been completed for SASOL operations (Sasolburg); Sapref Refinery (Durban); Health risk assessment of Island View Tank Farm (Durban Harbour).

Pulp and Paper Industry

Air quality studies have been undertaken or the expansion of Mondi Richards Bay, Multi-Boiler Project for Mondi Merebank (Durban), impact assessments for Sappi Stanger, Sappi Enstra (Springs), Sappi Ngodwana (Nelspruit) and Pulp United (Richards Bay).

Power Generation

Air quality impact assessments have been completed for numerous Eskom coal fired power station studies including the Coal 3 Power Project near Lephalale, Komati Power Station and Lethabo Power Stations. In addition to Eskom's coal fired power stations, projects have been completed for the proposed Mmamabula Energy Project (Botswana); Morupule Power Plant (Botswana), NamPower Erongo Power Project (Namibia), NamPower Van Eck Power Station (Namibia) and NamPower Biomass Power Plant (Namibia).

Apart from Eskom projects, heavy fuel oil power station assessments have also been completed in Kenya (Rabai Power Station) and Namibia (Arandis Power Plant).

Green energy projects included several Solar Photovoltaic Projects (Mulilo and Enertrag South Africa (Pty) Ltd) and assessing potential particulate matter impacts from Wind Farms near the South African Large Telescope (SALT)

Waste Disposal

Air quality impact assessments, including odour and carcinogenic and non-carcinogenic pollutants were undertaken for the proposed Coega Waste Disposal Facility (Port Elizabeth); Boitshepi Waste Disposal Site (Vanderbijlpak); Umdloti Waste Water Treatment Plant (Durban).

Cement Manufacturing

Impact assessments for ambient air quality have been completed for the PPC Cement Alternative Fuels Project (which included the assessment of the cement manufacturing plants in the North West Province, Gauteng and Western).

Vehicle emissions

Transport Air quality Management Plan for the Gauteng Department of Roads and Transport (Feb 2012); Platinum Highway (N1 to Zeerust); Gauteng Development Zone (Johannesburg); Gauteng Department of Roads and Transport (Transport Air Quality Management Plan); Mauritius Road Development Agency (Proposed Road Decongestion Programme); South African Petroleum Industry Association (Impact Urban Air Quality).

Government and International Strategy Projects

Hanlie in one of the Lead Authors of Section 1.1: Africa's Development: Challenges, Drivers and key objectives, of the United Nations Environment Programme (UNEP), Climate and Clean Air Coalition (CCAC) and Stockholm Environment Institute (SEI) coordinated 'Integrated Assessment of Air Pollution and Climate Change for Africa Report. She was also the Terminal Reviewer of the UNEP/UNDA project "Air quality data for health and environment policies in Africa and the Asia-Pacific region"

(May 2020). Hanlie was also the project Director on the APPA Registration Certificate Review Project for Department of Environmental Affairs (DEA); Green Strategy for Gauteng (2011).

EDUCATION

Ph.D Geography	University of Johannesburg, RSA (2014) Title: *A functional dependence analysis of wind erosion modelling system parameters to determine a practical approach for wind erosion assessments*
M.Sc Geography and Environmental Management	University of Johannesburg, RSA (1999) Title: *Air Pollution Population Exposure Evaluation in the Vaal Triangle using GIS*
B.Sc Hons. Geography	University of Johannesburg, RSA (1995) GIS & Environmental Management
B.Sc Geography and Geology	University of Johannesburg, RSA (1994) Geography and Geology

ADDITIONAL COURSES AND ACADEMIC REVIEWS

External Examiner (February 2021)	PhD Candidate: Ms NM Walton Aerosol source apportionment in southern Africa Faculty of Natural and Agricultural Sciences, North-West University
External Examiner (May 2018)	MSc Candidate: Ms A Quta Characterisation of Particulate Matter and Some Pollutant Gasses in the City of Tshwane Department of Environmental Sciences, University of South Africa
External Examiner (December 2017)	MSc Candidate: Ms B Wernecke Ambient and Indoor Particulate Matter Concentrations on the Mpumalanga Highveld Faculty of Natural and Agricultural Sciences, North-West University
External Examiner (January 2016)	MSc Candidate: Ms M Grobler Evaluating the costs and benefits associated with the reduction in SO_2 emissions from Industrial activities on the Highveld of South Africa Department of Chemical Engineering, University of Pretoria
External Examiner (August 2014)	MSc Candidate: Ms Seneca Naidoo Quantification of emissions generated from domestic fuel burning activities from townships in Johannesburg Faculty of Science, University of the Witwatersrand
Air Quality Law– Lecturer (2012 - 2016)	Environmental Law course: Centre of Environmental Management.
Air Quality law for Mining – Lecturer (2014)	Environmental Law course: Centre of Environmental Management.
Air Quality Management – Lecturer (2006 -2012)	Air Quality Management Short Course: NACA and University of Johannesburg, University of Pretoria and University of the North-West.

ESRI SA (1999)	ARCINFO course at GIMS: Introduction to ARCINFO 7 course
ESRI SA (1998)	ARCVIEW course at GIMS: Advanced ARCVIEW 3.1 course

COUNTRIES OF WORK EXPERIENCE

South Africa, Mozambique, Botswana, Namibia, Malawi, Mauritius, Kenya, Mali, Zimbabwe, Democratic Republic of Congo, Tanzania, Zambia, Madagascar, Guinea, Russia, Mauritania, Morocco, and Saudi Arabia.

EMPLOYMENT RECORD

March 2003 - Present

Airshed Planning Professionals (Pty) Ltd, Managing Director and Principal Air Quality Scientist, Midrand, South Africa.

January 2000 – February 2003

Environmental Management Services CC, Senior Air Quality Scientist.

May 1998 – December 1999

Independent Broadcasting Authority (IBA), GIS Analyst and Demographer.

February 1997 – April 1998

GIS Business Solutions (PQ Africa), GIS Analyst

January 1996 – December 1996

Annegarn Environmental Research (AER), Student Researcher

LANGUAGES

	Speak	Read	Write
English	Excellent	Excellent	Excellent
Afrikaans	Excellent	Excellent	Excellent

CONFERENCE AND WORKSHOP PRESENTATIONS AND PAPERS

- Dust and radon levels on the west coast of Namibia – What did we learn? Hanlie Liebenberg-Enslin, Detlof von Oertzen, and Norwel Mwananawa. Atmospheric Pollution Research, 2020. https://doi.org/10.17159/caj/2020/30/1.8467

- Understanding the Atmospheric Circulations that lead to high particulate matter concentrations on the west coast of Namibia. Hanlie Liebenberg-Enslin, Hannes Rauntenbach, Reneé von Gruenewaldt, and Lucian Burger. Clean Air Journal, 27, 2, 2017, 66-74.

- Cooperation on Air Pollution in Southern Africa: Issues and Opportunities. SLCPs: Regional Actions on Climate and Air Pollution. Liebenberg-Enslin, H. 17th IUAPPA World Clean Air Congress and 9th CAA Better Air Quality Conference. Clean Air for Cities - Perspectives and Solutions. 29 August - 2 September 2016, Busan Exhibition and Convention Center, Busan, South Korea.

- A Best Practice prescription for quantifying wind-blown dust emissions from Gold Mine Tailings Storage Facilities. Liebenberg-Enslin, H., Annegarn, H.J., and Burger, L.W. VIII International Conference on Aeolian Research, Lanzhou, China. 21-25 July 2014.

- Quantifying and modelling wind-blown dust emissions from gold mine tailings storage facilities. Liebenberg-Enslin, H. and Annegarn, H.J. 9th International Conference on Mine Closure, Sandton Convention Centre, 1-3 October 2014.
- Gauteng Transport Air Quality Management Plan. Liebenberg-Enslin, H., Krause,N., Burger, L.W., Fitton, J. and Modisamongwe, D. National Association for Clean Air Annual Conference, Rustenburg. 31 October to 2 November 2012. Peer reviewed.
- Developing an Air Quality Management Plan: Lessons from Limpopo. Bird, T.; Liebenberg-Enslin, H., von Gruenewaldt, R., Modisamongwe, D. National Association for Clean Air Annual Conference, Rustenburg. 31 October to 2 November 2012. Peer reviewed.
- Modelling of wind eroded dust transport in the Erongo Region, Namibia, H. Liebenberg-Enslin, N Krause and H.J. Annegarn. National Association for Clean Air (NACA) Conference, October 2010. Polokwane.
- The lack of inter-discipline integration into the EIA process-defining environmental specialist synergies. H. Liebenberg-Enslin and LW Burger. IAIA SA Annual Conference, 21-25 August 2010. Workshop Presentation. Not Peer Reviewed.
- A Critical Evaluation of Air Quality Management in South Africa, H Liebenberg-Enslin. National Association for Clean Air (NACA) IUAPPA Conference, 1-3 October 2008. Nelspuit.
- Vaal Triangle Priority Area Air Quality Management Plan – Baseline Characterisation, R.G. Thomas, H Liebenberg-Enslin, N Walton and M van Nierop. National Association for Clean Air (NACA) conference, October 2007, Vanderbijl Park.
- Air Quality Management plan as a tool to inform spatial development frameworks – City of uMhlathuze, Richards Bay, H Liebenberg-Enslin and T Jordan. National Association for Clean Air (NACA) conference, 29 – 30 September 2005, Cape Town.

CERTIFICATION

I, the undersigned, certify that to the best of my knowledge and belief, these data correctly describe me, my qualifications, and my experience.

21 July 2021

Full name of staff member: Hanlie Liebenberg-Enslin

9 APPENDIX B – DECLARATION OF INDEPENDENCE

I, Hanlie Liebenberg-Enslin, as the appointed independent air quality specialist for the proposed Project, hereby declare that I:

- acted as the independent specialist in this Environmental Impact Assessment;
- performed the work relating to the application in an objective manner;
- regard the information contained in this report as it relates to my specialist input/study to be true and correct,
- do not have and will not have any financial interest in the undertaking of the activity, other than remuneration for work performed in terms of the Air Quality Impact Assessment;
- declare that there are no circumstances that may compromise my objectivity in performing such work;
- have expertise in conducting the specialist report relevant to this application;
- have no, and will not engage in, conflicting interests in the undertaking of the activity;
- have no vested interest in the proposed activity proceeding;
- undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing the decision of the competent authority; and
- all the particulars furnished by us in this specialist input/study are true and correct.

Signature of the specialist:

Name of Specialists: Hanlie Liebenberg-Enslin

Date: 26 August 2021

10 Appendix C – Particle Size Distribution

Table 25: Particle size distribution of the WRD/TSF, the WRS and ROM stockpiles (given as a fraction) (from similar processes)

WRD/TSF		WRDs		ROM Stockpiles	
Size µm	Mass Fraction	Size µm	Mass Fraction	Size µm	Mass Fraction
4000.00	0.1257	4000.00	0.1932	4000	0.3213
2000.00	0.0399	2000.00	0.0545	2000	0.0990
555.71	0.0008	555.71	0.0015	555.71	0.0000
477.01	0.0104	477.01	0.0097	477.01	0.0031
409.45	0.0226	409.45	0.0178	409.45	0.0063
351.46	0.0348	351.46	0.0259	351.46	0.0092
301.68	0.0450	301.68	0.0332	301.68	0.0115
258.95	0.0518	258.95	0.0385	258.95	0.0130
222.28	0.0552	222.28	0.0423	222.28	0.0142
190.80	0.0554	190.80	0.0446	190.8	0.0151
163.77	0.0531	163.77	0.0458	163.77	0.0159
140.58	0.0502	140.58	0.0458	140.58	0.0169
120.67	0.0472	120.67	0.0454	120.67	0.0179
103.58	0.0441	103.58	0.0445	103.58	0.0190
88.92	0.0412	88.92	0.0431	88.91	0.0201
56.23	0.0355	56.23	0.0355	76.32	0.0209
48.27	0.0323	48.27	0.0322	65.51	0.0217
41.43	0.0293	41.43	0.0287	56.23	0.0223
35.56	0.0263	35.56	0.0252	48.27	0.0225
30.53	0.0237	30.53	0.0221	41.43	0.0225
26.20	0.0211	26.20	0.0194	35.56	0.0222
22.49	0.0187	22.49	0.0170	30.53	0.0217
19.31	0.0166	19.31	0.0152	26.2	0.0211
16.57	0.0146	16.57	0.0135	22.49	0.0204
14.22	0.0130	14.22	0.0124	19.31	0.0197
12.21	0.0114	12.21	0.0113	16.57	0.0190
10.48	0.0102	10.48	0.0105	14.22	0.0182
9.00	0.0091	9.00	0.0096	12.21	0.0174
7.73	0.0081	7.73	0.0088	10.48	0.0165
5.69	0.0068	5.69	0.0072	9	0.0156
4.88	0.0061	4.88	0.0066	7.72	0.0146
4.19	0.0053	4.19	0.0058	6.63	0.0134
3.60	0.0048	3.60	0.0052	5.69	0.0122
3.09	0.0043	3.09	0.0047	4.88	0.0110
2.65	0.0039	2.65	0.0043	4.19	0.0098
2.28	0.0034	2.28	0.0037	3.6	0.0086
1.95	0.0031	1.95	0.0033	3.09	0.0076
1.68	0.0028	1.68	0.0030	2.65	0.0067

WRD/TSF		WRDs		ROM Stockpiles	
Size µm	Mass Fraction	Size µm	Mass Fraction	Size µm	Mass Fraction
1.24	0.0023	1.24	0.0021	2.28	0.0059
1.06	0.0020	1.06	0.0018	1.95	0.0050
0.91	0.0018	0.91	0.0014	1.68	0.0043
0.78	0.0015	0.78	0.0011	1.44	0.0037
0.67	0.0012	0.67	0.0008	1.24	0.0031
0.49	0.0009	0.49	0.0004	1.06	0.0026
0.42	0.0008	0.42	0.0003	0.91	0.0020
0.36	0.0006	0.36	0.0002	0.78	0.0015
0.31	0.0005	0.31	0.0002	0.67	0.0012
0.27	0.0003	0.27	0.0001	0.58	0.0008
0.23	0.0002	0.23	0.0001	0.49	0.0006
0.20	0.0001	0.20	0.0001	0.42	0.0004
0.17	0.0001	0.17	0.0001	0.36	0.0003
0.15	0.0000	0.15	0.0000	0.31	0.0002
0.13	0.0001	0.13	0.0001	0.27	0.0001
0.11	0.0001	0.11	0.0001	0.23	0.0001
				0.2	0.0001
				0.17	0.0001
				0.15	0.0001
				0.13	0.0001
				0.11	0.0001
				0.09	0.0001
				0.08	0.0001
				0.07	0.0000
				0.06	0.0000