Updated Air Quality Impact Assessment for the Proposed Expansion Project at Dundee Precious Metals

Project done for **SLR Consulting**

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Draft	25 April 2017		
Rev1	18 May 2018	4, 5.2.5, 6.2.2.4	Changes based on client feedback

Glossary and Abbreviations

ADE	Australian Department of Environment
ADMS	Air Dispersion Modelling System
Airshed	Airshed Planning Professionals (Pty) Ltd
AQG(s)	Air Quality Guideline(s)
AQR(s)	Air Quality Receptor(s)
As	Arsenic
ASG	Atmospheric Studies Group
ASTM	American Society for Testing and Materials
BOD	Basis of Design
CALEPA	California Environmental Protection Agency
CERC	Cambridge Environmental Research Consultants
DEA	Department of Environmental Affairs (South Africa)
DEAT	Department of Environmental Affairs and Tourism (South Africa)
DPMT	Dundee Precious Metals
ESIA	Environmental and Social Impact Assessment
H_2SO_4	Sulphuric acid
MEI	Maximally Exposed Individual
NPI	National Pollutant Inventory
NPPO	Namibia Atmospheric Pollution Prevention Ordinance
NYSDOH	New York State Department of Health
PM	Particulate matter
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of 2.5 µm and smaller
PM_{10}	Particulate matter with an aerodynamic diameter of 10 µm and smaller
PFS	Pre-feasibility Study
RHF	Rotary holding furnace
RfC(s)	Reference Concentration(s)
SA	South Africa
SABS	South African Bureau of Standards
SA NAAQS	South African National Ambient Air Quality Standard(s)
SA NEMAQA	South African National Environmental Management: Air Quality Act 2004
SLR	SLR Environmental Consulting (Namibia) (Pty) Ltd
SO_2	Sulphur dioxide
t/a	Tonnes per annum
URFs	Unit Risk Factors
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VKT	Vehicle Kilometres Travelled
WHO	World Health Organisation

Executive Summary

Dundee Precious Metals Tsumeb (DPMT) owns and operates the Tsumeb smelter complex which processes high sulphur, high arsenic and low copper grade concentrates to produce blister copper. As from the end of 2017, the smelter processes 240 000 tonnes of concentrate per annum (t/a). DPMT proposes several upgrades to the smelter to increase processing capacity to 370 000 t/a. These include:

- Upgrades to the Ausmelt furnace to improve availability, including the installation of a continuous discharge weir to stabilise the bath level in the furnace.
- The installation of a rotary holding furnace (RHF).
- The implementation of slow cooling methods for slags from the RHF and converters.
- The upgrade of the slag mill to increase capacity and improve copper recovery.
- The installation of a third 13 ft by 30 ft Peirce-Smith Converter similar to those currently installed.

Airshed Planning Professionals (Pty) Ltd (Airshed) was appointed by SLR Environmental Consulting (Namibia) (Pty) Ltd (SLR) to update the air quality impact assessment (AQIA) as part of the Environmental and Social Impact Assessment (ESIA) process (originally completed in February 2017) for the proposed smelter expansion project.

Based on feedback received on the original AQIA the following tasks were included in the update of the air quality specialist study:

- Updating ambient air quality monitoring data sets (including weather data) to include 2017.
- The inclusion of 2017 stack emissions testing data;
- The inclusion of $PM_{2.5}$ in the emissions inventory and dispersion model given:
    - Results of particle size distribution (PSD) analyses on PM stack emissions testing data;
    - Recently available $PM_{2.5}$ ambient air quality data; and
    - $PM_{2.5}$ emission factors for fugitive dust sources.
- Updating fugitive emission estimates from furnace buildings given:
    - Personal exposure monitoring data; and
    - Pollutant concentration monitoring within furnace and converter buildings.
- Updating the overall fugitive dust emissions inventory to take into account:
    - Closure of the arsenic plant;
    - Handling and disposal of arsenic containing baghouse dust;
    - The waste disposal site; and
    - Other changes to on-site material movements.
- A one-day site visit to identify and finalise the fugitive dust emissions inventory.
- PSD and metal content analysis of material samples from key fugitive dust sources such as stockpiles, waste disposal areas, and road surfaces.
- Aligning assessment criteria for ambient arsenic concentrations with the data set approved by the health risk specialist.
- Update the specialist air quality specialist report.

In studying the receiving environment, the following was found:

- AQSRs in the project area include towns and scattered farmsteads/homesteads. The closest of these to the smelter complex are residents of Tsumeb and its suburbs to the south, farmhouses, and the Namfo agricultural area to the north. Ambient air quality monitoring stations, Plant Hill, Info Centre and Stadium are representative of receptors within Tsumeb.

- Three additional sensitive receptor locations (Ondundu, Endombo and Private school and hospital) were included in the dispersion modelling scenarios at the request of SLR.
- It was decided to update the dispersion model to rather use meteorological data recorded at the Stadium ambient monitoring station, as data recorded at the Plant Hill station previously used for dispersion modelling simulations has an unacceptably low data availability.
- Based on data collected at the Stadium air quality monitoring station, the area is affected by frequent south-easterly winds. Long term air quality impacts are therefore expected to be the most significant to the north-west of operations.
- The DPMTT Tsumeb smelter is the main source of ambient SO_2 and arsenic. SO_2 is however also emitted by vehicles and may be emitted in small quantities at the sewerage plant.
- There are several sources of atmospheric PM in the area. These include the smelter complex, opencast copper mining operations to the west, agricultural activities to the north, paved and unpaved public roadways, open areas exposed to wind, small scale industrial/commercial activities within and around Tsumeb and transboundary sources.
- An analysis of ambient air quality monitoring at the five DPMT owned and operated stations from 2013 to 2016 indicated:
  - Significant exceedances of SO_2 and PM_{10} ambient air quality limits up to the end of 2015.
  - A notable decrease in SO_2 and PM_{10} levels in 2016 and 2017 due to the commissioning of the acid plant and de-commissioning of the reverberatory furnace.
  - A current annual average SO_2 concentration at the complex boundary of between 25 µg/m^3 at Plant Hill and 58.5 µg/m^3 at the sewerage works.
  - An annual average PM_{10} concentration at the complex boundary ranging between 29 and 74 µg/m^3 in 2017.
  - An annual average $PM_{2.5}$ concentration of 27.7 µg/m^3 at the Stadium and 13 µg/m^3 at the Info Centre in 2017.
  - An annual mean arsenic concentration at the complex boundary of approximately 0.35 µg/m^3 in 2017.

The main findings of the impact assessment are as follows:

- SO_2, PM_{10}, $PM_{2.5}$, arsenic and H_2SO_4 emissions from the DPMT Tsumeb smelter complex were quantified.
- SO_2 emissions were calculated using stack testing results and acid plant availabilities provided by DPMT.
- Two operational scenarios were considered:
  - The base scenario is representative of current activities and a concentrate processing rate of 240 000 t/a.
  - The project scenario includes proposed plant upgrades and an increase in concentrate processing rate of 370 000 t/a.
- For SO_2 emissions two acid plant utilization scenarios (75% - the current online time and 90% - an achievable industry standard) were considered for the base and project scenarios.
- Base scenario SO_2, PM_{10}, $PM_{2.5}$, arsenic and H_2SO_4 emissions were estimated at 16 438 t/a, 348.4 t/a, 219.3 t/a 9.9 t/a and 115.2 t/a respectively. *Note that the SO_2 emission rate above is based on a 90% acid plant utilization.*
- At a processing rate of 370 000 t/a, SO_2, PM_{10}, $PM_{2.5}$, arsenic and H_2SO_4 emissions were estimated to increase to 26 842 t/a, 430.8 t/a, 292.5 t/a, 15.0 t/a and 177.6 t/a respectively.
- The emissions of all pollutants will increase mostly because of increased material throughput and production rates. The increase is expected to be proportional to the increase in the concentrate processing rate.
- Currently, SO_2 concentrations associated with the base scenario, exceed the South African 1-year average assessment criterion of 50 µg/m^3 at the Sewerage Works if the acid plant is utilized 75% of the time. For this scenario, the 24-hour average criterion (SA NAAQS and EU Directive, 125 µg/m^3) is exceeded at the Sewerage

Works, Plant Hill and the north-eastern part of Tsumeb including at the sensitive receptor locations of Ondundu and the Private School and Hospital. Hourly average concentrations exceed the adopted criterion (350 µg/m³ - SA NAAQS and EU Directive) at the Sewerage Works, Plant Hill and Info Centre as well as at all three of the newly included sensitive receptor locations. If the acid plant was 90% utilized (i.e. at least 90% on-line time while the Ausmelt furnace is active) simulated concentrations would comply with the annual and daily criteria, but the 99th percentile hourly SO_2 concentrations would still be exceeded at the three closest locations (Sewerage Works, Plant Hill and Ondundu).

- With an acid plant utilization of 75%, simulated annual average SO_2 concentrations due to the expanded operations exceed the South African 1-year average assessment criterion of 50 µg/m³ only at the Sewerage Works, but daily and hourly 99th percentile concentrations exceed the assessment criteria at almost all sensitive receptor locations. With a 75% utilization of the acid plant after the expansion, simulated SO2 concentrations exceed the assessment criteria at nearly all sensitive receptor locations. With a 90% (or higher) utilization of the acid plant after the expansion, impacts would be similar or slightly lower on average than current impacts at the sensitive receptor locations. It is therefore recommended that the acid plant utilization be at least 90% after the expansion to ensure compliance with the identified assessment criteria.
- An analysis of measured PM_{10} concentrations indicate that DPMT is likely the main source of elevated PM_{10} concentrations at the Sewerage Works, but that other sources contribute more to ambient PM_{10} concentrations at the other monitoring locations.
- Simulated base scenario ambient PM_{10} and $PM_{2.5}$ concentrations are below air quality criteria in both the long and short-term and, as expected, are below what was measured at ambient air quality stations in 2016. A 10% to 30% increase in ambient PM_{10} concentrations are expected as a result of the expansion.
- Simulated base scenario ambient arsenic concentrations exceed chronic screening criteria off-site at the Plant Hill and Sewerage Works locations.
- Simulated project scenario ambient arsenic concentrations exceed chronic screening criteria off-site at the Plant Hill, Sewerage Works, Ondundu and Emdombo locations.

To ensure the lowest possible impact on AQSRs and the environment it is recommended that the air quality management measures as set out in this report should be adopted. These include the mitigation of sources of emission, the management of associated air quality impacts and the monitoring of emissions and ambient air quality. Key aspects/recommendations are:

- Mitigation of dust generated at the slag crusher. Enclosure or moisture addition must be considered.
- Regular sweeping of all paved surfaces to reduce silt loading on roads and within raw materials, cooling and crushing areas. Good housekeeping will ensure minimal windblown dust emissions which are known to be a significant source of dust at the Tsumeb smelter complex.
- Furnace/converter building fugitive emissions must be addressed and reduced. DPMT currently has a project underway to address secondary/fugitive emissions.
- Fume capture and extraction systems at the RHF must be maintained and operated to specifications to ensure minimal fugitive emissions during charging, holding and pouring cycles.
- A minimum stack height of 70 m for the RHF baghouse release.
- SO_2 emissions have drastically reduced since the commissioning of the sulphuric acid plant and will continue to reduce as the plant's performance improves. Management and maintenance of systems feeding off-gas to the sulphuric acid plant, and the acid plant itself, is essential to maintaining improvements to SO_2 levels in the area. It will also ensure minimal H_2SO_4 emissions. The acid plant utilization must be increased to 90% to ensure off-site ambient SO_2 concentrations within assessment criteria.
- Process emission testing:
    - Continuous emission testing of the acid plant outlet is recommended.

  - To validate theoretical emission estimates, stack emission testing for the full operational cycle of the proposed RHF furnace must be conducted once the furnace is operational.
  - Stack emissions testing on the outlet of the converter baghouse must be conducted over the full converter cycle.
  - There is some uncertainty as to the extent of furnace and converter fugitive emissions. Building fugitive emissions measurements must be conducted once the RHF has been commissioned. These emissions need to be updated given the decommissioning of the reverberatory furnace as well as to determine the extent of fugitive emissions from the charging and pouring RHF.
- It is recommended that attempts be made to improve data availability on the wind field and PM_{10} analysers installed at the ambient monitoring stations.

The significance of the air quality impacts on AQSRs for the base/current scenario, which is also representative of the "no-go" option, was found to be *medium*. This assessment is based on measured and simulated ambient pollutant levels, simulated ambient pollutant levels, as well as observations made during a specialist site visit. With the air quality management and mitigation measures proposed in place, the significance of current impacts can be reduced to *low to medium*. Of specific importance to the base scenario is the mitigation/management of SO_2 and fugitive dust, especially arsenic containing dusts.

The significance of the air quality impacts on AQSRs for the proposed project scenario, which is representative of smelter complex operations including upgrades and increased production rates, was found to be *medium* without mitigation and *low to medium* with mitigation. The expansion project will not change the significance of air quality impacts currently experienced.

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1 Introduction

Dundee Precious Metals Tsumeb (DPMT) owns and operates the Tsumeb smelter complex which processes high sulphur, high arsenic and low copper grade concentrates to produce blister copper. As of the end of 2015, the smelter processes 240 000 tonnes of concentrate per annum (t/a). DPMT proposes several upgrades to the smelter to increase processing capacity to 370 000 t/a.

Airshed Planning Professionals (Pty) Ltd (Airshed) was appointed by SLR Environmental Consulting (Namibia) (Pty) Ltd (SLR) to update the air quality impact assessment (AQIA) as part of the Environmental and Social Impact Assessment (ESIA) process originally completed in February 2017 for the proposed smelter expansion project. The tasks included in the update are described below.

1.1 Scope of Work

To meet the study objective, the following tasks were included in the original scope of work (completed in February 2017):

- A review of project design parameters and information collation;
- A review of regulations governing air quality impacts;
- A study of the receiving environment, including;
    - The location of AQSRs in relation to the Tsumeb smelter and proposed upgrades;
    - Local atmospheric dispersion potential given meteorology, land-use and topography; and
    - Current/status quo ambient air pollution levels.
- A screening study to determine a suitable stack height for the new rotary holding furnace;
- Updating the existing Tsumeb smelter emissions inventory to include:
    - The most recent stack emissions testing data;
    - New sources of emission because of proposed upgrades; and
    - Increased processing rates.
- Atmospheric dispersion simulations;
- Compliance and impact assessment;
- The recommendation of suitable management and mitigation measures; and
- The preparation of a comprehensive specialist air quality specialist report.

Based on feedback received on the original AQIA the following tasks were included in the update of the air quality specialist study:

- Updating ambient air quality monitoring data sets (including weather data) to include 2017.
- The inclusion of 2017 stack emissions testing data;
- The inclusion of $PM_{2.5}$ in the emissions inventory and dispersion model given:
    - Results of particle size distribution (PSD) analyses on PM stack emissions testing data;
    - Recently available $PM_{2.5}$ ambient air quality data; and
    - $PM_{2.5}$ emission factors for fugitive dust sources.
- Updating fugitive emission estimates from furnace buildings given:
    - Personal exposure monitoring data; and
    - Pollutant concentration monitoring within furnace and converter buildings.
- Updating the overall fugitive dust emissions inventory to take into account:
    - Closure of the arsenic plant;

    - Handling and disposal of arsenic containing baghouse dust;
    - The waste disposal site; and
    - Other changes to on-site material movements.
- A one-day site visit to identify and finalise the fugitive dust emissions inventory.
- PSD and metal content analysis of material samples from key fugitive dust sources such as stockpiles, waste disposal areas, and road surfaces).
- Aligning assessment criteria for ambient arsenic concentrations with the data set approved by the health risk specialist.
- Update the specialist air quality specialist report.

1.2 Background and Project Description from an Air Quality Perspective

A detailed history of the Tsumeb smelter and the design of proposed upgrades can be found in the Basis of Design (BOD) and Pre-Feasibility Study (PFS) reports completed by Worley-Parsons for DPMT in 2015 (report ref. 207040-00149-00-GE-BOD-0001 and 207040-00149-00-PM-REP-0001). The summary below is included to provide context and background.

The original smelter at Tsumeb included a lead smelter consisting of a sinter plant and two blast furnaces, and a copper smelter with a reverberatory furnace and two Peirce-Smith converters. Production commenced in 1962 with 81 000 t/a lead and 32 000 t/a copper production capacities. In 1976, a third Peirce-Smith converter was commissioned. In 2008, the Ausmelt furnace, a Top Submerged Lance Furnace (TSL) originally constructed for lead processing, was re-commissioned as part of the copper smelting process.

DPMT acquired the plant in 2010 with the objective to treat high sulphur, high arsenic, and low copper grade concentrates. Following its acquisition, DPMT implemented a series of upgrades which included:

- The commissioning of a second oxygen plant in 2012;
- Improvement of off-gas cleaning systems from 2012 to 2013;
- The decommissioning of the reverberatory furnace in 2013;
- The commissioning of a 1 540 tonne per day (t/d) sulphuric acid plant in 2015;
- The addition of two new and larger (13 ft by 30 ft) Peirce-Smith converters at the end of 2015; and
- A new effluent treatment plant.

Arsenic trioxide was also produced as a by-product from smelter dusts at an arsenic plant. Arsenic trioxide by-product was sold to the insecticide and wood treatment industries. The arsenic plant was however decommissioned in February 2017. Dusts containing arsenic, previously treated at the arsenic plant, are now disposed of at the hazardous waste disposal site commissioned by DPMT in 2012.

The upgrades listed above increased the smelter's copper concentrate processing capacity to 240 000 t/a. To further eliminate the production bottleneck at the Ausmelt section because of limited matte holding capacity for converter feed, DPMT proposes the following upgrades to increase processing capacity to 370 000 t/a:

- Upgrades to the Ausmelt furnace to improve availability, including the installation of a continuous discharge weir to stabilise the bath level in the furnace.
- The installation of a rotary holding furnace (RHF).
- The implementation of slow cooling methods for slags from the RHF and converters.
- The upgrade of the slag mill to increase capacity and improve copper recovery.
- The installation of a third 13 ft by 30 ft Peirce-Smith Converter similar to the ones currently installed.

Atmospheric emissions and air quality impacts due to the smelter complex and its activities have been quantified in several specialist studies. The most comprehensive of these was the impact study by Airshed in 2011 (report ref. APP/09/SYN-06) (von Reiche & Liebenberg-Enslin, 2011). The study considered all sources of atmospheric emissions at the time. Stack emissions, which then included emissions from the reverberatory furnace through the copper stack, the Ausmelt or TSL stack, were determined from emission testing campaigns conducted in June 2009 and July 2010. Additionally, the reverberatory and Ausmelt furnace baghouse efficiencies and furnace fugitive emissions were determined. Fugitive dust emissions because of wind entrainment from waste disposal sites, raw material and product stockpiles; vehicle entrainment; materials handling; crushing; and screening were estimated by applying emission factors and site-specific source information. Although considering several gaseous and particulate matter emissions, the study identified particulate matter (PM_{10}), arsenic (As) and sulphur dioxide (SO_2) as the atmospheric pollutants of concern.

In 2013, Golder Associates submitted the ESIA for the sulphuric acid plant. The ESIA included an air quality impact assessment which determined the extent to which SO_2 emissions and ensuing air quality impacts would decrease because of the production of sulphuric acid from SO_2 contained in off-gas from the Ausmelt furnace and Peirce-Smith converters. The study determined that annual SO_2 emissions would reduce by 99.1%. A further important aspect to note with regards to the commissioning of the acid plant is that primary emissions from the Ausmelt furnace and Peirce-Smith converters are routed to the acid plant after gas cleaning and no longer released through the copper or Ausmelt stacks. Residual emissions from the acid plant, primarily SO_2 and sulphuric acid (H_2SO_4) mist, are released through the acid plant stack.

Presently and under normal operating conditions, emissions not captured by primary off-gas systems are cleaned and vented through the copper stack. Emissions from the copper stack include those captured by secondary hooding at the Ausmelt furnace and passed through the hygiene baghouse, as well as emissions captured by converter secondary hooding and passed through the new converter baghouse.

The proposed upgrades to the Tsumeb smelter will affect the impact of operations on the atmospheric environment. The commissioning and use of the RHF will result in additional emissions during furnace charging as well as matte and slag pouring. The RHF ventilation system will capture off-gas from the furnace as well as gas and fume from feed ladles and pouring spouts. Off-gas from the furnace itself will primarily consist of combustion gases from burners which will be captured by the off-gas hood along with dilution air to lower the gas temperature to 150 °C. Most emissions will however occur during ladle transfer i.e. the filling of ladles at the Ausmelt furnace and pouring of molten material from the ladles to the RHF feed. A winch driven movable hood will be installed to capture emissions from this process. Fume from the matte/slag pouring spouts will be captured by a stationary canopy hood. The combined gas from the three RHF ventilation hoods will be routed to a baghouse after the addition of cooling air through a damper to further reduce the gas temperature to 120 °C. Cleaned gas from the RHF baghouse will be vented to atmosphere via a new stack, the height requirement of 70 m was determined through dispersion simulations.

The proposed third 13 ft by 30 ft Peirce-Smith converter will allow two converters to be online while a third converter could be off-line for maintenance. Although an increase in concentrate processing rate from 240 000 t/a to 370 000 t/a will result in an increase in primary emissions from the converter section, these emissions are and will be captured and cleaned before being treated at the acid plant. By the time converter off-gases have passed through the acid plant, PM (incl. metal) emissions are expected to be minimal. SO_2 and H_2SO_4 emissions from the acid plant may however increase proportionally to processing rate.

Fugitive dust emissions (PM) are a direct function of processing rate. Emission factors applied in the estimation of fugitive dust emissions relate the quantity of a pollutant to the activity associated with the release of that pollutant. In broad terms, emissions from most dust generating activities are expected to increase proportionally to processing rates, the exception being windblown dust emissions. Process and fugitive sources of atmospheric emissions are listed in Figure 1.

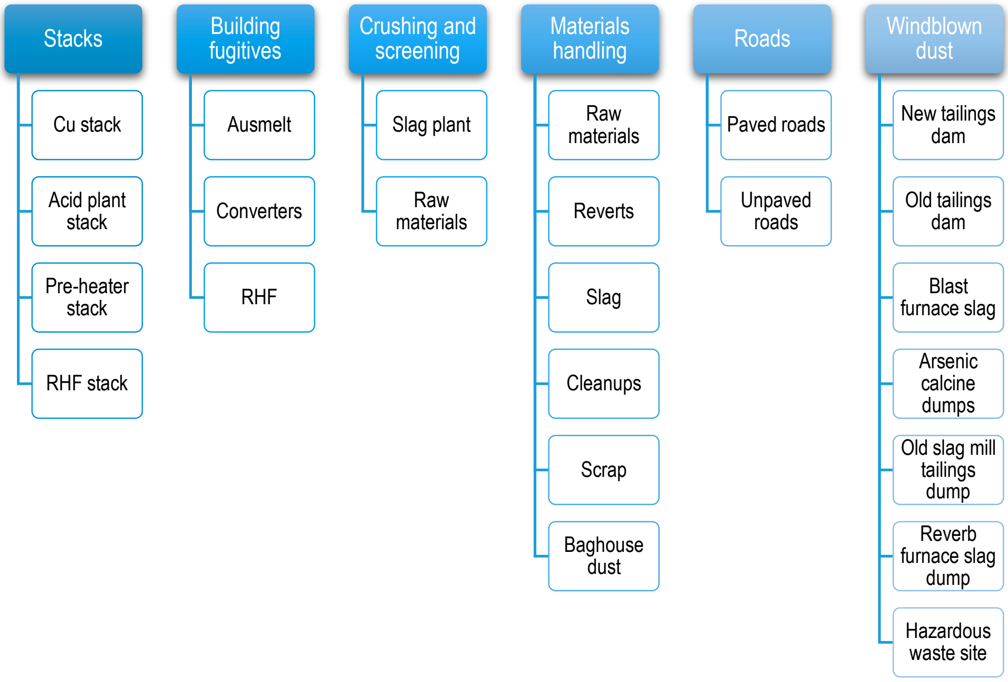

Figure 1: Process and fugitive emission sources

2 Methodology

A brief overview of the study methodology is included in this section.

2.1 Information Review

A review of information available for activities proposed as part of the Tsumeb smelter expansion was conducted. The following were considered in the review:

- The Tsumeb Smelter Expansion Basis of Design (Worley-Parsons, 2015)
- The Tsumeb Smelter Expansion Pre-Feasibility Study (Worley-Parsons, 2015)
- The Tsumeb Smelter Expansion Pre-Feasibility Study Process Design Criteria (Worley-Parsons, 2015)
- The DPMT Emission Testing report for the Tsumeb Smelter (Skyside, 2016)
- The Argos Scientific Ambient Air Quality Monitoring Report for Tsumeb | December 2016 (Winnaar, Ambient Air Quality Monitoring Report for Tsumeb | December 2016, 2017)
- The Argos Scientific Ambient Air Quality Monitoring Report for Tsumeb | December 2017 (Winnaar, 2018)
- Air Quality Impact Assessment for the Copper Smelter Operation near Tsumeb, Namibia (von Reiche & Liebenberg-Enslin, 2011)
- Environmental and Social Impact Assessment (ESIA) for the New Sulphuric Acid Plant, Tsumeb, Namibia (Golder Associates, 2013)
- Academic articles and on-line resources;
- Isokinetic Sampling Conducted by Skyside in 2017 and 2018; and
- Data supplied by DPMT and SLR via personal communication.

In concurrence with regulatory requirements, the following was determined from the information review:

- The likelihood of atmospheric emissions being generated by the proposed expansion;
- Source parameters and pollutants released; and
- Key pollutants to be included in the emissions inventory.

2.2 The Identification of Regulatory Air Quality Requirements and Assessment Criteria

Air quality requirements and assessment criteria were identified through the careful review of the following:

- The Namibian Atmospheric Pollution Prevention Ordinance (NPPO) (No. 11 of 1976);
- The European Commission (EC) First Daughter Directive (1999/30/EC);
- World Health Organisation (WHO) ambient air quality criteria;
- South African National Ambient Air Quality Standards (SA NAAQS) as set out in terms of the National Environmental Management Air Quality Act (Act No. 39 of 2004) (SA NEMAQA); and
- Inhalation health risk screening levels for non-criteria pollutants published by the various internationally recognised authorities.

2.3 Study of the Receiving Environment

Physical environmental parameters that influence the dispersion of pollutants in the atmosphere include meteorology, land-use and topography. An understanding of the atmospheric dispersion potential of the area is essential to an air quality impact assessment. Use was previously made of data from the DPMT owned Plant Hill ambient monitoring station which is situated along the southern boundary of the smelter complex. After thorough consideration it was decided to update the dispersion model to rather use meteorological data recorded at the Stadium ambient monitoring station, as data recorded at the Plant Hill station is very incomplete (Table 1) compared to data recorded at the Stadium station. The Stadium ambient and meteorological monitoring station is located approximately 2 km southwest of the DPMT operations.

Table 1: Plant Hill vs Stadium Data Availability.

Year	Plant Hill Station Data Availability	Stadium Station Data Availability
2013	75%	88%
2014	59%	82%
2015	19%	84%
2016	13%	90%
2017	45%	91%
Total	**42%**	**87%**

Data for the period January 2013 to December 2017 was obtained from Argos Scientific who manages data from the Stadium station on behalf of DPMT. Readily available terrain and land-use data from the Atmospheric Studies Group (ASG) via the United States Geological Survey (USGS) web site was studied.

In addition to the Plant Hill and Stadium ambient air quality monitoring station, DPMT owns and operates three more stations in and around Tsumeb. Ambient PM_{10} and SO_2 concentrations recorded at these stations from January 2013 to December 2017 were supplied by Argos Scientific and studied to determine the air quality status quo. Sampling at the Stadium and Info Centre stations was expanded to include $PM_{2.5}$ sampling in 2017. Periodically sampled ambient arsenic levels at all sampling locations are also referred to.

2.4 Determining the Impact of the Project on the Receiving Environment

To determine the impact of the Tsumeb smelter given the proposed upgrades and expansion, is a key outcome of the current study. To achieve this, a study methodology that would consider existing Tsumeb smelter activities as well as the proposed upgrades, had to be adopted in order to assess cumulative impacts.

The emissions inventory for the Tsumeb smelter, compiled in 2011, included particulate and gaseous emissions from the reverberatory furnace, Ausmelt furnace, converters and arsenic plant as well as fugitive building emissions and dust from crushing and screening, materials handling, paved roads, unpaved roads and areas exposed and prone to wind erosion. The 2011 assessment identified SO_2, PM_{10} and arsenic as pollutants of concern. As such, and given the nature of proposed upgrades, the impact assessment focussed on the change in the impact of these pollutants specifically. Due to the significant changes to the process since 2011 (i.e. the commissioning of the acid plant, and the decommissioning of the reverberatory furnace and arsenic plant), a new emissions inventory was compiled for the DPMT operations making use of the following:

- Isokinetic stack emission testing completed by Skyside in January 2018;
- Fugitive emissions from buildings making use of building dimensions and occupational health sampling data;
- Fugitive dust emissions from material handling and crushing operations making use of internationally published emission factors and material composition and moisture data sampled in February 2018.
- Vehicle entrainment emissions from unpaved road surfaces making use of internationally published emission factors and road surface material data sampled in February 2018.
- Wind blown dust emissions making use of the ADDAS (Airborne Dust Dispersion from Area Sources) model and material characteristics sampled in February 2018.
- Stack and building fugitive emissions from the proposed RHF; and,
- Increased concentrate processing rates from 240 000 t/a to 370 000 t/a and the associated increase in fugitive dust emissions.

In the quantification of emissions, use was made of available design criteria and emission factors which associate the quantity of a pollutant to the activity associated with the release of that pollutant. Use was specifically made of the comprehensive sets of emission factors and equations published by the United States Environmental Protection Agency (US EPA) and Australian Department of Environment (ADE) National Pollutant Inventory (NPI). Ten samples were collected of different stockpile and road surface material and analysed for moisture content, density, particle size distribution as well as metallic composition.

In the simulation of ambient air pollutant concentrations and dustfall rates use was made of the Atmospheric Dispersion Modelling System (ADMS) developed by 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 numerous computer models which include ADMS.

Simulated pollutant concentrations were compared to ambient air quality limits and guidelines to assess compliance. The findings of the above components informed recommendations of air quality management measures, including mitigation and monitoring where applicable.

3 Assumptions, Limitations and Exclusions

The following important assumptions, exclusions and limitations to the specialist study should be noted:

1. All project information required to calculate emissions for proposed operations was provided by SLR and DPMT.
2. The phase during which upgrades will be installed/constructed was not assessed. Impacts during this time are expected to be related to fugitive dust and of short duration. General good practice management and mitigation measures will be applicable to the construction phase.
3. Meteorology:
    a. It was decided to update the dispersion model to rather use meteorological data recorded at the Stadium ambient monitoring station, as data recorded at the Plant Hill station previously used for dispersion modelling simulations is very incomplete.
4. Emissions:
    a. The impact assessment was limited to SO_2, PM_{10}, $PM_{2.5}$, arsenic and H_2SO_4.
    b. The quantification of sources of emission was restricted to the Tsumeb smelter complex. Although other existing sources of emission within the area were identified, such sources were not quantified as part of the emissions inventory and simulations. Their impact is however included in the analysis of the ambient air quality monitoring data.
    c. Most fugitive dust emissions were assumed to be proportional to the increase in plant processing capacity.
5. Impacts:
    a. A screening level health impact assessment for arsenic was conducted. A more thorough discussion regarding health and cancer impacts is available in the Community Health Impact Assessment as part of the EIA.
    b. In estimating increased lifetime cancer risk, use was made of simulated annual average arsenic concentrations. This approach is conservative since it assumes an individual will be exposed to this concentration constantly over a period of 70 years.

4 Air Quality Regulations and Assessment Criteria

Prior to assessing the impact of current and proposed activities on the atmospheric environment, reference needs to be made to environmental regulations and guidelines governing emissions and impacts of such operations. Air quality guidelines and standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site. The ambient air quality standards and guideline values indicate safe daily exposure levels for most of the population, including the very young and the elderly, throughout an individual's lifetime. Air quality guidelines and standards are normally given for specific averaging or exposure periods

This section summarises both national and international legislation pertaining to air pollution and criteria pollutants relevant to the current study. A discussion on inhalation health risk and cancer risk associated with non-criteria pollutants is also provided.

4.1 National Regulations

Namibia has an Atmospheric Pollution Prevention Ordinance (NAPPO) (No. 11 of 1976) which addresses the following:

- Part II – Control of noxious or offensive gases
- Part III – Atmospheric pollution by smoke
- Part IV – Dust control
- Part V – Air pollution by fumes emitted by vehicles

The Namibian Atmospheric Pollution Prevention Ordinance (No. 11 of 1976) does however not include any ambient air standards, and only prescribes opacity guidelines for smoke under Part I. It is implied that the Director[1] provides air quality guidelines for consideration during the issuing of Registration Certificates. Registration Certificates are only issued for so called "Scheduled Processes" which are processes resulting in noxious or offensive gasses and typically pertain to point source emissions. Scheduled Processes at DPMT Tsumeb include Sulphuric Acid Processes and Copper Processes. Up to the end of 2016, Arsenic Processes would also have needed to be considered. The Ordinance defines a range of pollutants as noxious and offensive gasses but air pollution guidelines are usually primarily for criteria pollutants namely, SO_2, oxides of nitrogen (NO_x), carbon monoxide (CO), ozone (O_3), lead (Pb) and PM.

4.2 International Guidelines and Regulations for Criteria Pollutants

Typically, when no local ambient air quality criteria exist, or are in the process of being developed, reference is made to international criteria. 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 WHO. South African (SA) National Ambient Air Quality Standards (NAAQS) are also referenced since these are regarded representative indicators for Namibia due to the similar environmental, social and economic characteristics of the two countries.

Air quality guidelines (AQGs) have been published by the WHO in 1987 and were 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

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[1] *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.

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.

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 higher than the WHO AQGs themselves, to promote steady progress towards meeting the WHO AQGs. There are between two and three interim targets 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 WHO permits a 1% frequency of exceedance per calendar year.

Reference is also made to the European Commission Air Quality Legislation as published in EC Directives 2008/50/EC, 1999/30/EC and 2004/107/EC. Limit values published by the European Commission are mostly similar to the SA NAAQS as described below.

The South African Bureau of Standards (SABS) was engaged to assist the Department of Environmental Affairs (DEA, then known as the Department of Environmental Affairs and Tourism or DEAT) in the facilitation of the development of ambient air quality standards from 2004. This included the establishment of a technical committee to oversee the development of standards. Standards were determined based on international best practice for PM_{10}, $PM_{2.5}$, dustfall, SO_2, NO_2, O_3, CO, Pb and benzene.

The final revised SA NAAQS were published in the Government Gazette on 24 of December 2009 and included a margin of tolerance (i.e. frequency of exceedance) and implementation timelines linked to it. SA NAAQS 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.

Table 2: Assessment guidelines and standards for criteria pollutants considered in the assessment

Pollutant	Averaging (exposure period)	Limit value (µg/m³)	Limit value (ppb)	Limit value reference	Permitted frequency of exceedance	Reference
PM_{10}	24-hour	75	Not applicable	WHO IT-3 and SA NAAQS	4	WHO and SA NAAQS
	1-year	40	Not applicable	SA NAAQS	-	-
$PM_{2.5}$	24-hour	40	Not applicable	WHO IT-3[(a)] and SA NAAQS	4	WHO and SA NAAQS
	1-year	20	Not applicable	EU, WHO IT-2[(b)] and SA NAAQS	-	-
SO_2	10-minute	500	191	SA NAAQS	526	SA NAAQS
	1-hour	350	134	EU, SA NAAQS	24, 88	EU, SA NAAQS
	24-hour	125	48	EU, WHO IT-1 and SA NAAQS	3, 4	WHO, EU and SA NAAQS
	1-year	50	19	SA NAAQS	-	-

Notes: a) The WHO IT-3 for 24-hour $PM_{2.5}$ is 37.5 µg/m³

b) The 1-year $PM_{2.5}$ WHO IT-3 is 15 µg/m³ and the WHO IT-2 is 25 µg/m³.

4.3 Inhalation Health Criteria and Risk Factors for Non-criteria Pollutants

The potential for health impacts associated with non-criteria pollutants considered in this study are assessed per guidelines published by the following institutions:

1. California Environmental Protection Agency (CALEPA); and
2. World Health Organisation (WHO)

Chronic and acute inhalation criteria and unit risk factor (URFs) (the latter applicable to pollutants with a carcinogenic impact) for arsenic and H_2SO_4 are summarised in Table 3. A more thorough assessment of simulated and sampled arsenic concentrations on human health and cancer risk will be conducted as part of the Community Health Impact Assessment conducted as part of the EIA process for the expansion.

Table 3: Chronic and acute inhalation screening criteria and cancer unit risk factors

Pollutant	Chronic Screening Criteria (µg/m$_3$)	Acute Screening Criteria (µg/m^3)
Arsenic	0.006 (EU)$^{(a)}$	0.2 (CALEPA)
H_2SO_4	1 (CALEPA)	120 (CALEPA)

Notes: a) The EU community standard is based on a one in 100 000 increased lifetime cancer risk.

5 The Receiving Atmospheric Environment

5.1 Local Study Area and Air Quality Receptors

The local study area for the air quality impact assessment was selected based on the extent of expected air quality impacts and possible sensitive receptors such as individual homes and communities. A study area of 15 km east-west by 15 km north-west with the Tsumeb smelter complex located approximately in the centre, was identified. The study area includes the town of Tsumeb and its suburbs to the south and south-west, scattered farmsteads and the Namfo (Pty) Ltd agricultural area to the north (Table 4). These are areas considered sensitive to changes in ambient air quality. Ambient concentrations simulated by the dispersion model were also calculated at the five ambient station locations as well as at three additional locations (Table 4) requested by SLR.

Table 4: Additional Sensitive Receptor Locations Included in the AQIA Update (as requested by SLR)

Receptor Name	Latitude	Longitude
Ondundu	19°14'25.69 S	17°43'36.02'' E
Endombo	19°14'28.39'' S	17°42'18.86'' E
Private School and Hospital	19°14'32.85'' S	17°43'19.29'' E

5.2 Atmospheric Dispersion Potential

Meteorological mechanisms govern the dispersion, transformation, and eventual removal of pollutants from the atmosphere. The analysis of land-use and topography as well as wind speed, wind direction, temperature and atmospheric stability is necessary to facilitate a comprehensive understanding of the dispersion potential of the site.

5.2.1 Topography and Land-use

The DPMT Tsumeb site is located approximately 1 268 m above sea level and the study area characterized by rolling terrain and low hills. It is likely that the topography of the study area will influence especially the dispersion of pollutants released by ground level sources. Land use/cover includes agriculture, commercial and residential properties and open bushveld.

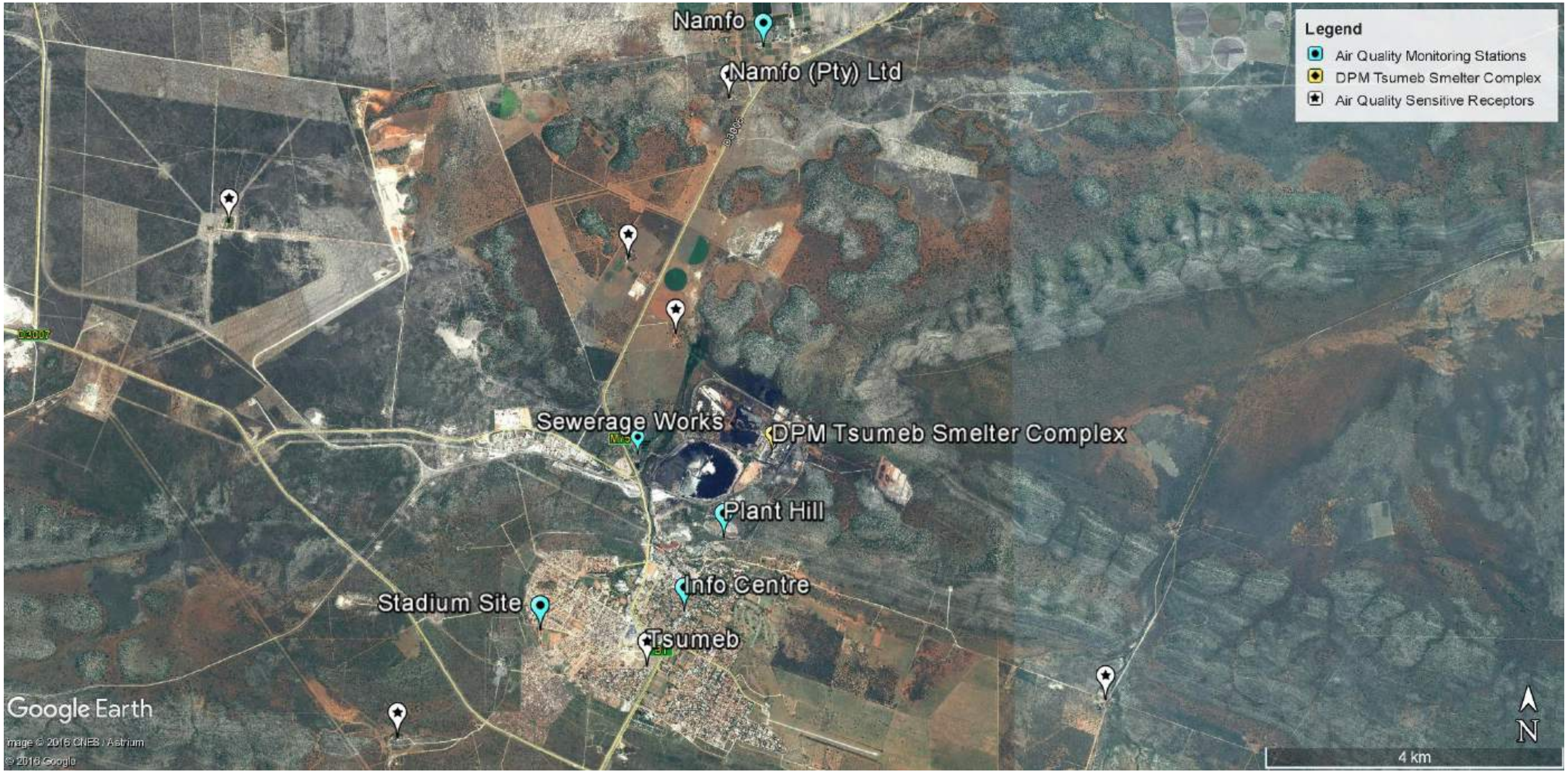


Figure 2: Locations of air quality sensitive receptors and monitoring stations

5.2.2 Surface Wind Field

The wind field determines both the distance of downward transport and the rate of dilution of pollutants. The generation of mechanical turbulence is a function of the wind speed, in combination with the surface roughness. The wind field for the study area is described with the use of wind roses.

Wind roses comprise 16 spokes, which represent the directions from which winds blew during a specific period. The colours used in the wind roses below, reflect the different categories of wind speeds; the yellow area, for example, representing winds in between 2 and 3 m/s. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. The frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s are also indicated. The data described below is data from the DPMT Stadium air quality monitoring station, which has a much higher data availability compared to the Plant Hill data used in previous assessments (Table 1).

Wind roses for the period January 2013 to December 2017 are shown in Figure 3. The wind field is uniform with frequent south-easterly winds. Calm conditions prevailed 9.7% during the recording period with a period average wind speed of 2.3 m/s. During day-time the wind field is mostly characterised by wind from the east-southeast and east with an average wind speed of 2.6 m/s and 4.8% calm conditions. The average wind speed decreased to 1.9 m/s during night-time hours and blew mostly from the southeast with 12.4% calm conditions.

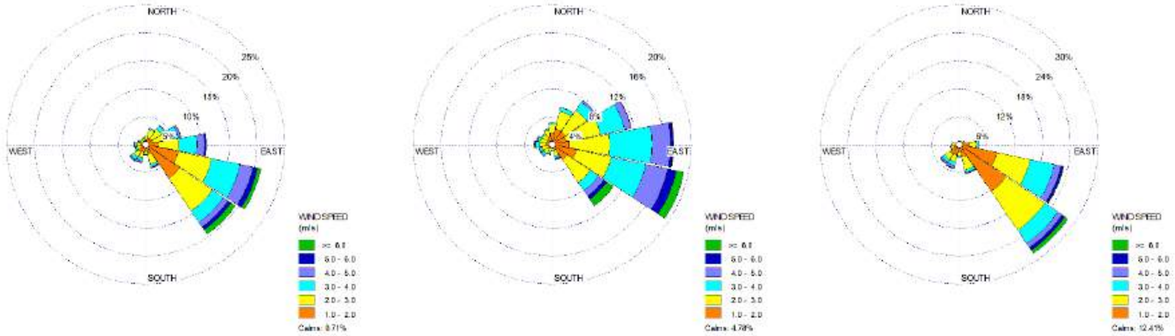


Figure 3: Period average wind roses (average, daytime and night time) (Stadium data, January 2013 to December 2017)

5.2.3 Temperature

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher a pollution plume can rise), and determining the development of the mixing and inversion layers. Minimum, maximum and mean temperatures as recorded at the Stadium station, are shown in Table 5. Period average, maximum and minimum temperatures were 23.9 °C, 45 °C and 2 °C respectively.

Table 5: Minimum, maximum and average temperatures

°C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min	14.0	16.0	17.0	12.0	6.0	6.0	2.0	8.0	13.0	14.0	16.0	18.0
Max	39.0	38.0	37.0	34.0	32.0	31.0	32.0	45.0	38.0	39.0	40.0	38.0
Ave	25.8	25.0	24.4	23.2	21.4	19.1	19.1	22.5	26.8	29.2	28.4	26.1

5.2.4 Rainfall

Rainfall is not at present recorded at any of the DPMT air quality monitoring stations. Long term monthly average rainfall data for Tsumeb was obtained from weatherbase.com (Canty and Associates LCC, 2017). The area receives, on average, 520 mm of rain per year. Rainfall is received from October to April (Figure 4).

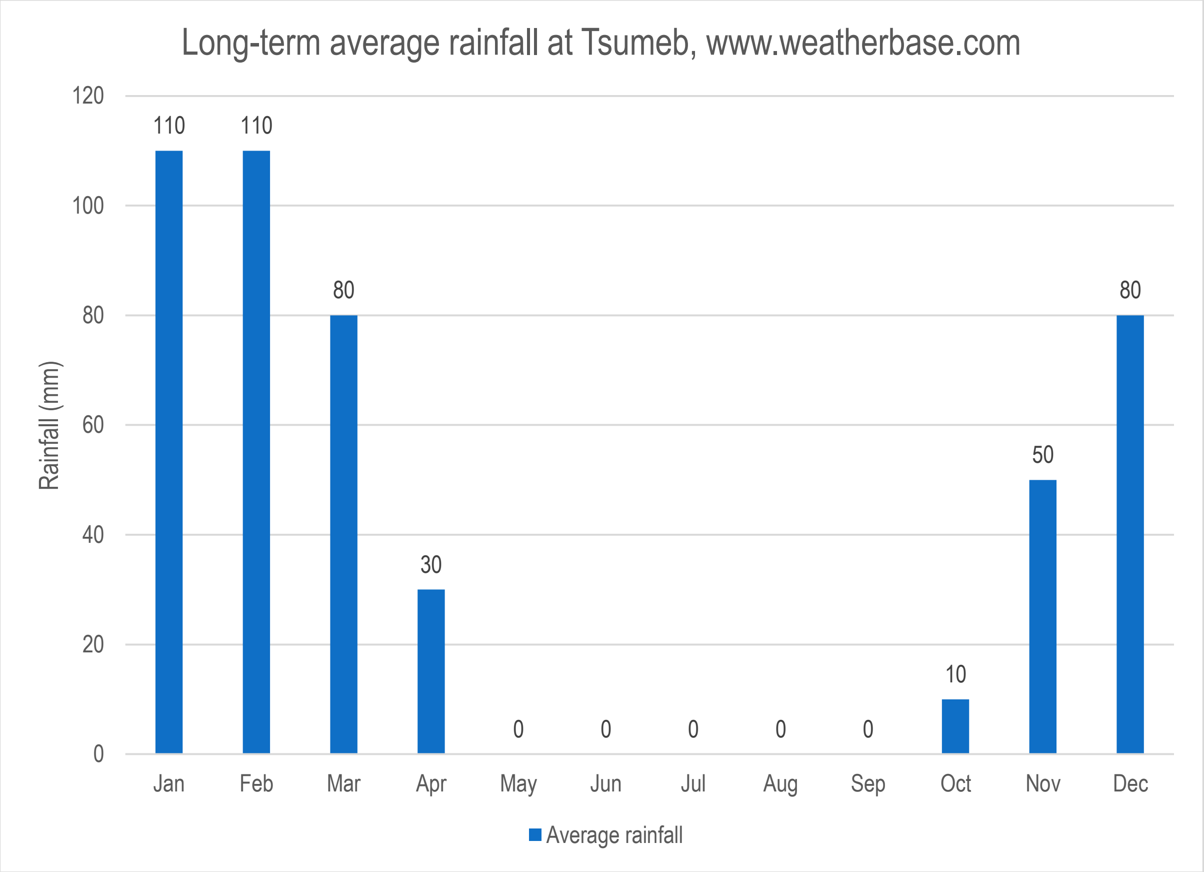


Figure 4: Long term average rainfall at Tsumeb, weatherbase.com (Canty and Associates LCC, 2017)

5.2.5 Atmospheric Stability

The new generation air dispersion models differ from the models traditionally used in several ways, the most important of which is the description of atmospheric stability as a continuum rather than discrete classes. Two parameters therefore describe the atmospheric boundary layer properties; the boundary layer depth and the Monin-Obukhov length, rather than in terms of the single parameter Pasquill Class. The Monin-Obukhov length (L_{Mo}) provides a measure of the importance of buoyancy generated by the heating of the ground and mechanical mixing generated by the frictional effect of the earth's surface. Physically, it can be thought of as representing the depth of the boundary layer within which mechanical mixing is the dominant form of turbulence generation (CERC, 2004). The atmospheric boundary layer constitutes the first few hundred metres of the atmosphere. During daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface. Night-times are characterised by weak vertical mixing and the predominance of a stable layer. These conditions are normally associated with low wind speeds and lower dilution potential.

Diurnal variation in atmospheric stability, as calculated from on-site data, and described by the inverse Monin-Obukhov length and the boundary layer depth is illustrated in Figure 5. The highest concentrations for ground level, or near-ground level releases from non-wind dependent sources would occur during weak wind speeds and stable (night-time) atmospheric conditions. For elevated releases (Figure 6), unstable conditions can result in very high concentrations of poorly diluted emissions close to the stack. This is called *looping* and occurs mostly during daytime hours. Neutral conditions disperse the plume equally in both the vertical and horizontal planes and the plume shape is referred to as *coning*. Stable conditions prevent the plume from mixing vertically, although it can still spread horizontally and is called *fanning* (Tiwary & Colls, 2010). For ground level releases the highest ground level concentrations will occur during stable night-time conditions.

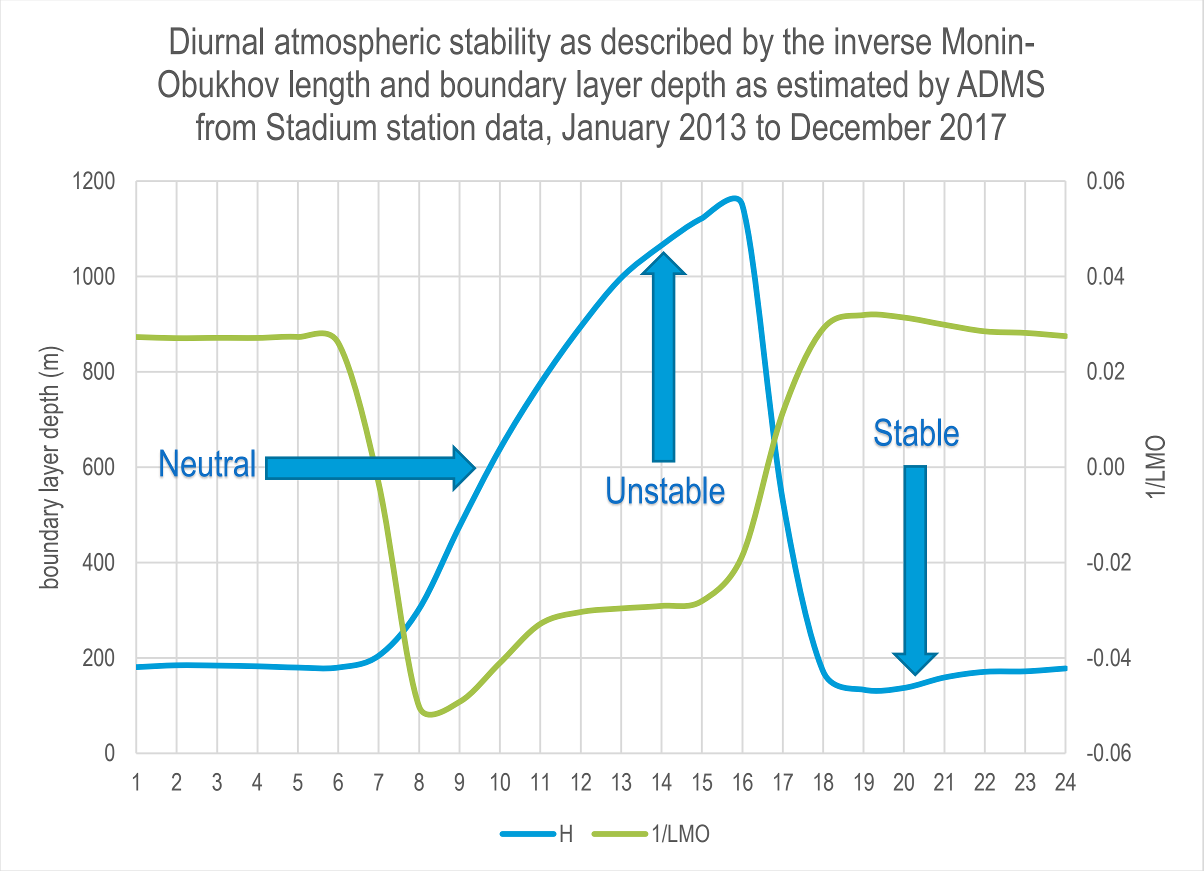


Figure 5: Diurnal atmospheric stability as described by the inverse Monin-Obukhov length and boundary layer depth as estimated by ADMS from Stadium data, January 2013 to December 2017

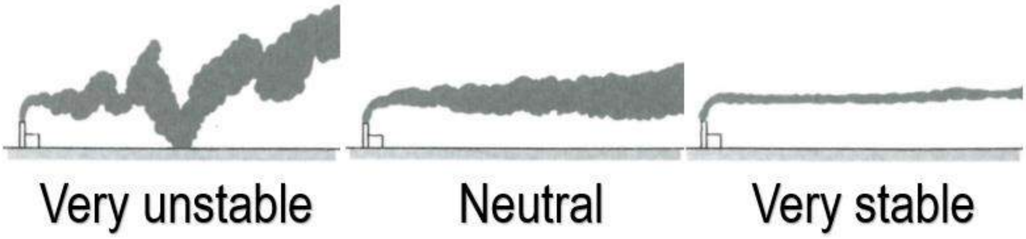


Figure 6: Elevated Plume Behaviour under different Atmospheric Stabilities

5.3 Status Quo Air Quality

5.3.1 Sources of Atmospheric Emission

The DPMT Tsumeb smelter is the main industrial source of air pollution in the area. Ambient SO_2 and arsenic levels are primarily caused by emissions from this complex (See section 5.3.2). SO_2 is however also emitted by vehicles and may be emitted in small quantities at the municipal sewerage works.

There are several sources of atmospheric PM in the area. These include opencast copper mining operations to the west, agricultural activities to the north, paved and unpaved public roadways, open areas exposed to wind, small scale industrial/commercial activities within and around Tsumeb and trans-boundary sources.

5.3.2 Measured Ambient Air Pollutant Levels

As mentioned earlier, DPMT owns and operates five ambient air quality stations in and around Tsumeb (Table 6). In addition to weather parameters, these stations record PM_{10}, SO_2 and arsenic concentrations, three key pollutants resulting from their operations. Data availability over the January 2013 to December 2017 period for SO_2 and PM_{10} is indicated in Table 6. Current levels of SO_2 and PM_{10} are discussed and assessed against selected air quality limits in 5.3.2.1 and 5.3.2.2 respectively. Arsenic levels are discussed in Section 5.3.2.4.

Table 6: Ambient air quality data availability over the period Jan-13 to Dec-17

Year	Info Centre	Namfo	Plant Hill	Sewerage Works	Sports Stadium
			SO_2		
2013	82%	81%	82%	82%	96%
2014	99%	78%	94%	94%	98%
2015	80%	96%	84%	84%	97%
2016	77%	81%	71%	71%	81%
2017	88%	95%	92%	51%	92%
			PM_{10}		
2013	81%	80%	98%	98%	95%
2014	92%	90%	37%	37%	88%
2015	62%	57%	84%	84%	92%
2016	70%	55%	24%	24%	9%
2017	66%	54%	92%	30%	65%

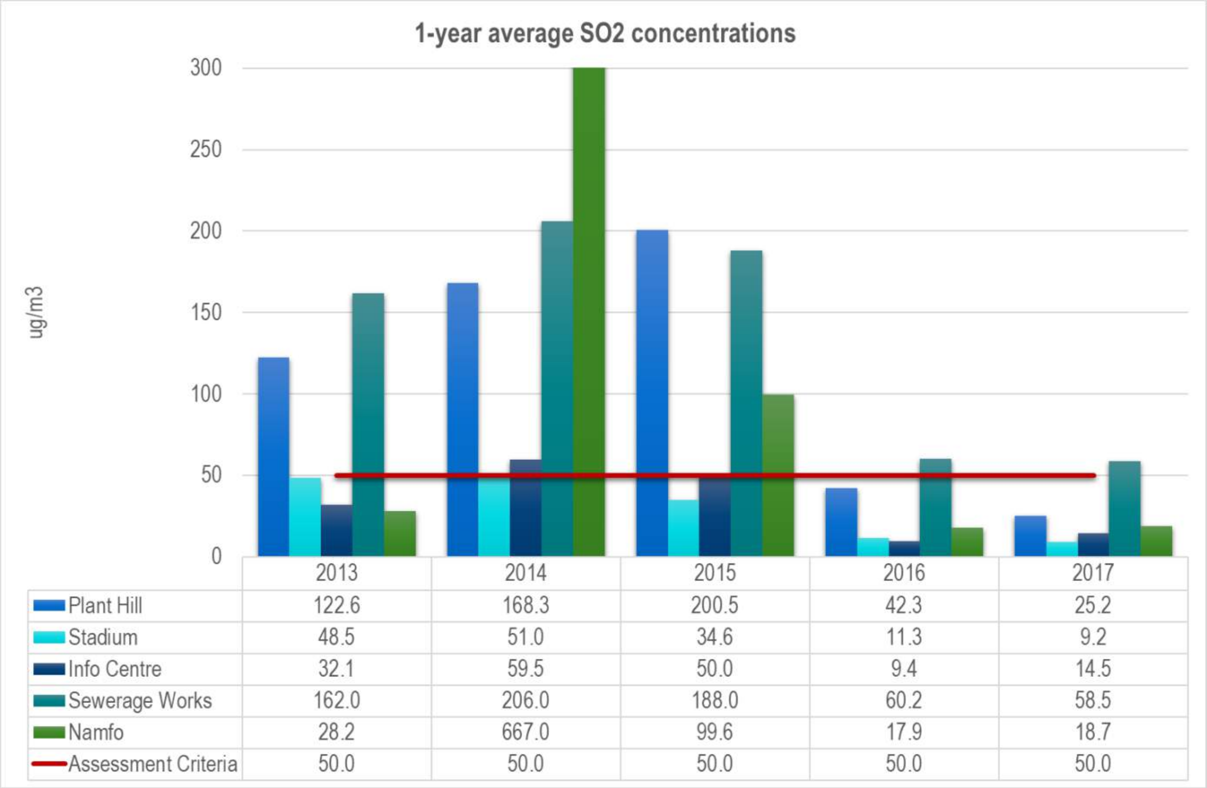
5.3.2.1 Sulphur Dioxide Levels

SO_2 concentrations are recorded at all five of the monitoring stations. Annual average SO_2 concentrations at each station for each year from 2013 to 2017 are shown in Figure 7.

Ambient SO_2 concentrations recorded at the monitoring stations have significantly decreased since the commissioning of the acid plant in 2015. In 2014 the annual average SO_2 concentration exceeded the assessment criteria of 50 µg/m³ at all sampling locations. In 2016 and 2017 annual average SO_2 concentrations were well below 50 µg/m³ at all sampling locations with the exception of the Sewerage Works, which is located close to and directly downwind of the DPMT operations.

Polar and time variation plots were generated from hourly SO_2 data for all five stations. These plots enable the interpreter to understand where peak concentrations originate from and during what time of the day peaks occur. A polar plot shows concentrations as a function of magnitude, wind speed and wind direction with the sampling location representing the centre of the plot. Time variation plots show the variation in SO_2 concentrations for each hour, weekday and month.

The polar plots show that DPMT is the main source of SO_2 in the study area, but that there are instances when slightly higher SO_2 concentrations are recorded when the wind direction is not from DPMT towards the monitoring stations, indicative of other smaller SO_2 sources in the study area.



	2013	2014	2015	2016	2017
Plant Hill	122.6	168.3	200.5	42.3	25.2
Stadium	48.5	51.0	34.6	11.3	9.2
Info Centre	32.1	59.5	50.0	9.4	14.5
Sewerage Works	162.0	206.0	188.0	60.2	58.5
Namfo	28.2	667.0	99.6	17.9	18.7
Assessment Criteria	50.0	50.0	50.0	50.0	50.0

Figure 7: Annual Average SO_2 Concentrations at DPMT Stations - 2013 to 2017

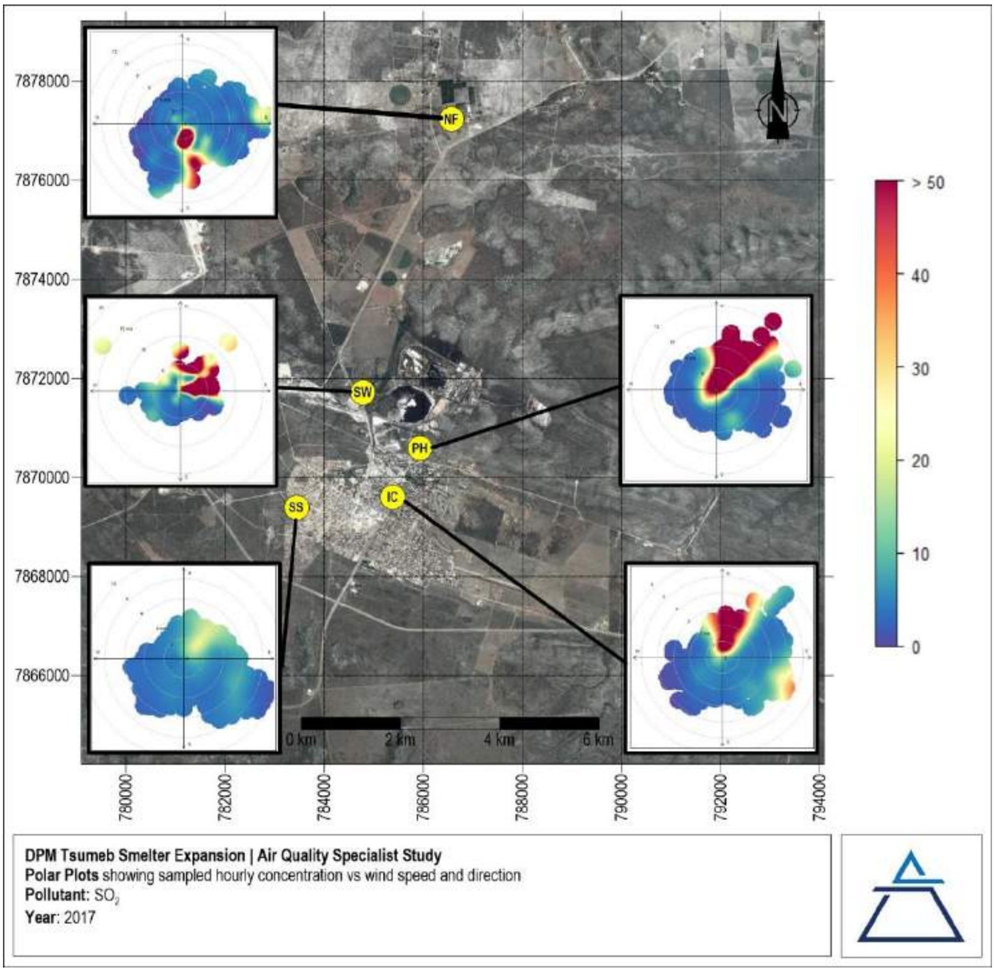


Figure 8: SO_2 Polar Plots – 2017

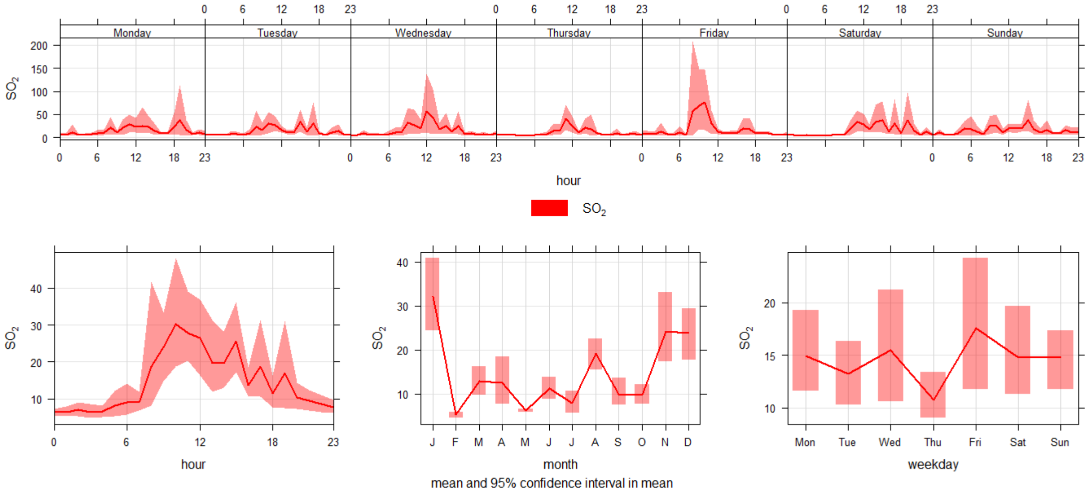


Figure 9: SO_2 Time Variation – Info Centre

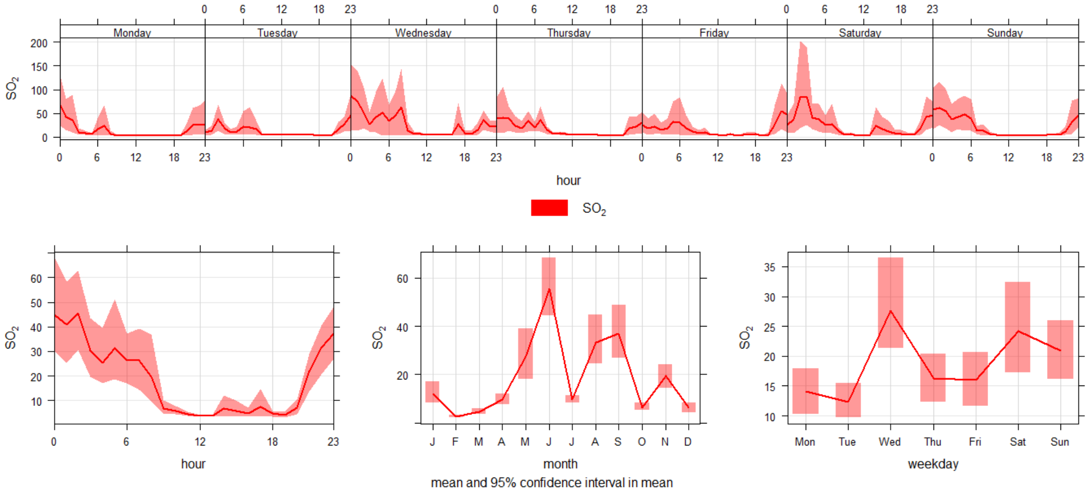


Figure 10: SO_2 Time Variation – NAMFO

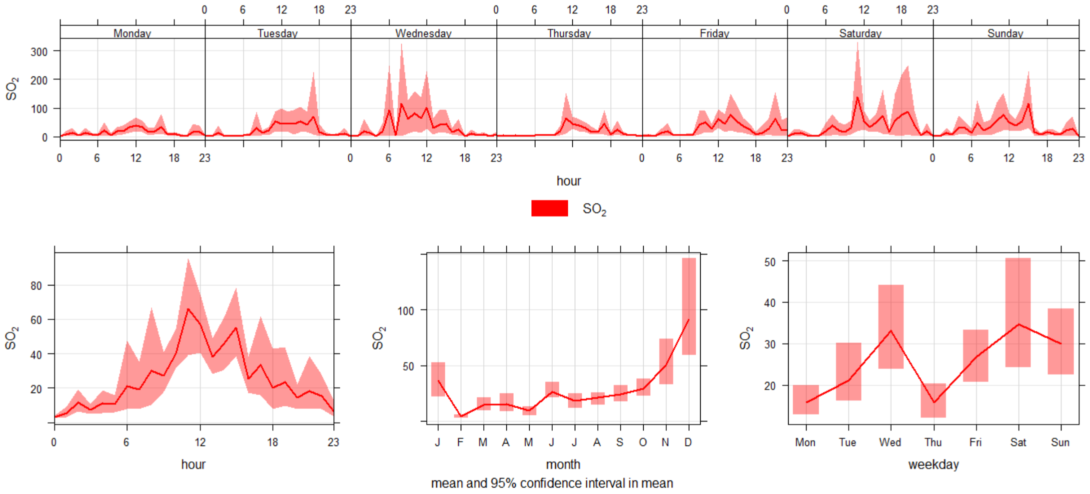


Figure 11: SO_2 Time Variation – Plant Hill

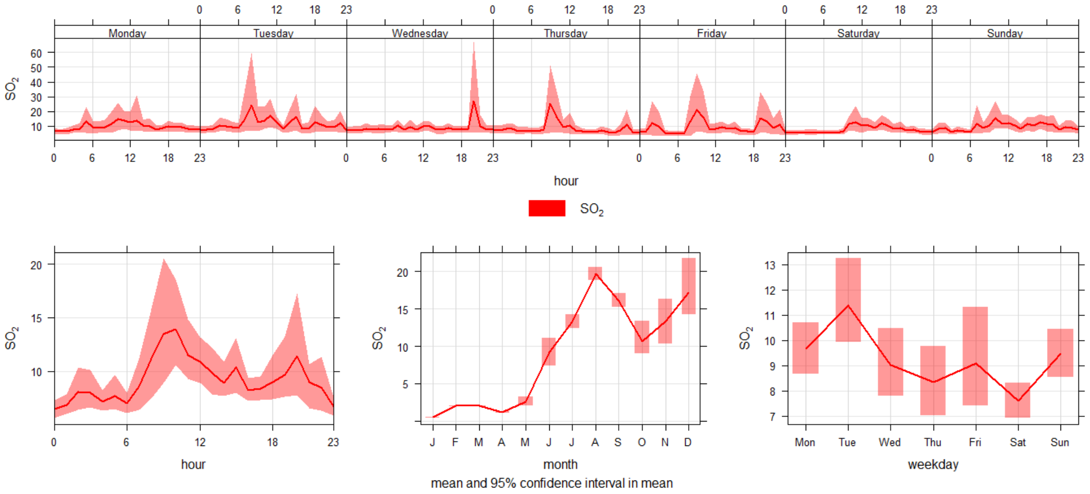


Figure 12: SO_2 Time Variation – Sports Centre

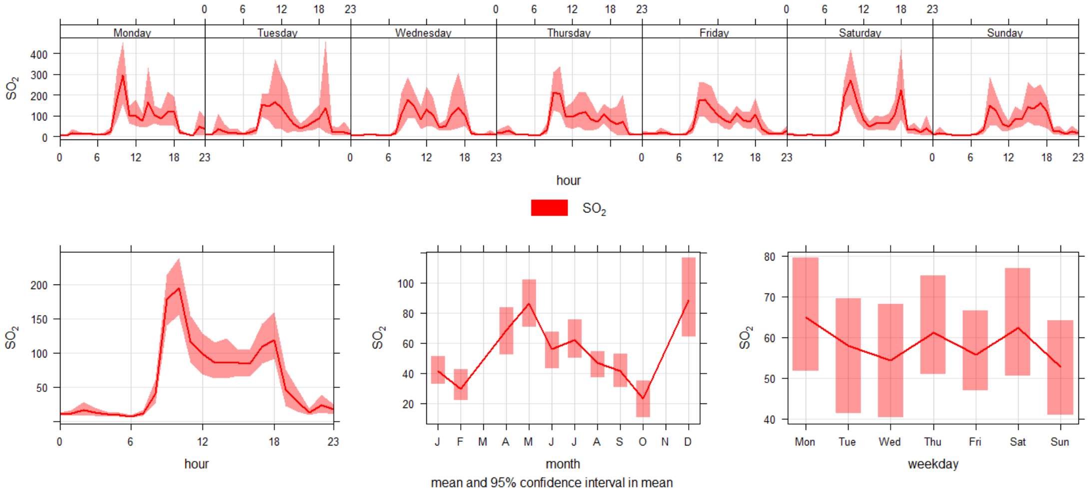
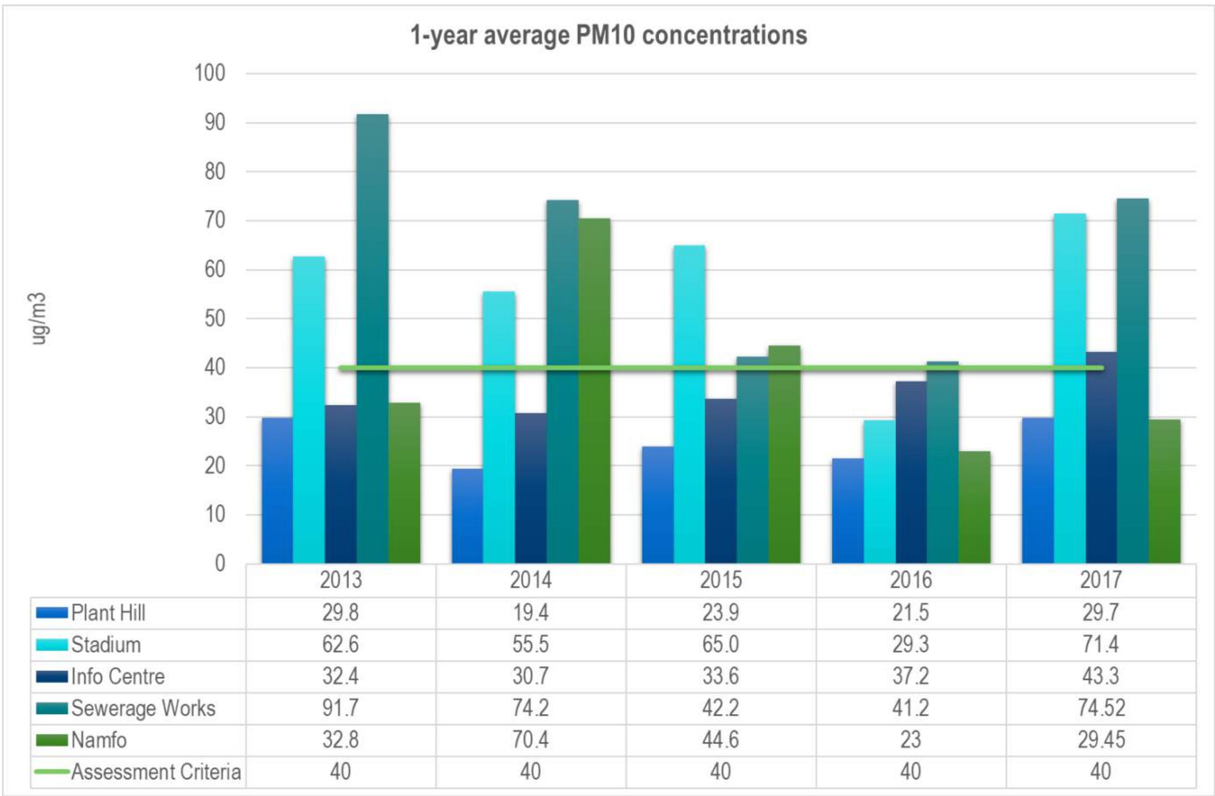


Figure 13: SO$_2$ Time Variation – Sewerage Works

5.3.2.2 PM_{10} Levels

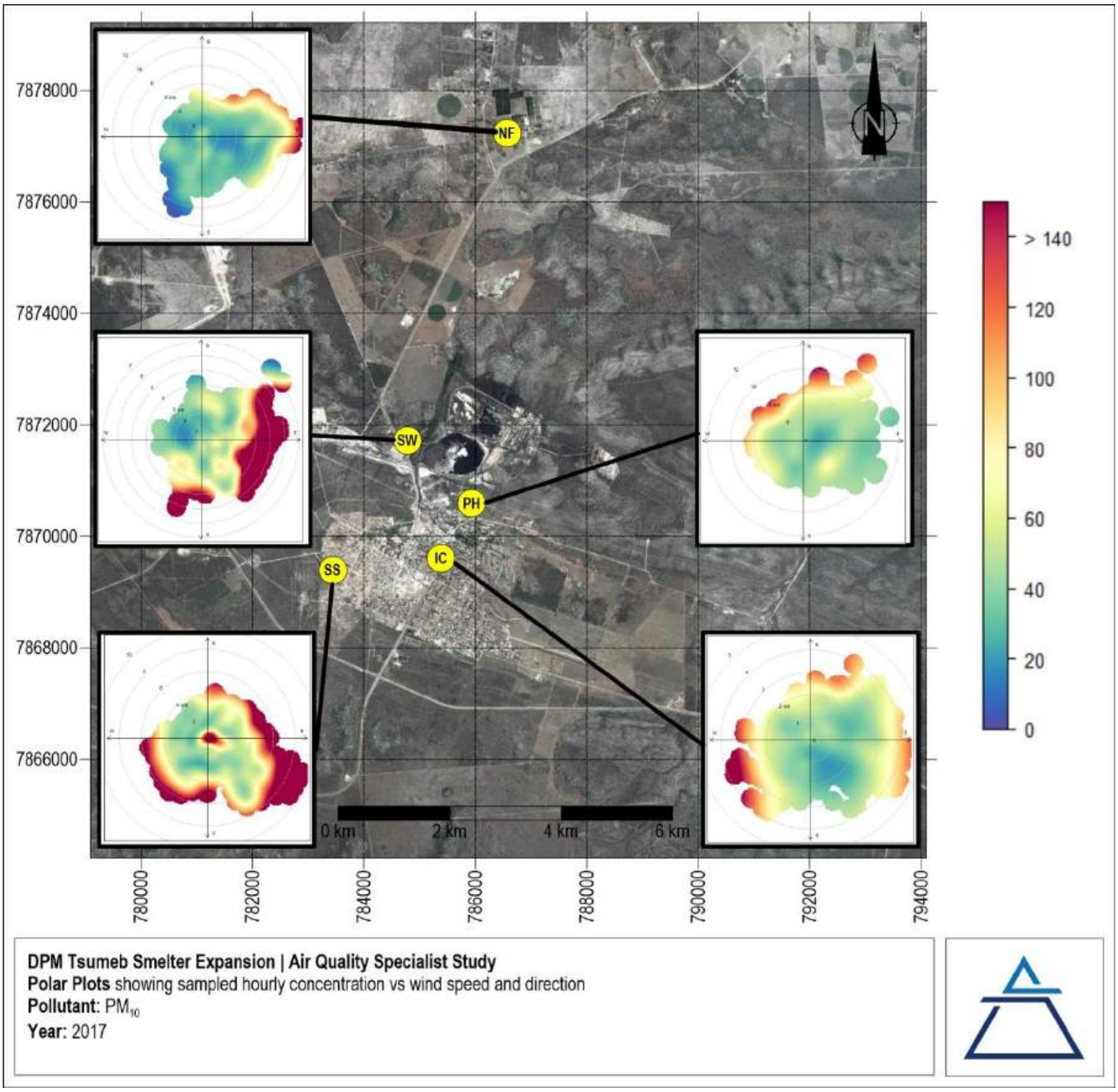
Recorded annual average PM_{10} concentrations at the five monitoring stations are shown in Figure 14. Annual average PM10 concentrations have been steadily decreasing from 2013 to 2016, but 2017 concentrations were higher than those recorded in 2016.

Polar and time variation plots for PM_{10} are shown below. While PM_{10} concentrations were highest when the wind was towards the Sewerage and Plant Hill stations (the two stations closest to the DPMT operations), the highest concentrations at the Info Centre, Namfo and Stadium stations occurred at high wind speeds from other directions, indicative of other particulate emission sources contributing to elevated PM_{10} levels at these stations. Very high PM_{10} concentrations were recorded at the Stadium and Sewerage Works stations. An analysis of the generated polar plots as well as the time variation graphs indicate that DPMT is likely the main source of elevated PM_{10} concentrations at the Sewerage Works, but that other sources to the south east and south west of the Stadium station are the highest contributors to high PM_{10} concentrations at this station. The time variation graph show that these sources mainly impact between 18h00 and 21h00 in the evening, likely sources during this time period include vehicle traffic, domestic fuel burning and community activities.



	2013	2014	2015	2016	2017
Plant Hill	29.8	19.4	23.9	21.5	29.7
Stadium	62.6	55.5	65.0	29.3	71.4
Info Centre	32.4	30.7	33.6	37.2	43.3
Sewerage Works	91.7	74.2	42.2	41.2	74.52
Namfo	32.8	70.4	44.6	23	29.45
Assessment Criteria	40	40	40	40	40

Figure 14: Annual Average PM_{10} concentrations recorded at Plant Hill (Jan-13 to Oct-16)



DPM Tsumeb Smelter Expansion | Air Quality Specialist Study
Polar Plots showing sampled hourly concentration vs wind speed and direction
Pollutant: PM_{10}
Year: 2017

Figure 15: PM_{10} Polar Plots – 2017

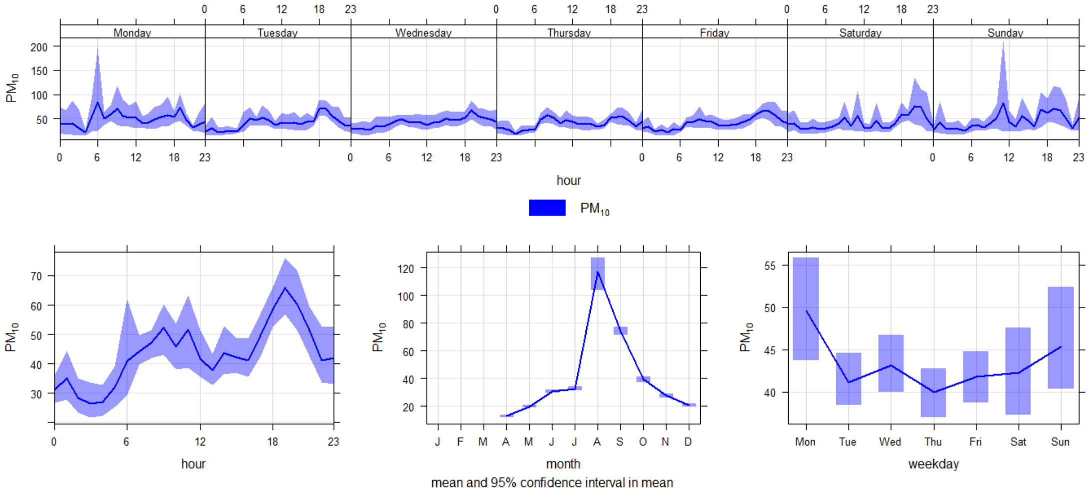


Figure 16: PM_{10} Time Variation – Info Centre

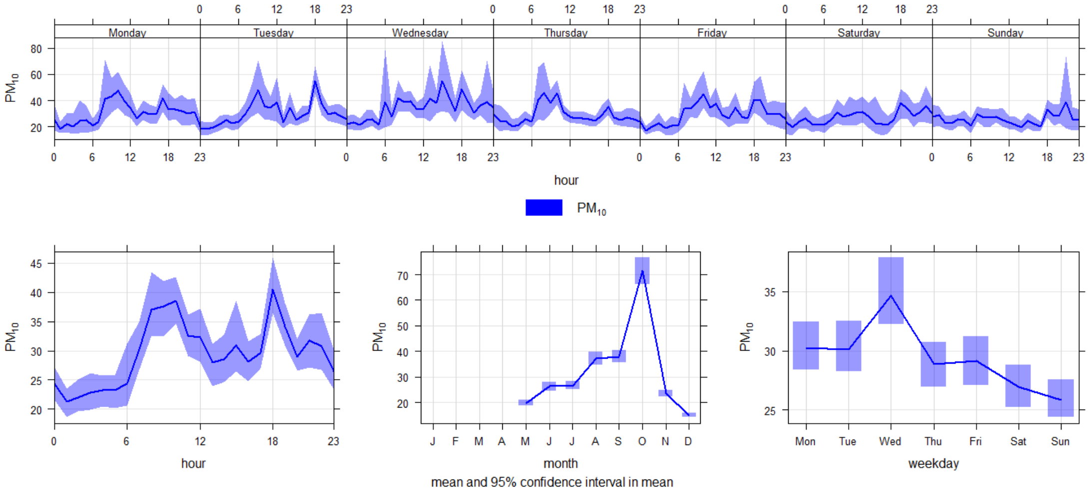


Figure 17: PM$_{10}$ Time Variation – NAMFO

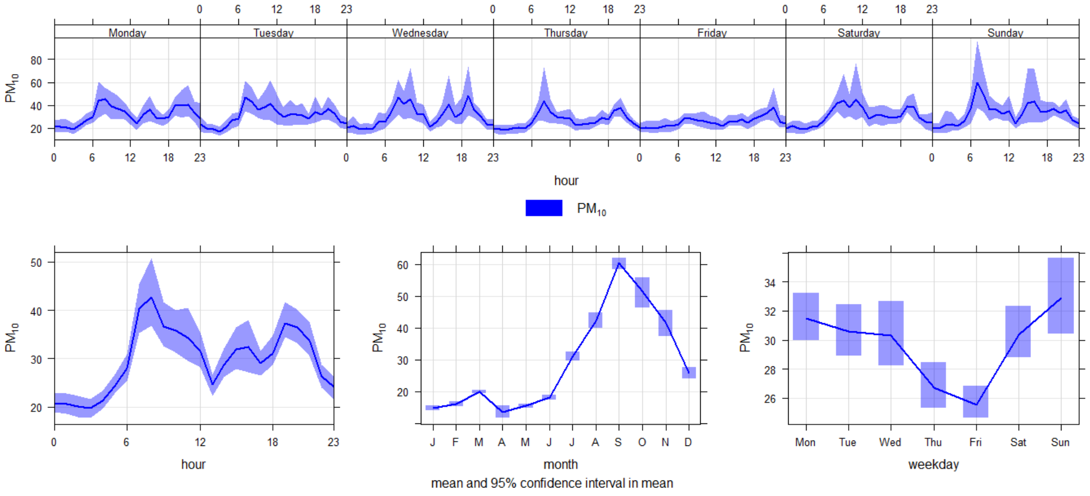


Figure 18: PM$_{10}$ Time Variation – Plant Hill

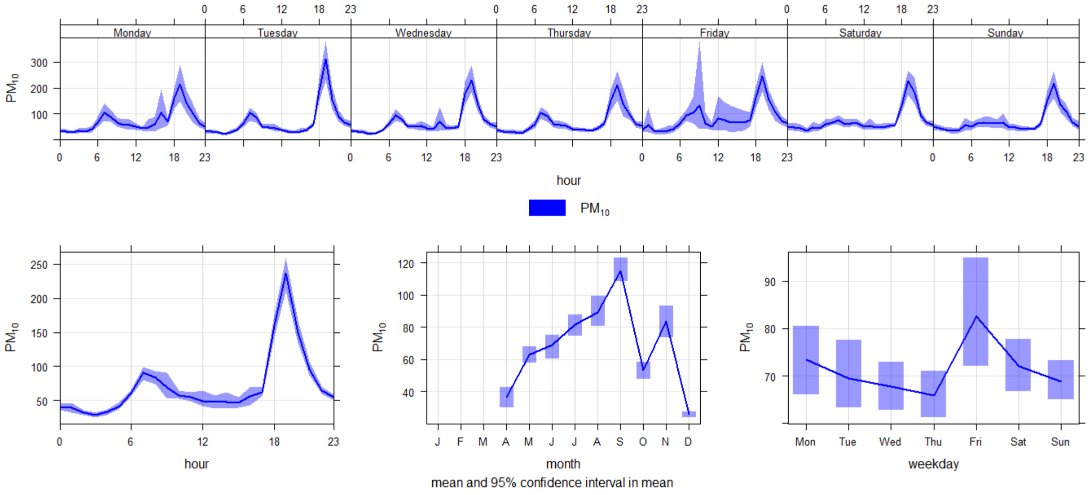


Figure 19: PM$_{10}$ Time Variation – Sports Centre

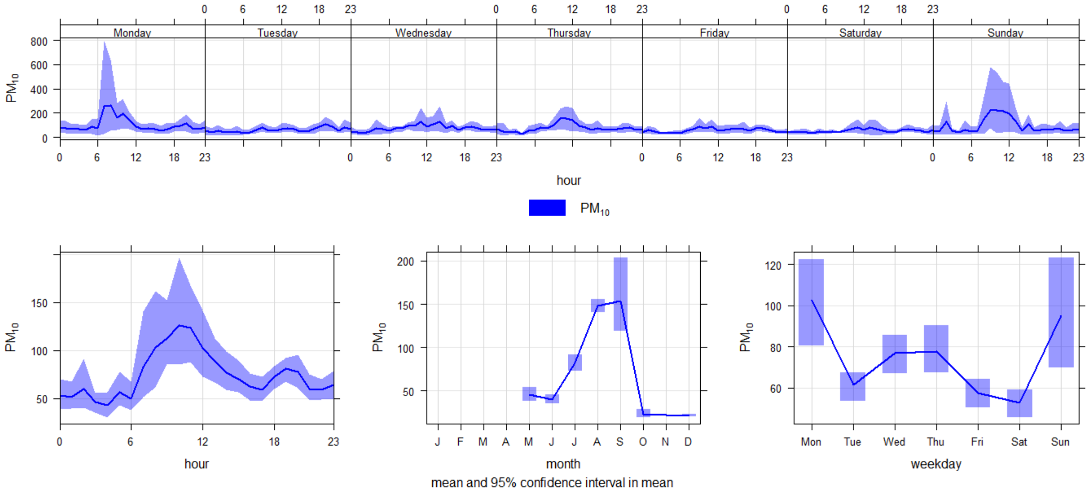


Figure 20: PM_{10} Time Variation – Sewerage Works

5.3.2.3 $PM_{2.5}$ Levels

Monitoring of ambient $PM_{2.5}$ concentrations was started at the Stadium and Info Centre stations in 2017. The annual average concentration at the Stadium station in 2017 was 27.7 µg/m³ while the annual average concentration at the Info Centre station for the same period was 13 µg/m³.

Polar plots and time variation plots for recorded $PM_{2.5}$ concentrations are shown below. Similar to PM_{10} the polar plots and time variation plots indicate that a variety of sources contribute to elevated $PM_{2.5}$ concentrations, the highest concentrations at both stations were recorded in the evening between 18h00 and 21h00.

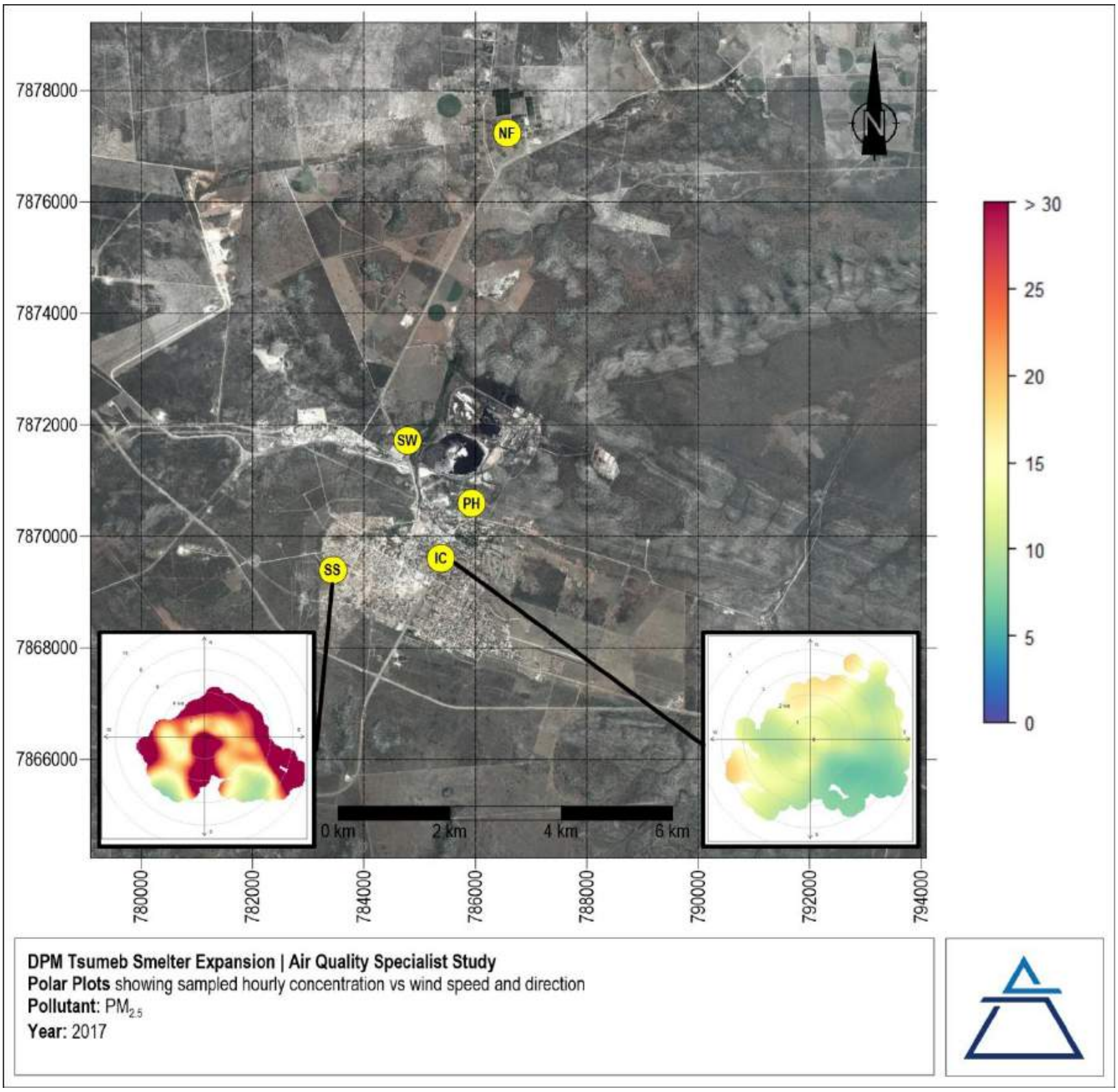


Figure 21: $PM_{2.5}$ Polar Plots – 2017

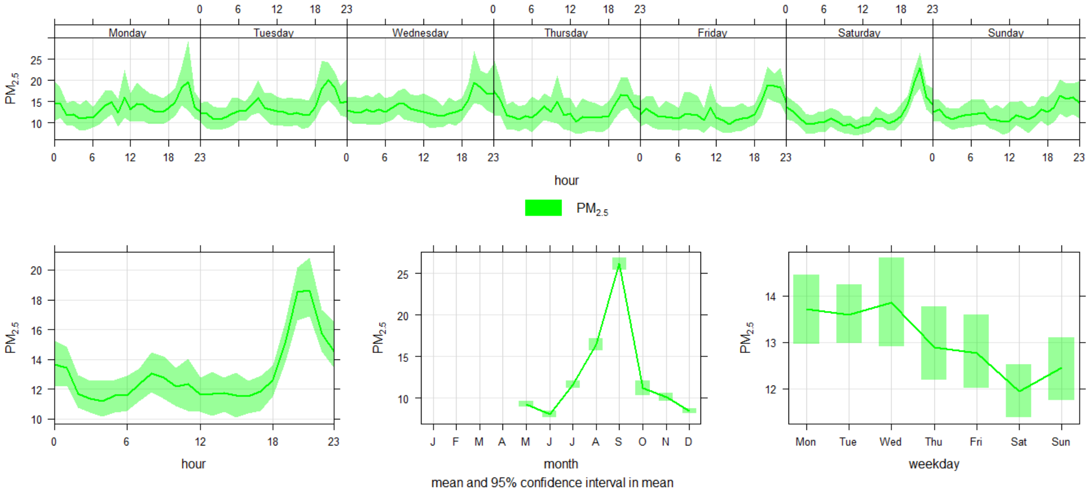


Figure 22: $PM_{2.5}$ Time Variation – Info Centre

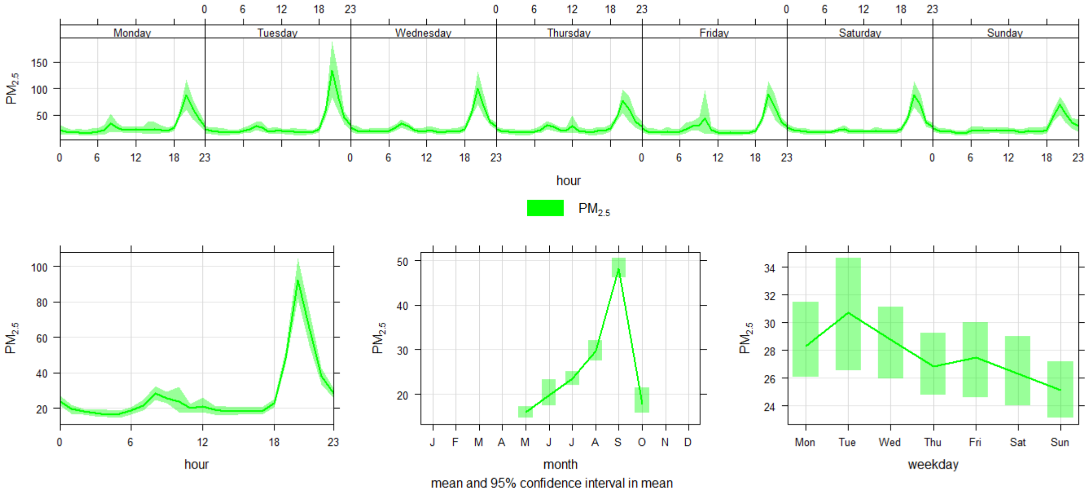


Figure 23: $PM_{2.5}$ Time Variation – Stadium

5.3.2.4 Arsenic Levels

Arsenic in the PM_{10} fraction is reported at all five ambient air quality stations. Recorded ambient arsenic concentrations (Figure 24) at all five sampling locations has steadily decreased from 2013 to 2016, with a very slight increase in concentrations recorded in 2017 at the Plant Hill, Sewerage Works and Namfo stations relative to those recorded in 2016. The following long-term trends were reported for the 2012 to 2017 period (Winnaar, 2018)

- At the Sewerage Works the maximum annual average concentration of just over 2.75 µg/m³ was recorded in 2014. A notable decrease in annual average arsenic concentrations occurred in 2015 and 2016 with the minimum of 0.25 µg/m³ occurring in 2016. 2017 concentrations were slightly higher at 0.52 µg/m³ but still significantly lower than concentration recorded in 2012, 2013 and 2014.
- At Plant Hill, a maximum annual average arsenic concentration of 1.5 µg/m³ was recorded in 2014. The lowest concentration of 0.27µg/m³ was recorded in 2016 with a slightly higher concentration of 0.54 µg/m³ recorded in 2017.
- Arsenic levels at the Sports Stadium show a decrease from just under 0.5 µg/m³ in 2013 to approximately 0.07 µg/m³ in 2017.
- Average ambient arsenic levels at the Info Centre site have historically been the lowest. Since 2013, the annual mean concentration has decreased from approximately 0.25 µg/m³ to less than 0.08 µg/m³ in 2017.
- The Argos Scientific report (Winnaar, 2017) also clearly shows higher ambient arsenic levels during dry and windy months. This would indicate fugitive dust rather than stack emissions as the cause of elevated arsenic concentrations.

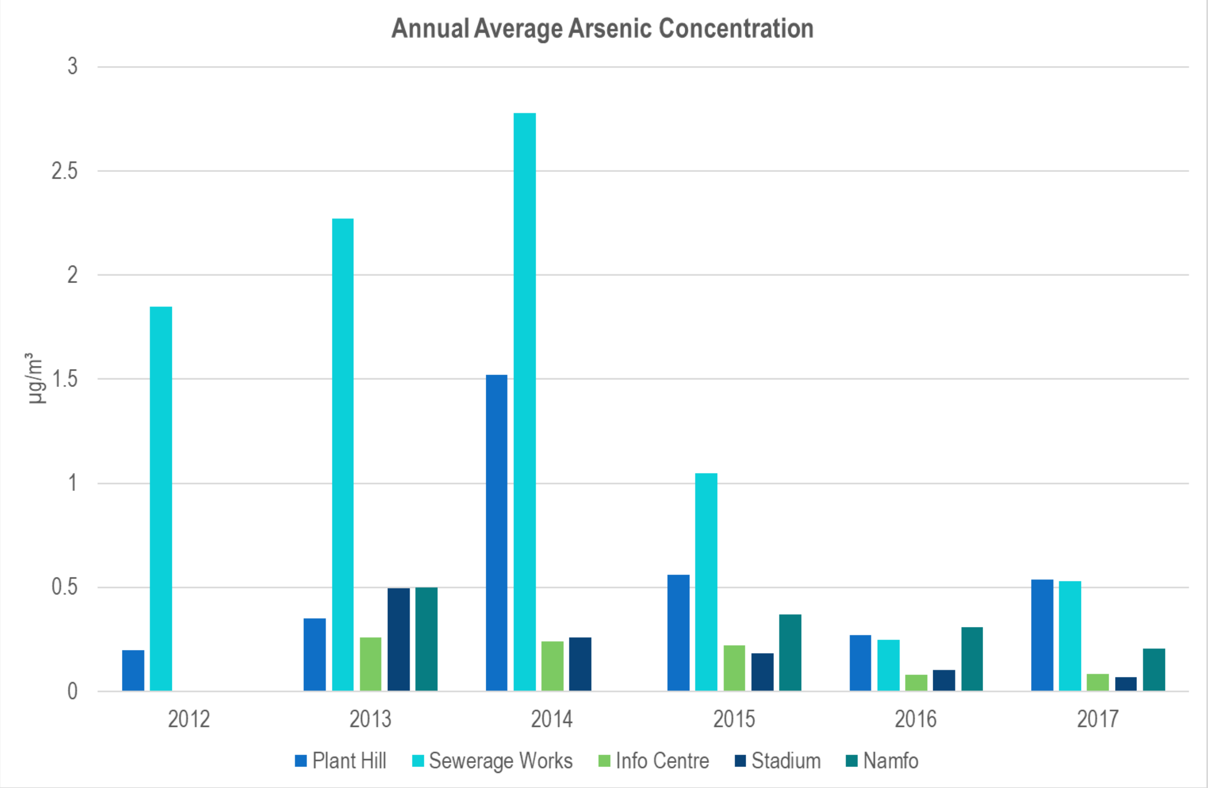


Figure 24: Annual Average Arsenic Concentration – 2012 to 2017

6 Impact Assessment

6.1 Atmospheric Emissions Inventory

The establishment of a comprehensive emissions inventory formed the basis for the assessment of the air quality impacts of the Tsumeb smelter complex and proposed upgrades on the receiving environment.

Sources of emission and associated pollutants considered in the emissions inventory included:

- Stack emissions:
  - The copper stack, emissions from the hygiene and new converter baghouses (SO_2, PM_{10}, $PM_{2.5}$ and arsenic);
  - The acid plant stack (SO_2 and H_2SO_4):
  - The new RHF baghouse stack (SO_2, PM_{10}, $PM_{2.5}$ and arsenic)
- Fugitive emissions (SO_2, PM_{10}, $PM_{2.5}$ and arsenic):
  - Furnace and converter fugitives:
    - Ausmelt building area;
    - Converter building area;
    - New RHF building area;
  - Crushing and screening (PM_{10}, $PM_{2.5}$ and arsenic);
  - Materials handling and transfer (PM_{10}, $PM_{2.5}$ and arsenic);
  - Vehicle entrained dust because of raw materials, product and waste transport on internal paved and unpaved roads (PM_{10}, $PM_{2.5}$ and arsenic); and
  - Windblown dust from raw materials areas, waste and tailings disposal areas.

Emissions were quantified for both the current or "base" scenario and a design or "Project" scenario. The base scenario is representative of current activities at a current concentrate processing rate of 240 000 t/a. The project scenario includes proposed plant upgrades and a concentrate processing rate of 370 000 t/a.

6.1.1 Stack Parameters and Emissions

6.1.1.1 Current Point Sources

Emissions vented to atmosphere from point sources at DPMT were estimated based on isokinetic stack sampling conducted by Skyside in January 2018. Point sources at DPMT include the Copper Stack (through which captured secondary emissions from the Ausmelt furnace and converters is emitted), the Ausmelt stack (that is used as a by-pass for primary Ausmelt furnace emissions when the acid plant is off-line) and the Acid Plant stack (through which the tail gas from the acid plant is emitted to atmosphere).

Stack parameters (as reported in previous studies) and emission rates (as recorded by Skyside in January 2018) are shown in Table 7. The following assumptions were made:

- Captured secondary emissions from the converters was recorded by Skyside before the baghouse. It was assumed that SO_2 concentrations remained unchanged through the baghouse and that particulate and arsenic concentrations are removed with 90% efficiency in the baghouse.
- The annual total of emissions through the Ausmelt stack were estimated based on acid plant availability and utilization provided by DPMT. Dispersion modelling simulations were conducted for 75% utilization and 90%

utilization scenarios. Only primary off-gas from the Ausmelt furnace is vented through this stack when the acid plant is off-line, as the converters undergo an emergency roll-out when the acid plant trips.

- Emission results on the secondary emissions from converters was captured at a time when the emissions were above average (while the converters were blowing). In 2016 Skyside conducted a 7-hour sampling campaign before the baghouse serving the secondary converter emissions which is deemed to be much more representative of secondary converter emissions.

Table 7: Stack Parameters and Emissions – Current Operations

	Copper Stack	Acid Plant Stack	Ausmelt Stack	
			(75% Acid Plant Utilization)	(90% Acid Plant Utilization)
Average volumetric flow rate (dNm^3/h)	259 163	101 150	21 512	8 605
Diameter (m)	3.05	1.61	3.962	3.962
Height (m)	137	80	145	145
Temperature (°C)	58.4	57	76.5	76.5
SO_2 Emission Rate (t/a)	2 799.4	467.0	32 768	13 107
PM_{10} Emission Rate (t/a)	20.0	0.0	50.6	20.2
$PM_{2.5}$ Emission Rate (t/a)	20.0	0.0	50.6	20.2
Arsenic Emission Rate (t/a)	2.3	0.0	6.7	2.7

6.1.1.2 New RHF Baghouse Stack

Emissions, volumetric gas flow rates, and temperatures for the various operational cycles of the proposed RHF, were supplied by DPMT as determined by the furnace design.

A minimum stack height of 70 m was previously determined from dispersion simulations. In selecting suitable impact criteria, the guideline of the IFC was adopted. The IFC recommends, in their General Environmental, Health and Safety (EHS) Guidelines, that facilities should be designed to meet 25% of impact criteria to allow for the impact of other sources of emission.

Emissions and parameters for the new RHF baghouse stack are included in Table 9. These parameters are the time-weighted averages of the data contained in Table 8.

Table 8: RHF cycle design emission rates, volumetric flow rates, and temperatures as supplied by DPMT

Cycle	RHF charging	Matte pouring	Slag pouring	One-fan charging
Hours in 24-hour cycle	3.6 (15%)	2.5 (10%)	2.9 (12%)	0.0 (0%)
Dry standard volumetric flow rate (dNm^3/h)	231 450	168 450	168 450	115 950
Actual volumetric flow rate (m$_3$/h)	335 031	237 423	236 526	182 708
Off-gas temperature (°C)	54.0	46.0	44.0	83.0
SO_2 concentration (mg/dNm^3)	1 075	1 725	87.5	2 143

PM concentration (mg/dNm^3)	0.045	0.086	0.087	0.163
As concentration (mg/dNm^3)	0.022	0.043	0.043	0.082
SO_2 emission rate (g/s)	**69.1**	**80.7**	**4.1**	**69.0**
PM_{10} emission rate (g/s)	**0.003**	0.004	0.004	0.005
$PM_{2.5}$ emission rate (g/s)	**0.003**	0.004	0.004	0.005
As emission rate (g/s)	**0.001**	0.002	0.002	0.003

Table 9: RHF baghouse stack emissions and parameters

	Project scenario (370 000 t/a)
Plant processing capacity (t/d)	1 014
Stack height	70
Stack tip diameter	2.40
Dry standard volumetric flow (dNm^3/h)	193 785
Actual volumetric flow (m^3/h)	276 389
Exit velocity (m/s)	17.0
Release temperature (°C)	48.6
SO_2 concentration (mg/dNm^3)	941
PM concentration (mg/dNm^3)	0.0697
As (mg/dNm^3)	0.0349
SO_2 emission rate (g/s)	**50.7**
PM_{10} emission rate (g/s)	**0.004**
$PM_{2.5}$ emission rate (g/s)	**0.004`**
As emission rate (g/s)	**0.002**

6.1.1.3 Future Point Sources

Point sources emissions were scaled from the current processing rate to a processing rate of 370 000 t/a. Future point source emissions are shown in Table 10.

Table 10: Stack Parameters and Emissions – Future Operations

	Copper Stack	**Acid Plant Stack**	**Ausmelt Stack**		**RHF Baghouse Stack**
			(75% Acid Plant Utilization)	(90% Acid Plant Utilization)	
Average volumetric flow rate (dNm^3/h)	259 163	101 150	21 512	8 605	193 785
Diameter (m)	3.05	1.61	3.962	3.962	2.4
Height (m)	137	80	145	145	70
Temperature (°C)	58.4	57	76.5	76.5	48.6
SO_2 Emission Rate (t/a)	4316	720	50518	20207	1599
PM_{10} Emission Rate (t/a)	30.8	0	78.0	31.2	0.13
$PM_{2.5}$ Emission Rate (t/a)	30.8	0	78.0	31.2	0.13
Arsenic Emission Rate (t/a)	3.6	0	10.3	4.1	0.06

6.1.2 Fugitive Emissions

Since the fugitive emissions inventory for DPMT was compiled in 2011 considerable changes to the process have occurred. Apart from the processing rates being significantly higher than in 2011, the arsenic plant has been decommissioned and a new hazardous waste site commissioned to the south of the operations. The slag crushing plant along the main access road near the slag mill was also commissioned and the acid plant commissioned in 2015. Due to the above changes to the process at DPMT a new fugitive emissions inventory was compiled taking into account the following:

- Fugitive emissions from buildings making use of building dimensions and occupational health sampling data;
- Fugitive dust emissions from material handling and crushing operations making use of internationally published emission factors and using material composition and moisture data sampled in February 2018.
- Vehicle entrainment emissions from unpaved road surfaces making use of internationally published emission factors and road surface material data sampled in February 2018
- Windblown dust emissions making use of the ADDAS (Airborne Dust Dispersion from Area Sources) model and material characteristics sampled in February 2018.
- Increased concentrate processing rates from 240 000 t/a to 370 000 t/a and the associated increase in fugitive dust emissions.

The emission estimation techniques used to estimate fugitive emissions are described in Table 11. During a site visit in February 2018 ten samples (Figure 25) were collected of different stockpile and road surface material. A summary of the laboratory analysis of the ten samples is given in Table 12, the full results are attached in Appendix A.

Table 11: Fugitive emission estimation techniques

Source Group	Emission Estimation Technique	Input parameters/Notes
Building fugitives	Fugitive emissions from buildings were estimated using occupational health sampling data provided by DPMT. Personal sampling data for 2016 and 2017 at various locations were provided for SO_2, PM, As, Cu and Pb. Building dimensions were calculated from provided drawings for the buildings, satellite imagery and photographs taken during the site visit. Fugitive emissions were estimated based on average pollutant concentrations in the buildings and twelve volume changes per hour was assumed for the buildings.	Ausmelt Building • Average SO_2 = 1.53 mg/m³ • Average PM = 1.36 mg/m³ • Average As = 0.0536 mg/m³ • Volume = ~ 180 000 m³ Converter Building • Average SO_2 = 1.96 mg/m³ • Average PM = 0.49 mg/m³ • Average As = 0.018 mg/m³ • Volume = ~ 60 000 m³ Utilities • Average SO_2 = 2.54 mg/m³ • Average PM = 2.52 mg/m³ • Average As = 0.46 mg/m³ • Volume = ~ 20 000 m³ Slag Mill • Average PM = 0.9 mg/m³ • Average As = 0.01 mg/m³ • Volume = ~ 90 000 m³ Receiving Bay • Average PM = 1.62 mg/m³ • Average As = 0.04 mg/m³

<table>
<tr><th>Source Group</th><th>Emission Estimation Technique</th><th>Input parameters/Notes</th></tr>
<tr><td></td><td></td><td>- Volume = ~ 290 000 m^3</td></tr>
<tr><td>Crushing and Screening</td><td>NPI single valued emission factors for low moisture ore (ADE, 2011)
- PM_{10} – 0.02 kg/tonne (primary crushing)
- PM_{10} – 0.04 kg/tonne (secondary crushing)
- PM_{10} – 0.06 kg/tonne (screening)</td><td>Slag crushing
- 18.9 t/h
- 0.4% As from collected slag dump sample
Raw material and reverts crushing
- 4.71 t/h
- 5.5% As average assumed.</td></tr>
<tr><td>Materials Handling</td><td>US EPA emission factor equation (US EPA, 2006)
$$EF = k \cdot 0.0016 \cdot \left(\frac{U}{2.3}\right)^{1.3} \cdot \left(\frac{M}{2}\right)^{-1.4}$$
Where
- EF is the emission factor in kg/tonne material handled
- k is the particle size multiplier (k_{PM10} – 0.35)
- U is the average wind speed in m/s
- M is the material moisture content in %</td><td>Average wind speed of 2.3 m/s
800 t/d raw material
113 t/d reverts
230 t/d product
0.9% moisture in raw material</td></tr>
<tr><td>Vehicle Entrained Dust from Paved Roads</td><td>US EPA emission factor equation (US EPA, 2011)
$$EF = k \cdot (sL)^{0.91} \cdot (W)^{1.02}$$
Where
- EF is the emission factor in g/vehicle kilometre travelled (VKT)
- k is the particle size multiplier (k_{PM10} – 0.62)
- sL is the road surface material silt loading in g/m^2
- W is the average weight vehicles in tonnes</td><td></td></tr>
<tr><td>Vehicle Entrained Dust from Unpaved Roads</td><td>US EPA emission factor equation (US EPA (2), 2006)
$$EF = k \cdot \left(\frac{S}{12}\right)^{a} \cdot \left(\frac{W}{3}\right)^{b} \cdot 281.9$$
Where
- EF is the emission factor in g/vehicle kilometre travelled (VKT)
- k is the particle size multiplier (k_{PM10} – 1.5)
- a and b are empirical constants (a_{PM10} – 0.9, b_{PM10} – 0.45)
- S is the road surface material silt loading in g/m^2
- W is the average weight vehicles in tonnes</td><td>800 t/d raw material
230 t/d products
Assumed average truck capacity of 30 tonnes
15.35% silt on delivery road (from collected sample)
12.42% silt on hazardous waste site road (from collected sample)
1.2% As content on delivery road (previously deposited – re-entrained)
0.1% As content on waste site road
170 trips per month on road to waste site with 11.9 tonne average capacity (from manifest provided by DPMT)</td></tr>
<tr><td>Windblown Dust</td><td>Windblown dust emissions calculated using the ADDAS model with inputs as described in Table 12 and Appendix A. Arsenic fraction of PM_{10} calculated using the concentration as per Table 12.

The number of windblown dust sources are not expected to decrease or increase notably given changes to the process or proposed upgrades. Windblown dust emissions were therefore not scaled to account for processing rate increases.</td><td><table>
<tr><th>Description</th><th>Area (m^2)</th></tr>
<tr><td>Slag Mill tailings on New Tailings Dam</td><td>42 341</td></tr>
<tr><td>Mine tailings on New Tailings Dam</td><td>100 732</td></tr>
<tr><td>Reverb Slag tailings on Old Tailings Dam</td><td>239 974</td></tr>
<tr><td>Blast Furnace Slag</td><td>52 169</td></tr>
<tr><td>Arsenic Calcine Dumps</td><td>14 414</td></tr>
<tr><td>Converter Slag</td><td>50 820</td></tr>
<tr><td>Old Slag Mill Tailings Dump</td><td>109 026</td></tr>
<tr><td>Mine tailings on Old Tailings Dam</td><td>273 258</td></tr>
</table></td></tr>
</table>

Table 12: Summary of laboratory analysis of samples.

Determinant	Total Mass	Mass <1mm	Mass >1mm	Bulk Density	Total solids	Moisture	Arsenic Content	Silt Content
Sample ID	g	g	g	ρ_t $^m/_v$	%	%	mg/kg	%
TS1	5.0438	1.6269	3.3933	1.6628	100.00	0.00	1517.13	
TS2	5.0562	1.5671	3.4609	0.8758	84.17	15.83	3165.65	96.35
TS3	5.0483	3.2713	1.7608	1.8511	99.92	0.08	22691.04	31.42
TS4	5.0341	4.1402	0.8764	1.5009	99.99	0.01	990.13	0.25
TS5	5.0554	2.3506	2.6864	1.8202	99.95	0.05	12679.03	15.35
TS6	5.0108	4.3133	0.6563	0.8244	93.48	6.52	163.40	25.52
TS7	5.0381	5.0253	0.0045	1.7046	99.99	0.01	4737.36	8.92
TS8	5.0696	1.6707	3.3486	1.0886	88.01	11.99	3060.99	92.60
TS9	5.0178	3.4017	1.5809	0.8063	94.35	5.65	1446.61	84.73
TS10	5.0556	2.0006	3.0414	1.4974	99.97	0.03	1003.08	12.42

Figure 25: Stockpile and road surface sampling locations

6.1.3 Emissions Summary

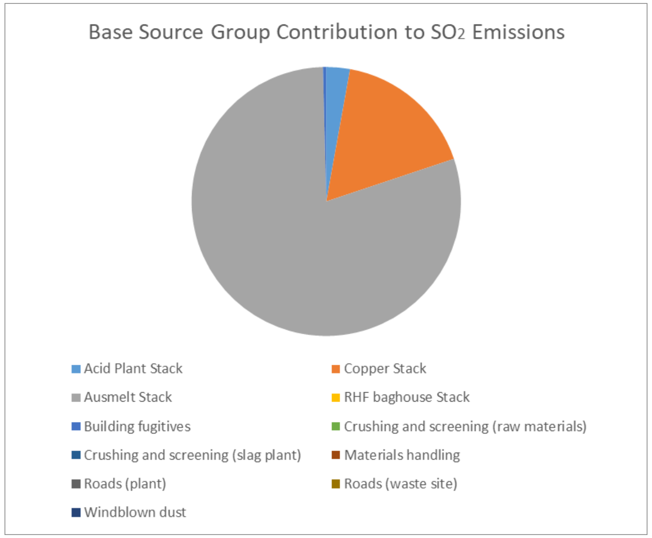
Annualised emission summaries for the DPMT Tsumeb smelter complex for the base and project scenarios are supplied in Table 13 and Table 14 respectively.

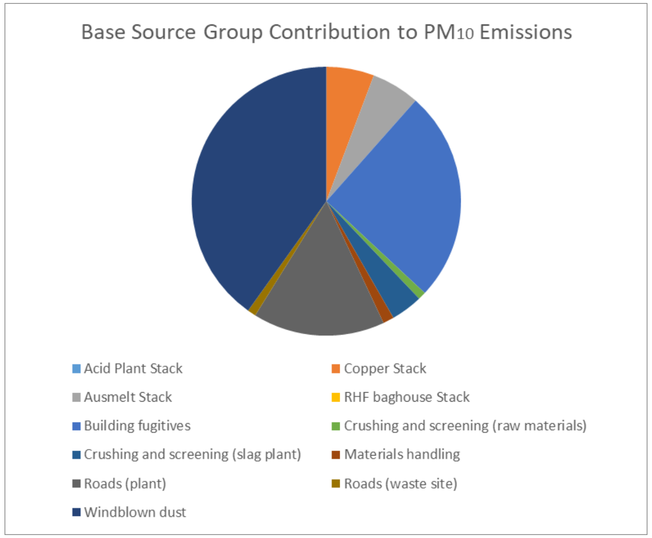
Table 13: Base scenario (240 000 t/a) annualised emissions summary

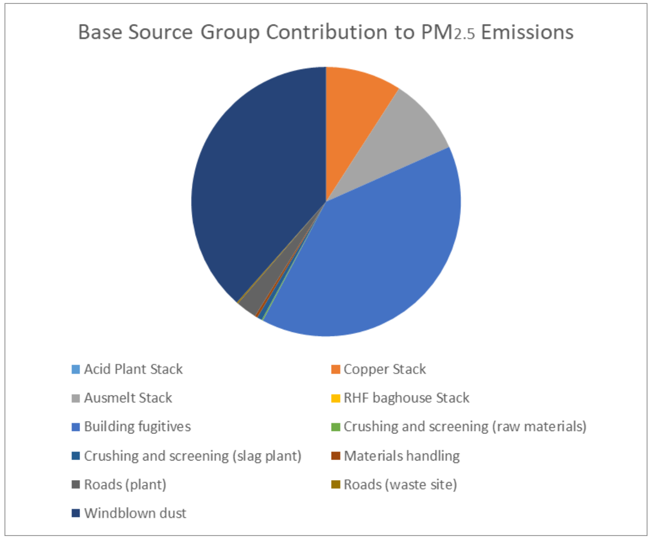
Source/Source Group	SO_2 (t/a)	PM_{10} (t/a)	$PM_{2.5}$ (t/a)	Arsenic (t/a)	H_2SO_4 (t/a)
Acid Plant Stack	467				115.2
Copper Stack	2 800	20	20	2.3	
Ausmelt Stack	13 107	20.2	20.2	2.7	
RHF baghouse Stack					
Building fugitives	65	88.5	86.5	3.7	
Crushing and screening (raw materials)		3.3	0.3	0.2	
Crushing and screening (slag plant)		13.2	1.3	0.1	
Materials handling		4.6	0.7	0.3	
Roads (plant)		55.2	5.5	0.1	
Roads (waste site)		3.5	0.4	0.0	
Windblown dust		139.8	84.4	0.7	
Total	**16438**	**348.4**	**219.3**	**9.9**	**115.2**

Table 14: Project scenario (370 000 t/a) annualised emissions summary

Source/Source Group	SO_2 (t/a)	PM_{10} (t/a)	$PM_{2.5}$ (t/a)	Arsenic (t/a)	H_2SO_4 (t/a)
Acid Plant Stack	720				177.6
Copper Stack	4 316.00	30.8	30.8	3.6	
Ausmelt Stack	20 207	31.2	31.2	4.1	
RHF baghouse Stack	1 599	0.13	0.13	0.06	
Building fugitives	99.81	136.46	133.35	5.63	
Crushing and screening (raw materials)	0.0	5.1	0.5	0.3	
Crushing and screening (slag plant)		20.4	2.0	0.2	
Materials handling		7.1	1.1	0.4	
Roads (plant)		85.1	8.5	0.1	
Roads (waste site)		5.5	0.5	0.0	
Windblown dust		139.8	84.4	0.7	
Total	**26 842.0**	**430.8**	**292.5**	**15.09**	**177.6**







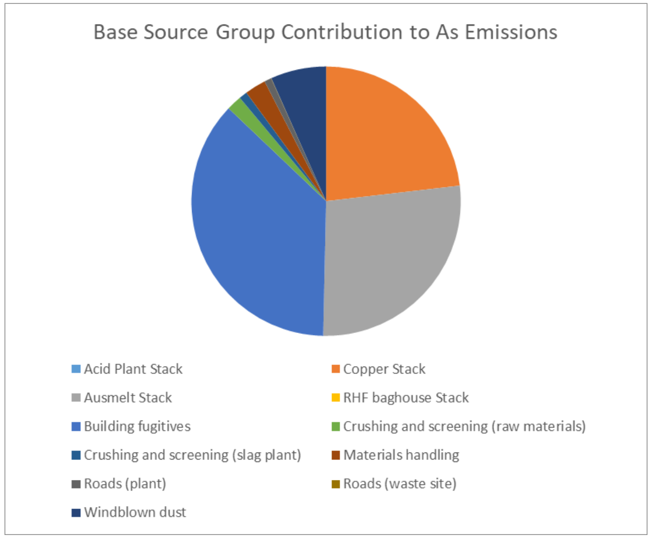


Figure 26: Source group contributions to emission – Base scenario (240 000 t/a)

6.2 Atmospheric Dispersion Simulations

The assessment of the impact of the Tsumeb smelter complex on the atmospheric 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 (as discussed in Section 4);
- The location of likely AQSRs (Section 5.1);
- The potential of the atmosphere to disperse and dilute pollutants emitted by the project (Section 5.2);
- Existing ambient pollutant concentrations (Section 5.3); and
- Atmospheric emissions (Section 6.1)

Dispersion models simulate ambient pollutant concentrations and fallout rates 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.

6.2.1 Dispersion Model Selection and Inputs

For the current study, it was decided to use 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 several computer models which include ADMS. This model simulates a wide range of buoyant and passive releases to the atmosphere either individually or in combination and has been the subject of many inter-model comparisons.

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 United Kingdom (UK) and Wales, the Scottish Environmental Protection Agency (SEPA) and regulatory authorities including the UK Health and Safety Executive (HSE).

Concentration and fallout 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 is normally performed with more complicated dispersion models specifically fine-tuned and validated for the location. For the purposes of this report, the shortest time modelled is one hour.

There will always be some error in any geophysical model, but it is desirable to structure the model in such a way to minimise the total error. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model description of atmospheric physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere. Nevertheless, dispersion modelling is generally accepted as a valid tool to quantify and analyse the atmospheric impact of existing installations and for determination of the impact of future installations. Input data types required for the ADMS model include source data, meteorological data, terrain data and information on the nature of the receptor grid. Use was made of meteorological data recorded at the Stadium station from January 2013 to December 2017. The dispersion of pollutants was simulated over a 15 km by 15 km area at a resolution of 150 m and height of 1.5 m above ground level. Topographical data was included in simulations.

6.2.2 Simulation Results

Dispersion simulations was undertaken to determine annual average, 24 hour and hourly average ground level concentrations and fallout rates for each of the pollutants considered in the study. Averaging periods were selected to facilitate the comparison of simulated pollutant concentrations to relevant ambient air quality and inhalation health criteria as well as dustfall regulations.

Ground level concentration (GLC) isopleths plots presented in this section depict interpolated values from the concentrations predicted by ADMS for each of the receptor grid points specified. Short term air quality limits (i.e. 1-hour and 24-hour) allow the exceedance of certain limit values for 1% of the time per calendar year. For compliance assessment purposes, therefore, the 99th percentile of 1-hour and 24-hour average pollutant concentrations is presented. It should 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 public has access i.e. off-site. Results are discussed in more detail in subsequent sections.

6.2.2.1 Simulated SO_2 Concentrations

Simulated SO_2 concentrations at ambient air quality monitoring station locations as well as the additional sensitive receptor locations (as described in Section 5.1) are presented in Table 15. The dispersion modelling results for a 75% acid plant utilization and a 90% acid plant utilization are shown. A comparison between simulated annual average concentrations (with a 75% acid plant utilization) and concentrations measured in 2017 is shown in Figure 27.

Currently, SO_2 concentrations associated with the base scenario, exceed the South African 1-year average assessment criterion of 50 µg/m^3 at the Sewerage Works if the acid plant is 75% utilized (2017). The 24-hour average criterion (4 days of exceedance of 125 µg/m^3) is exceeded at the Sewerage Works, Plant Hill and the north-eastern part of Tsumeb (Figure 32) including at the newly included sensitive receptor locations of Ondundu and the Private School and Hospital. The 99th percentile of 1-hour average concentrations (equivalent to the 88th highest hour) exceeds the adopted criterion of 350 µg/m^3 (or 88 hours of exceedance of 350 µg/m^3) at the Sewerage Works, Plant Hill and Info Centre (Figure 36) as well as at all three the newly included sensitive receptor locations. If the acid plant was 90% utilized (i.e. at least 90% on-line time while the Ausmelt furnace is active) simulated concentrations comply with the annual and daily criteria, but 99th percentile hourly SO_2 concentrations would still be exceeded at the three closest locations (Sewerage Works, Plant Hill and Ondundu).

With an acid plant utilization of 75%, simulated annual average SO_2 concentrations due to the expanded operations exceed the South African 1-year average assessment criterion of 50 µg/m^3 only at the Sewerage Works, but daily and hourly 99th percentile concentrations exceed the assessment criteria at almost all sensitive receptor locations. With a 90% (or higher) utilization of the acid plant after the expansion, impacts would be similar or slightly lower on average than current impacts at the sensitive receptor locations.

It is therefore recommended that the acid plant utilization be at least 90% after the expansion to ensure compliance with the identified assessment criteria.

Table 15: Simulated SO_2 concentrations at ambient air quality monitoring sites and newly included sensitive receptor locations

Receptor name	**(75% Acid Plant Utilization)**			**(90% Acid Plant Utilization)**		
	Annual Average	Hourly	Daily	Annual Average	Hourly	Daily
	Base Scenario (240 000 t/a)					
Plant Hill	22	900	149	10	409	67
Info Centre	10	396	60	4	179	27
Stadium	11	301	74	5	136	34
Sewage Works	76	890	214	35	403	97
Namfo	2	56	50	1	25	23
Ondundu	19	903	169	8	410	77
Emdombo	22	546	118	10	248	54
Private School and Hospital	14	621	138	7	282	62
	Project Scenario (370 000 t/a)					
Plant Hill	34	1403	219	16	666	109
Info Centre	14	558	120	7	291	45
Stadium	16	434	95	8	221	55
Sewage Works	126	1652	435	57	652	160
Namfo	8	220	151	2	47	40
Ondundu	29	1262	341	14	675	125
Emdombo	29	741	167	16	400	87
Private School and Hospital	21	936	192	11	461	102

Note: Exceedances of the assessment criteria are shown with blue shading

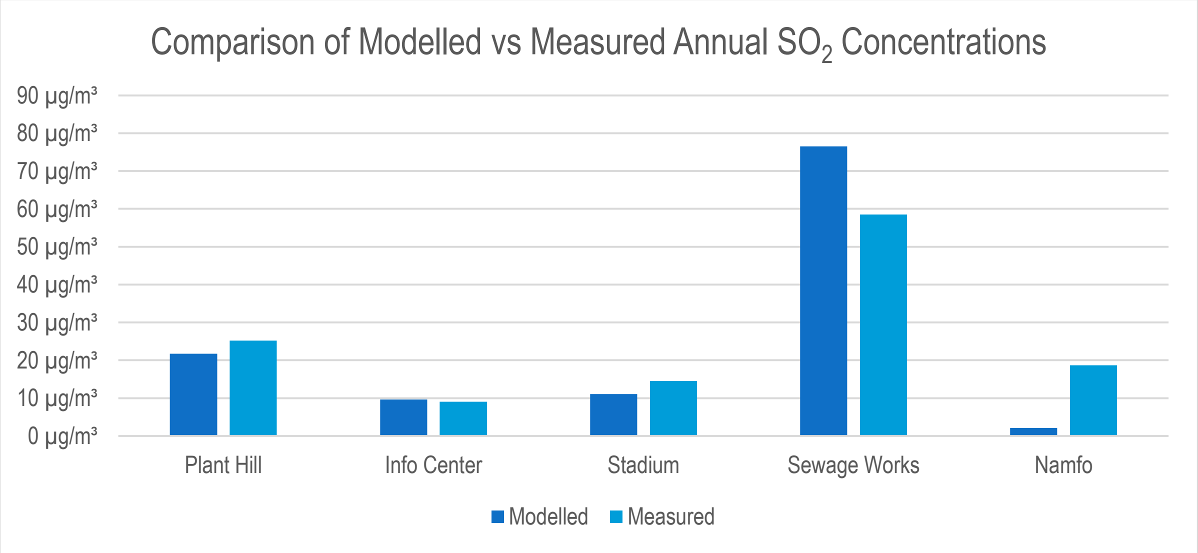


Figure 27: Comparison of Modelled and Measured Concentrations - 2017

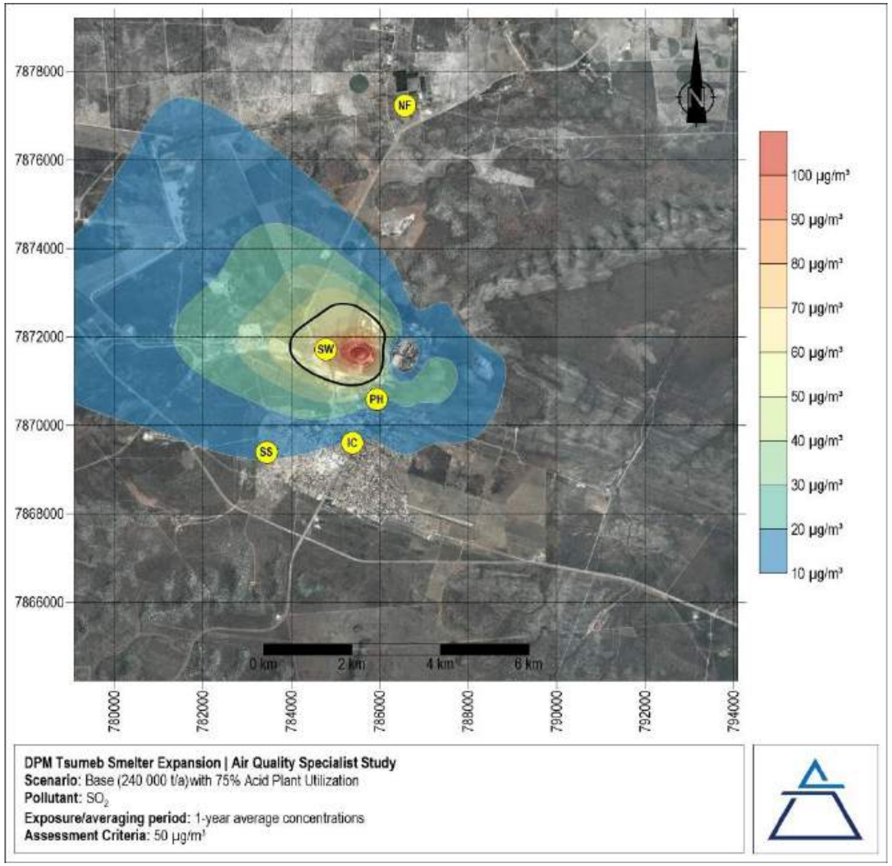


Figure 28: Base scenario, simulated 1-year average SO_2 concentrations (75% acid plant utilization) (The assessment criteria, 50 µg/m³, is indicated with a black line)

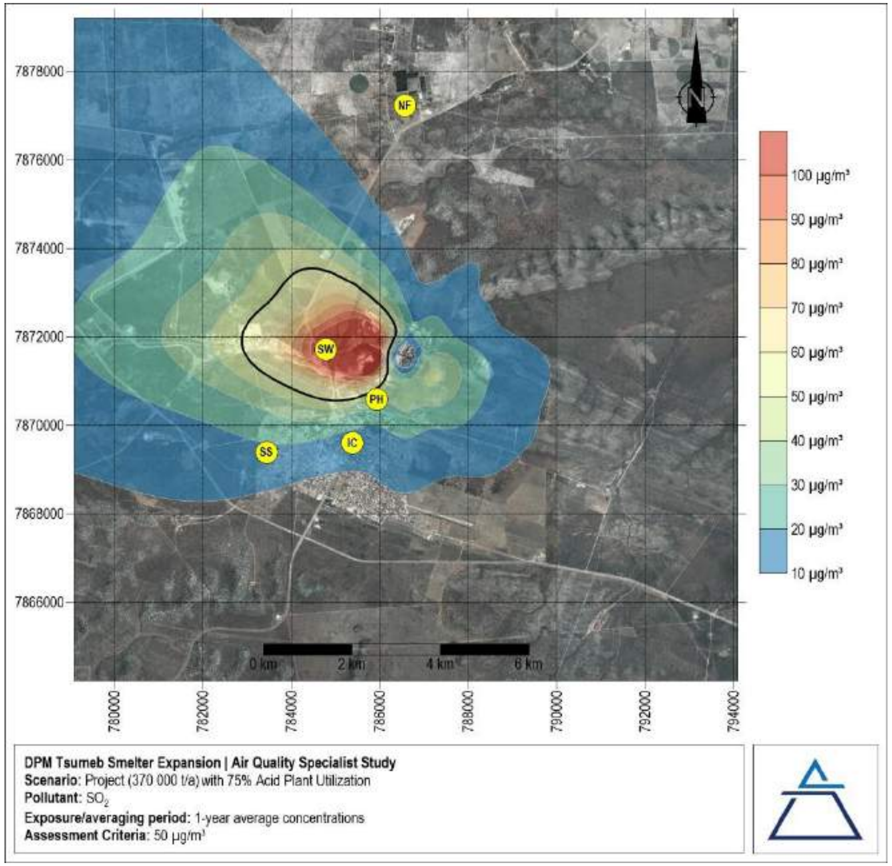


Figure 29: Project scenario, simulated 1-year average SO_2 concentrations (75% acid plant utilization) (The assessment criteria, 50 µg/m³, is indicated with a black line)

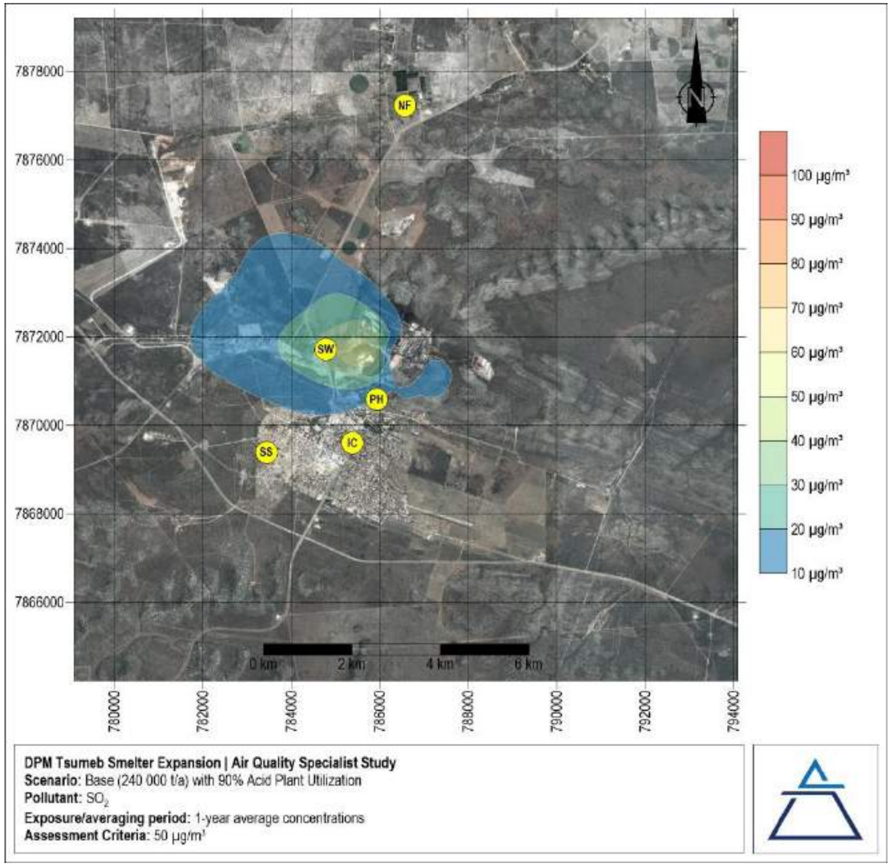


Figure 30: Base scenario, simulated 1-year average SO_2 concentrations (90% acid plant utilization) (The assessment criteria, 50 µg/m³, is indicated with a black line)

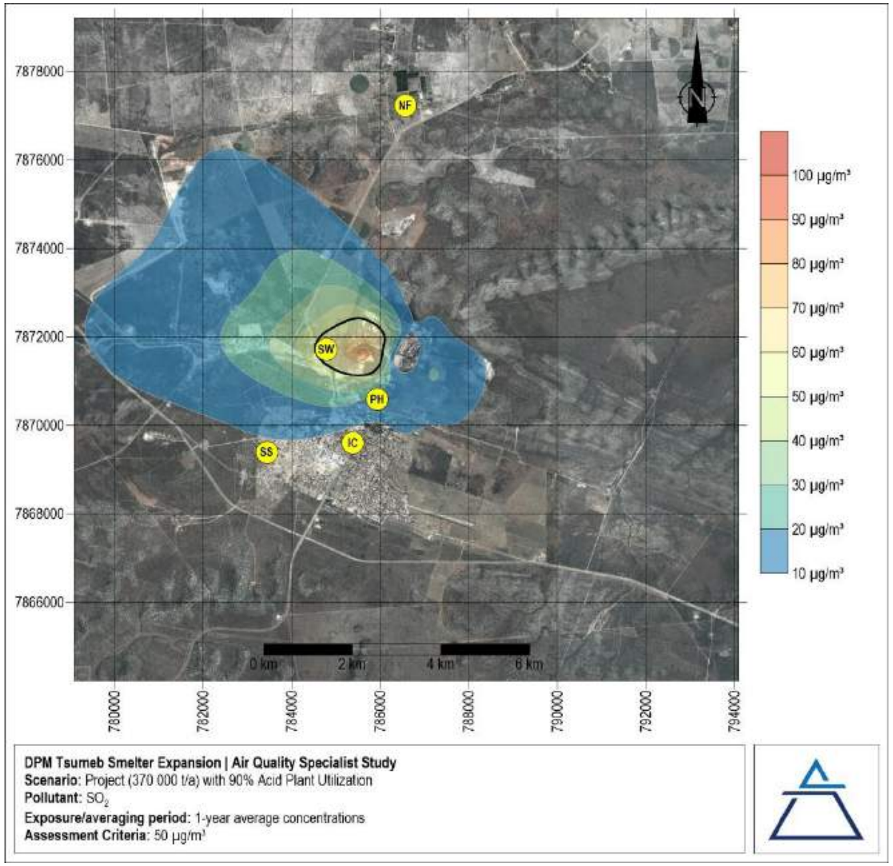


Figure 31: Project scenario, simulated 1-year average SO_2 concentrations (90% acid plant utilization (The assessment criteria, 50 µg/m³, is indicated with a black line)

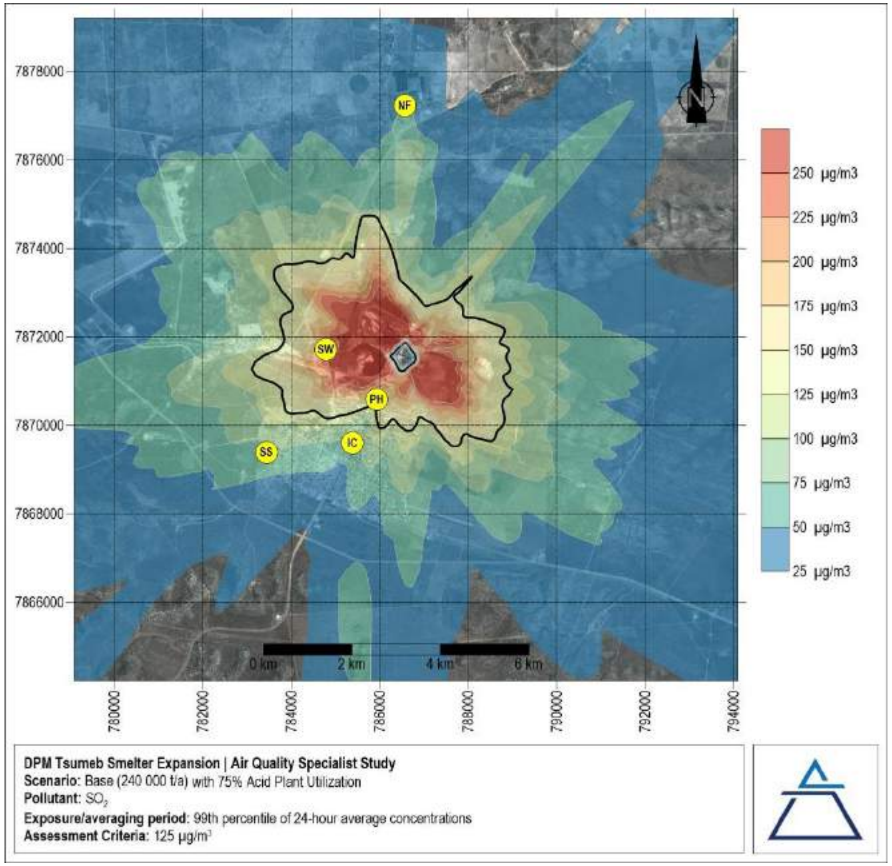


Figure 32: Base scenario, 99th percentile of simulated 24-hour average SO_2 concentrations (75% acid plant utilization) (The assessment criteria, 125 µg/m³, is indicated with a black line)

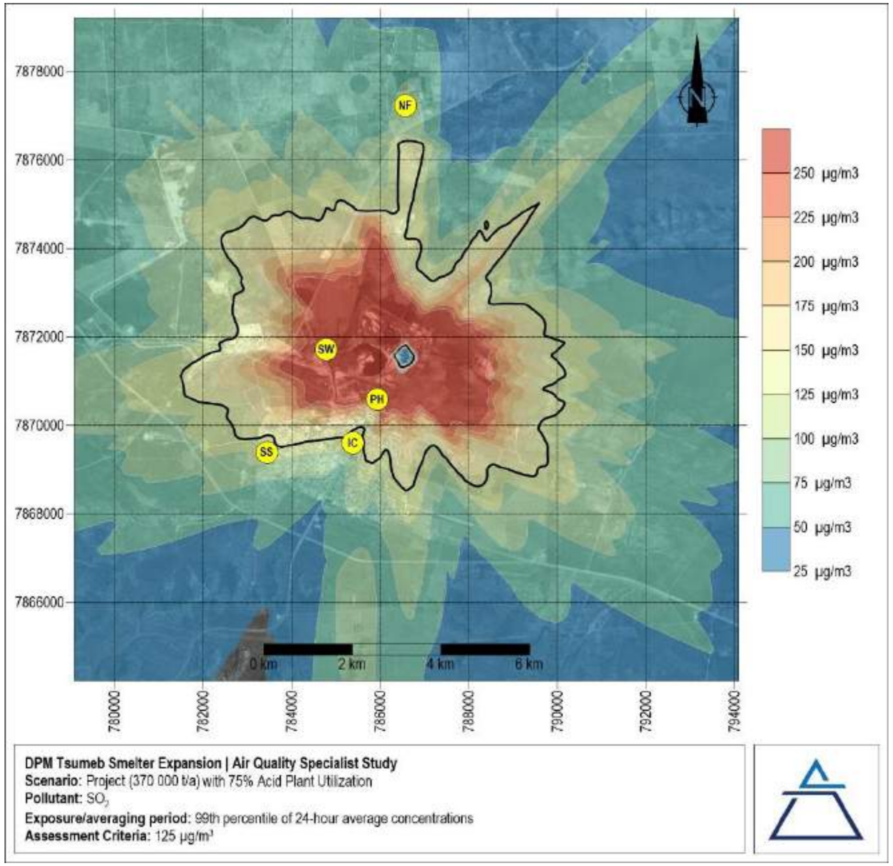


Figure 33: Project scenario, 99th percentile of simulated 24-hour average SO_2 concentrations (75% acid plant utilization) (The assessment criteria, 125 µg/m³, is indicated with a black line)

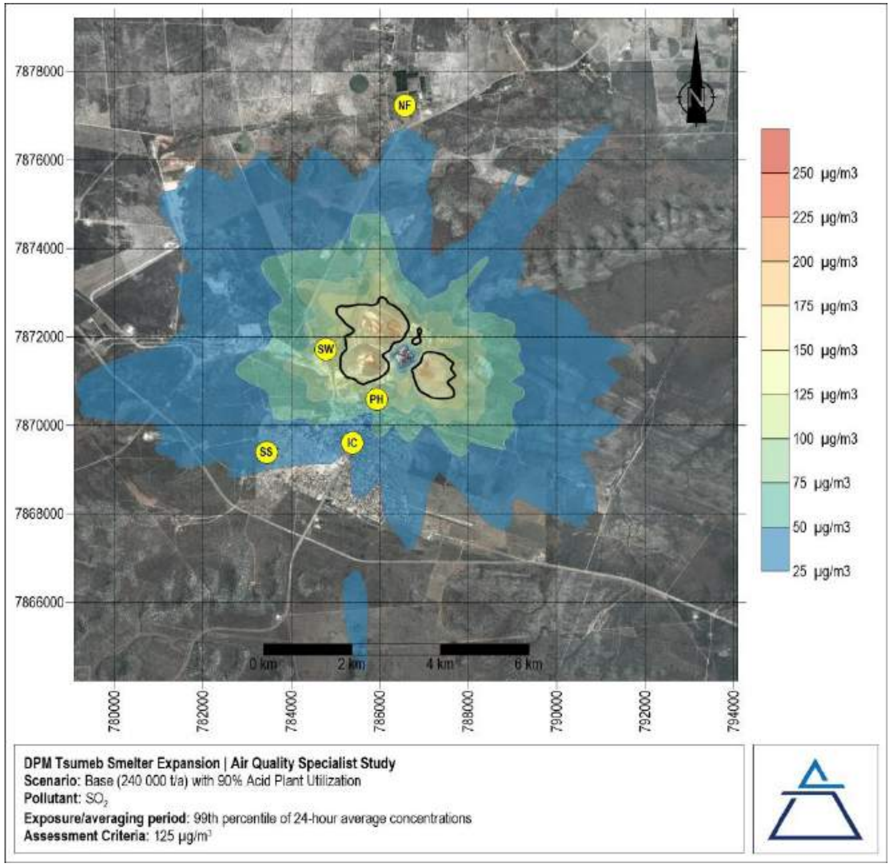


Figure 34: Base scenario, 99th percentile of simulated 24-hour average SO_2 concentrations (90% acid plant utilization) (The assessment criteria, 125 µg/m³, is indicated with a black line)

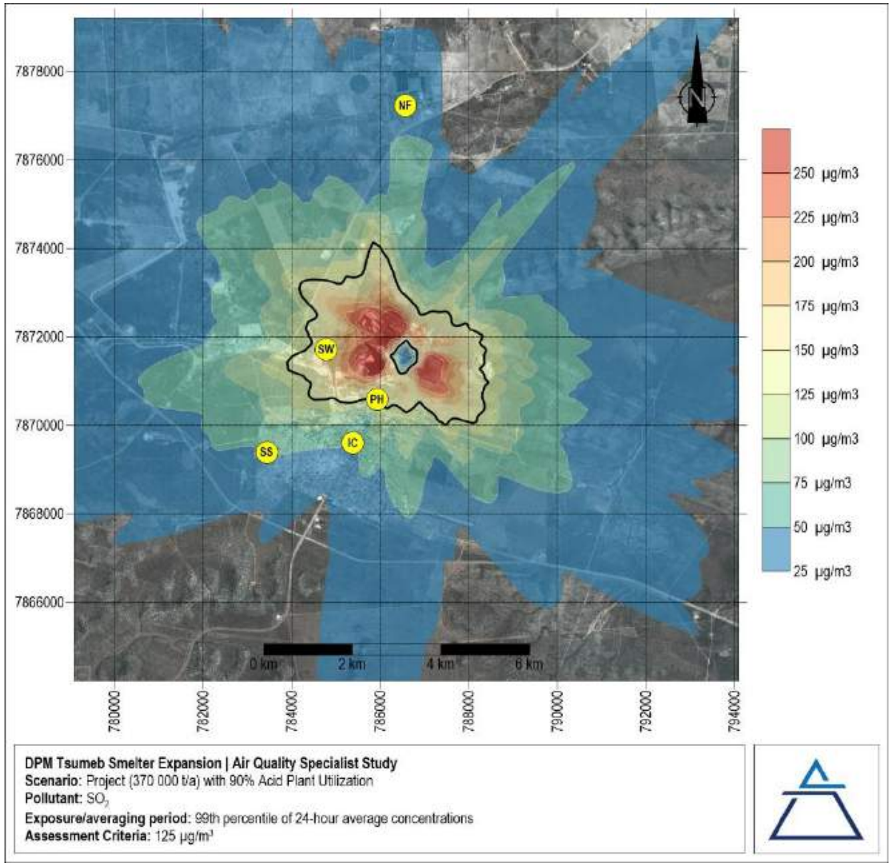


Figure 35: Project scenario, 99th percentile of simulated 24-hour average SO_2 concentrations (90% acid plant utilization) (The assessment criteria, 125 µg/m³, is indicated with a black line)

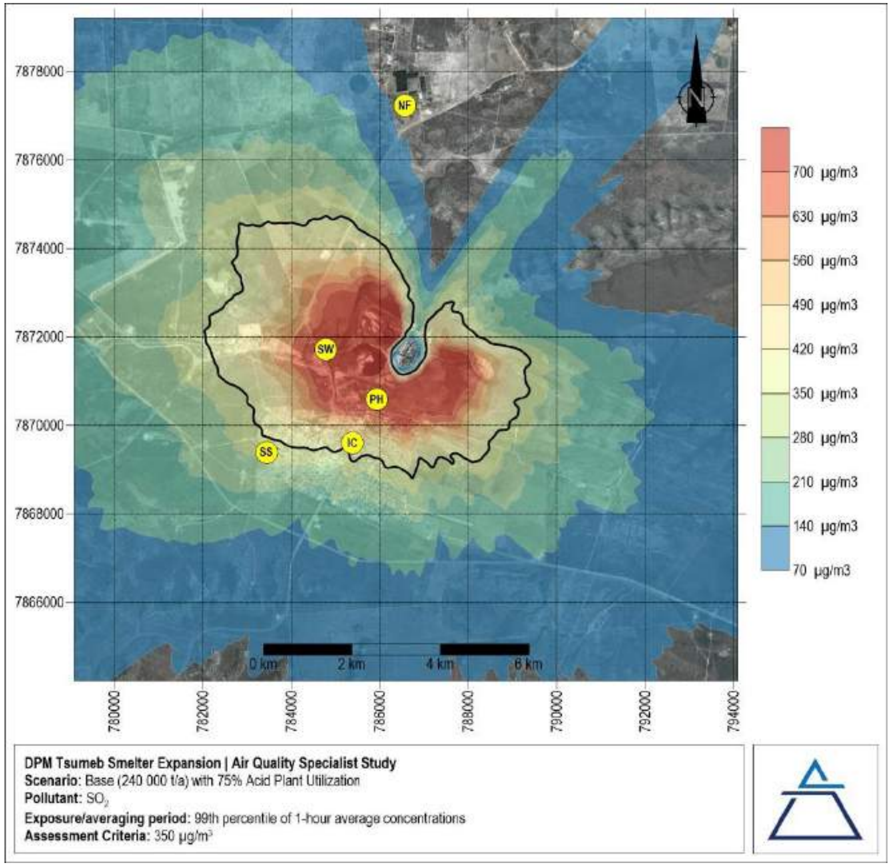


Figure 36: Base scenario, 99th percentile of simulated 1-hour SO_2 concentrations (75% acid plant utilization) (The assessment criteria, 350 µg/m³, is indicated with a black line)

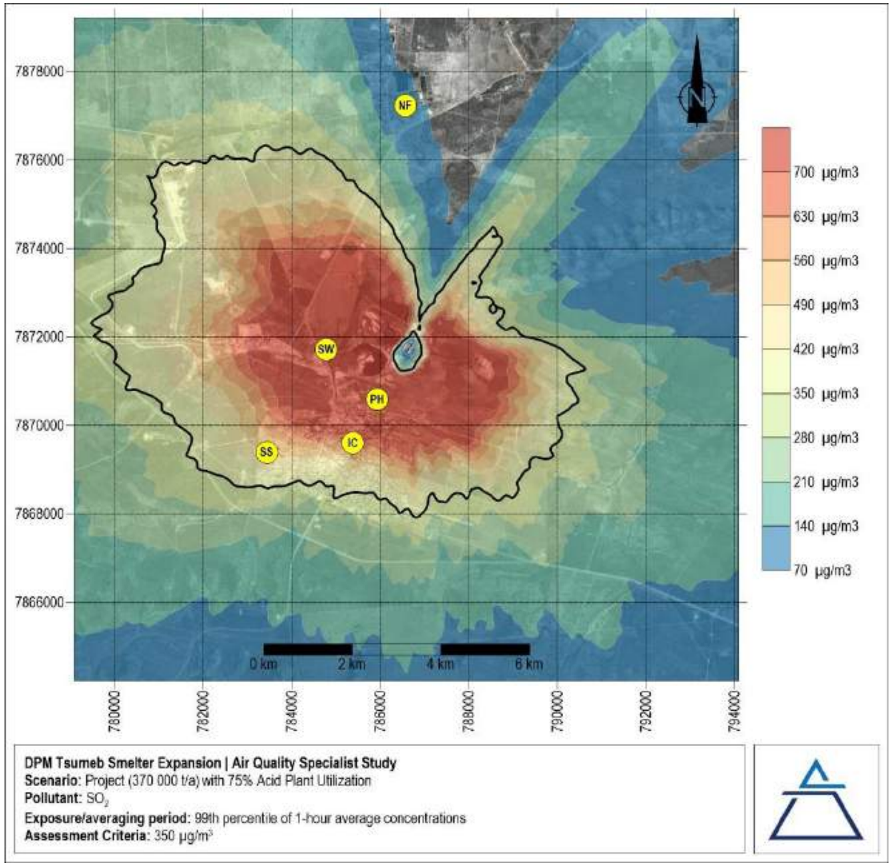


Figure 37: Project scenario, 99th percentile of simulated 1-hour SO_2 concentrations (75% acid plant utilization) (The assessment criteria, 350 µg/m³, is indicated with a black line)

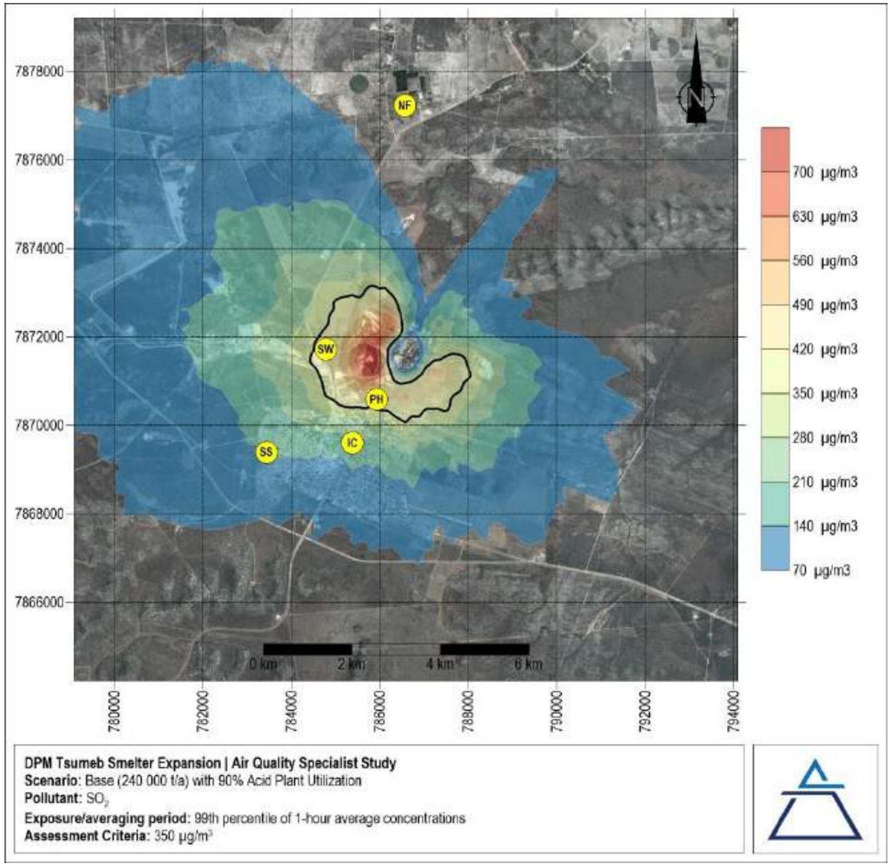


Figure 38: Base scenario, 99th percentile of simulated 1-hour SO_2 concentrations (90% acid plant utilization) (The assessment criteria, 350 µg/m³, is indicated with a black line)

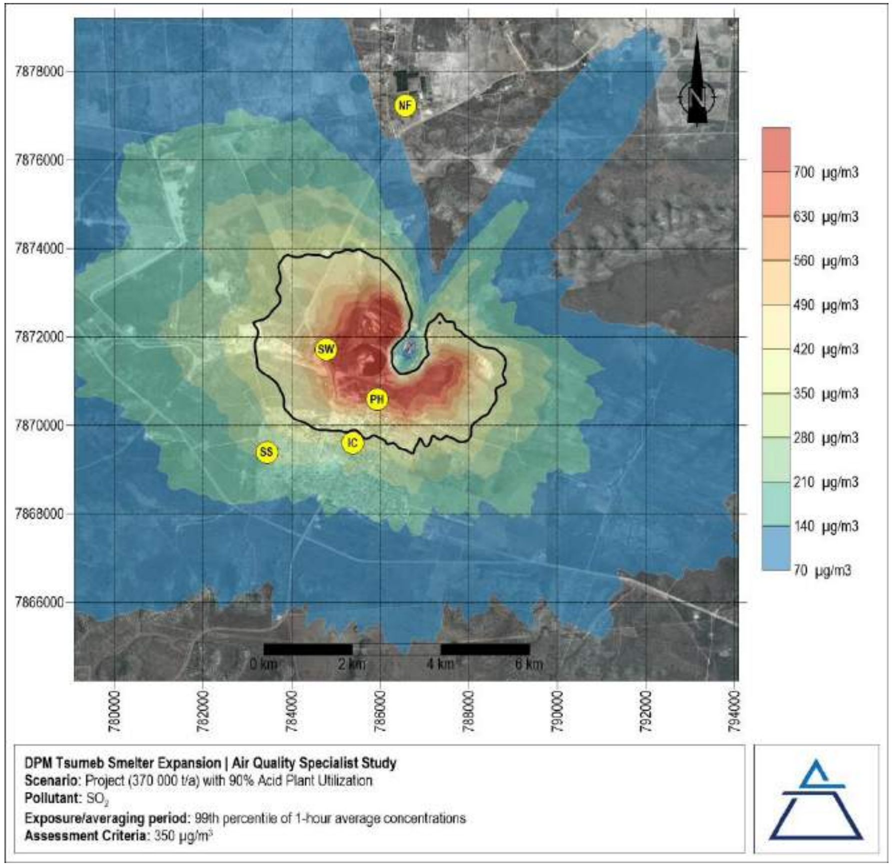


Figure 39: Project scenario, 99th percentile of simulated 1-hour SO_2 concentrations (90% acid plant utilization) (The assessment criteria, 350 µg/m³, is indicated with a black line)

6.2.2.2 Simulated PM_{10} Concentrations

Base scenario ambient PM_{10} levels are below air quality limits in both the long and short-term (Table 16). Simulated levels are well below what was measured at ambient air quality stations in 2016. It should however be noted that DPMT Tsumeb smelter is not the only source of PM_{10} emissions in the area and it is therefore expected that simulations would underestimate measured ambient PM_{10} levels.

The proposed upgrades and processing capacity increase are expected to increase both long and short-term ambient PM_{10} concentrations (due to DPMT sources only) by 100 to 300% and cumulative concentrations by 10 to 30%, depending on the location. Simulated levels associated with the project scenario do not exceed PM_{10} air quality limits off-site. Refer to Figure 40 to Figure 43 for visual representations of the impact areas for the two scenarios.

Table 16: Simulated PM_{10} concentrations at ambient air quality monitoring sites and newly included sensitive receptor locations

	1-year average PM_{10} conc. (µg/m^3)	**99th percentile of 24-hour average PM_{10} conc. (µg/m^3)**
Assessment criteria	*40*	*75*
Base scenario (240 000 t/a)		
Plant Hill	0.8	7.2
Info Centre	0.1	2.0
Stadium	0.1	0.9
Sewage Works	2.4	31.5
Namfo	0.3	2.3
Ondundu	0.3	2.2
Emdombo	0.3	1.7
Private School and Hospital	0.2	2.8
Project scenario (370 000 t/a)		
Plant Hill	6.7	27.3
Info Centre	0.4	3.8
Stadium	0.2	1.8
Sewage Works	4.2	32.6
Namfo	0.7	4.7
Ondundu	1.7	11.7
Emdombo	0.7	4.1
Private School and Hospital	0.9	11.5

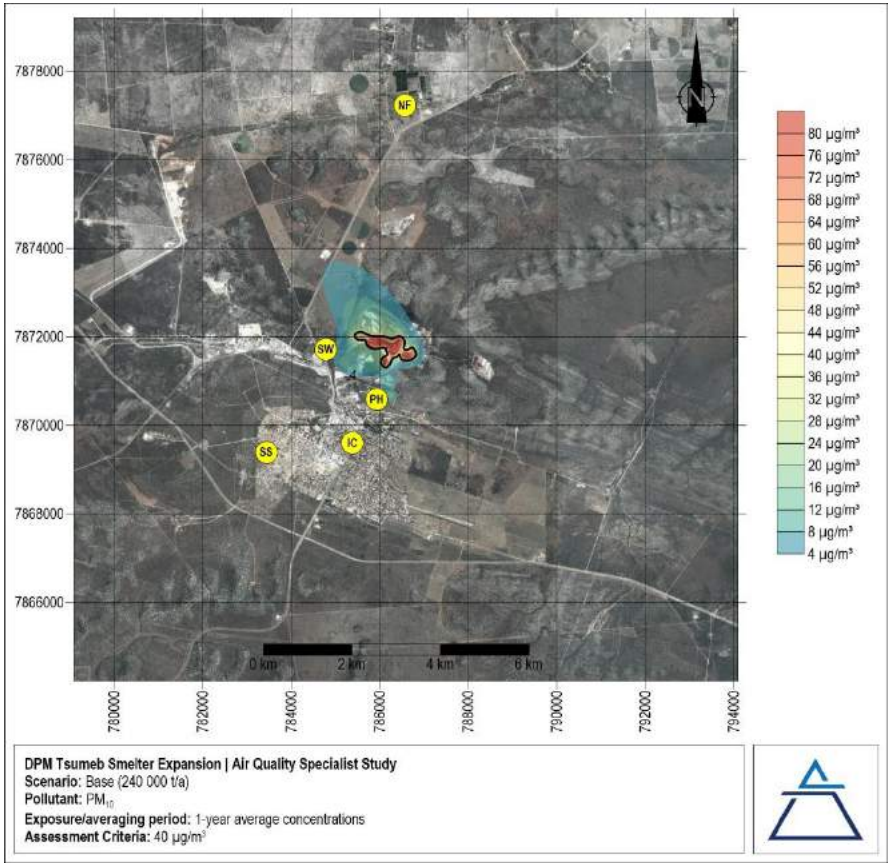


Figure 40: Base scenario, simulated 1-year average PM_{10} concentrations (The assessment criteria, 40 µg/m³, is indicated with a black line)

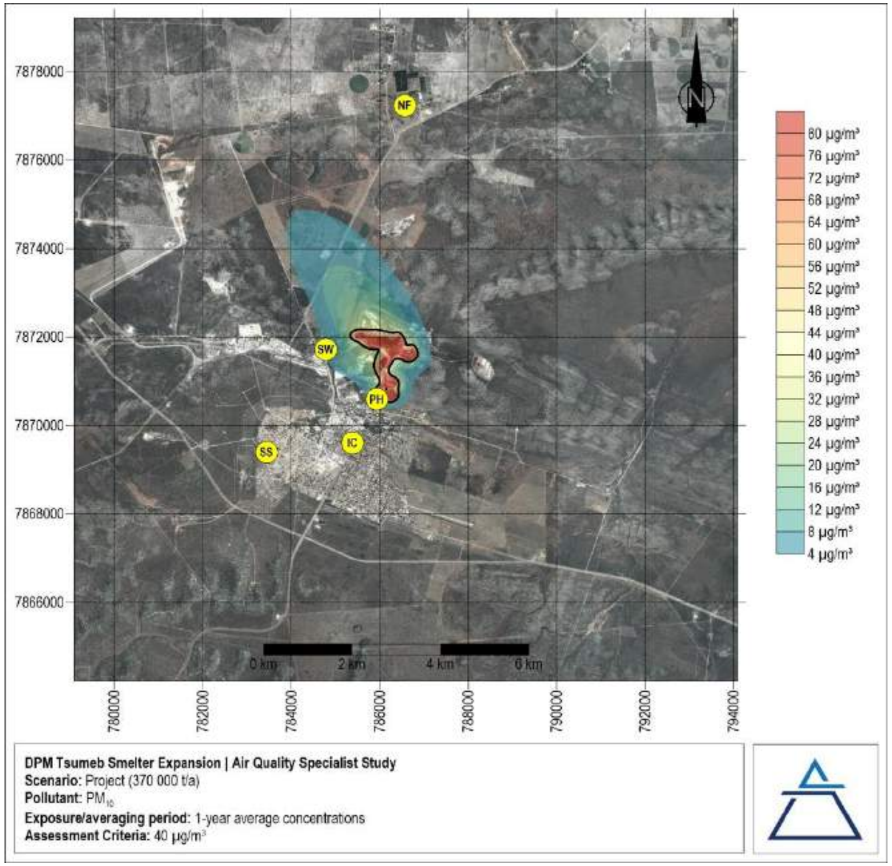
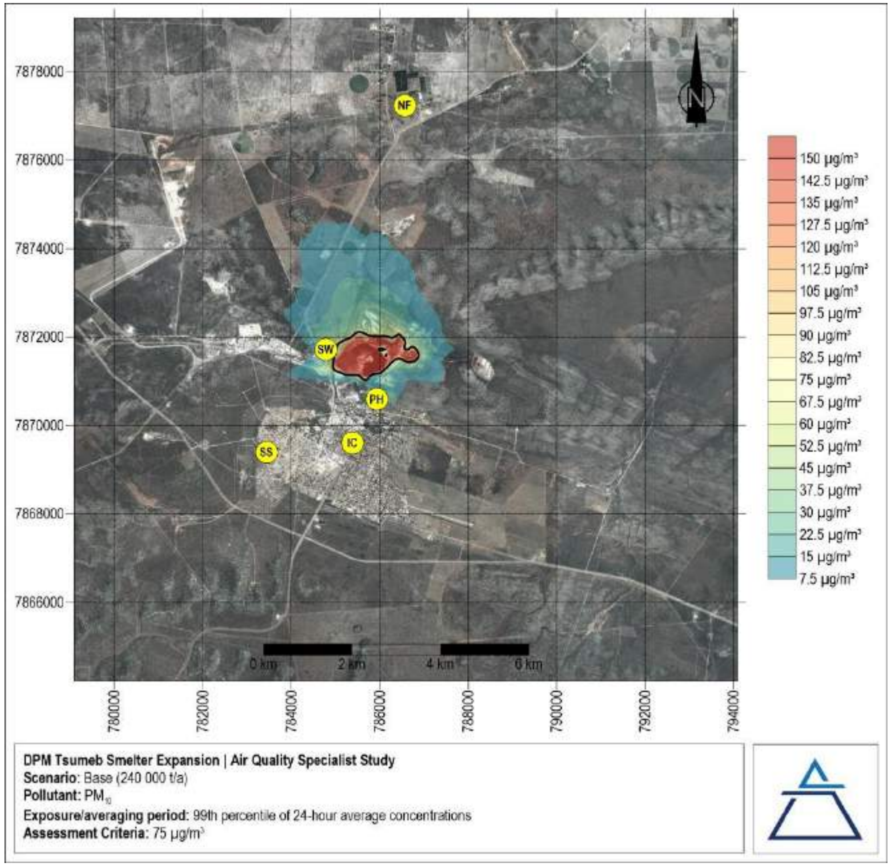
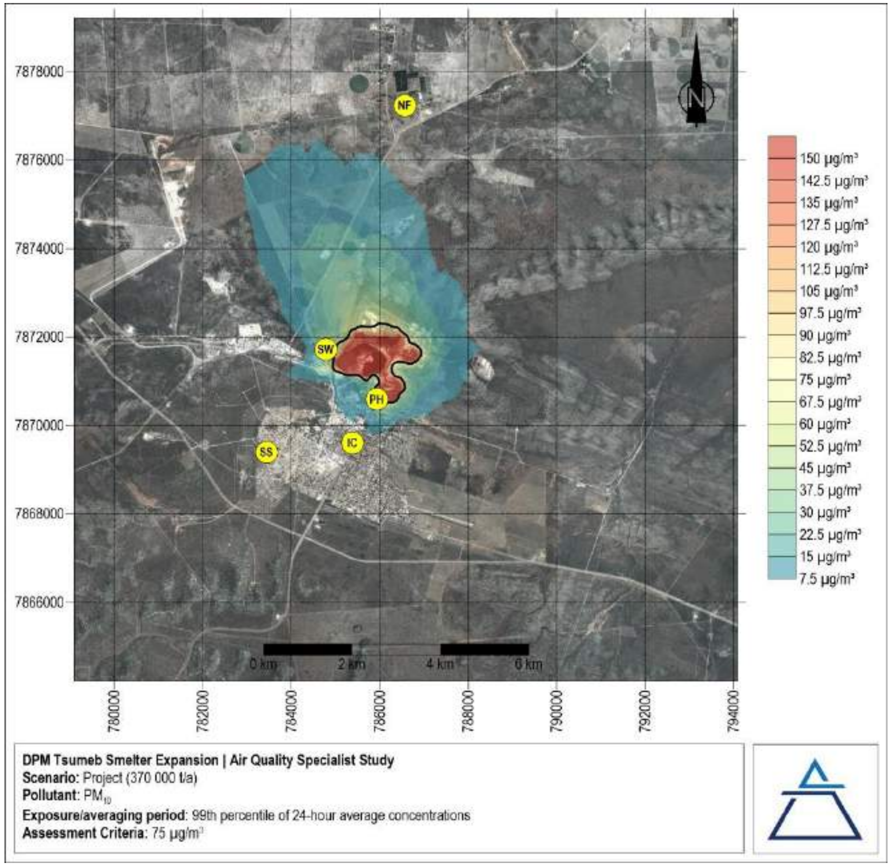


Figure 41: Project scenario, simulated 1-year average PM_{10} concentrations (The assessment criteria, 40 µg/m³, is indicated with a black line)



DPM Tsumeb Smelter Expansion | Air Quality Specialist Study
Scenario: Base (240 000 t/a)
Pollutant: PM_{10}
Exposure/averaging period: 99th percentile of 24-hour average concentrations
Assessment Criteria: 75 μg/m^3

Figure 42: Base scenario, 99th percentile of simulated 24-hour average PM_{10} concentrations (The assessment criteria, 75 μg/m^3, is indicated with a black line)



DPM Tsumeb Smelter Expansion | Air Quality Specialist Study
Scenario: Project (370 000 t/a)
Pollutant: PM_{10}
Exposure/averaging period: 99th percentile of 24-hour average concentrations
Assessment Criteria: 75 μg/m^3

Figure 43: Project scenario, 99th percentile of simulated 24-hour average PM_{10} concentrations (The assessment criteria, 75 μg/m^3, is indicated with a black line)

6.2.2.3 *Simulated $PM_{2.5}$ Concentrations*

Similar to simulated PM_{10} concentrations, simulated long and short-term $PM_{2.5}$ concentrations (Table 17) are well below the assessment criteria at all off-site locations.

The proposed upgrades and processing capacity increase are expected to increase both long and short-term ambient PM_{10} concentrations by 100 to 150%, depending on the location. Simulated levels associated with the project scenario do not exceed $PM_{2.5}$ air quality limits off-site.

Table 17: Simulated $PM_{2.5}$ concentrations at ambient air quality monitoring sites and newly included sensitive receptor locations

	1-year average $PM_{2.5}$ conc. (µg/m^3)	**99th percentile of 24-hour average $PM_{2.5}$ conc. (µg/m^3)**
Assessment criteria	*40*	*75*
Base scenario (240 000 t/a)		
Plant Hill	0.5	2.0
Info Centre	0.0	0.5
Stadium	0.1	0.3
Sewage Works	1.0	18.9
Namfo	0.1	0.4
Ondundu	0.1	0.9
Emdombo	0.1	0.4
Private School and Hospital	0.1	0.8
Project scenario (370 000 t/a)		
Plant Hill	0.7	3.1
Info Centre	0.1	0.7
Stadium	0.1	0.4
Sewage Works	1.2	19.0
Namfo	0.1	0.6
Ondundu	0.2	1.3
Emdombo	0.2	0.6
Private School and Hospital	0.1	1.3

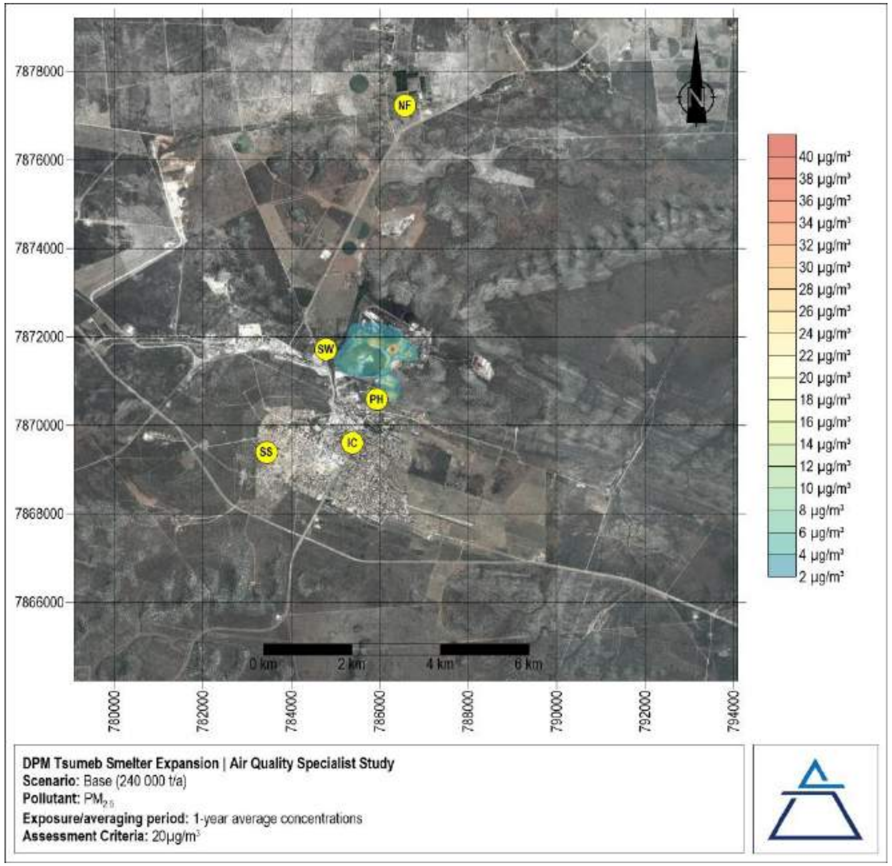


Figure 44: Base scenario, simulated 1-year average $PM_{2.5}$ concentrations

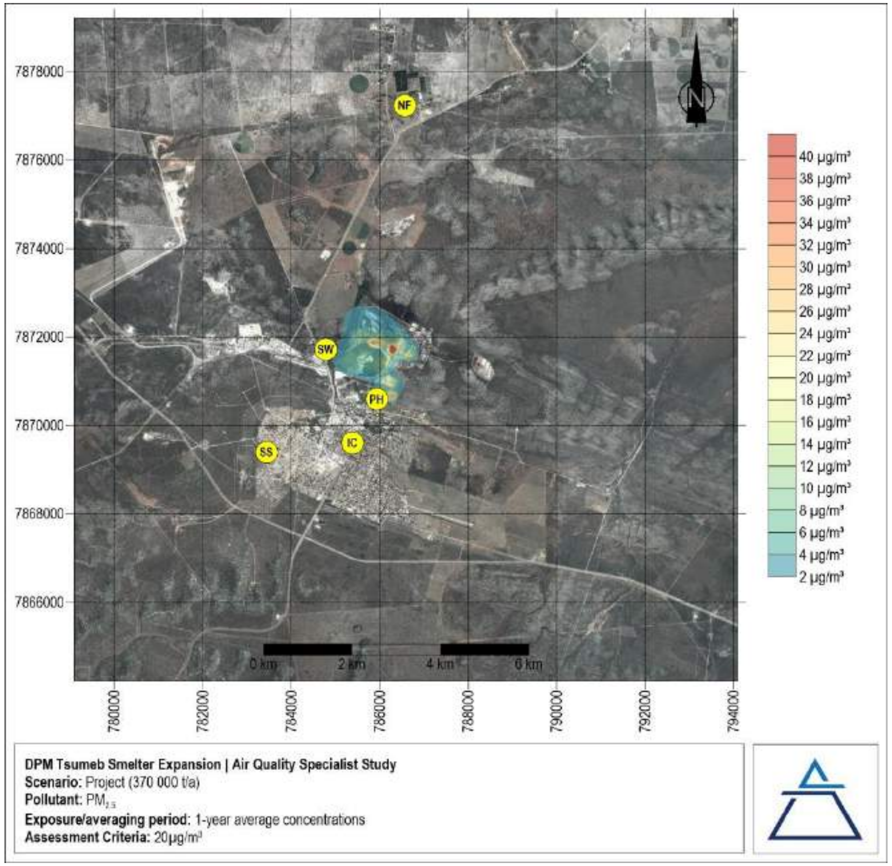


Figure 45: Project scenario, simulated 1-year average $PM_{2.5}$ concentrations

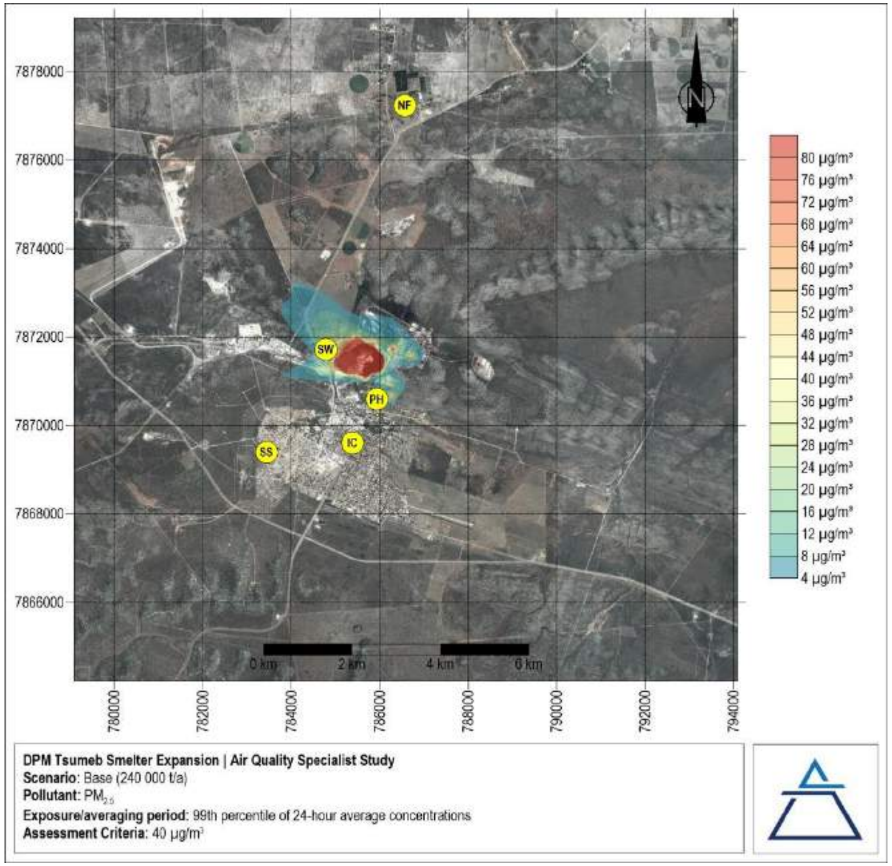


Figure 46: Base scenario, 99th percentile of simulated 24-hour average $PM_{2.5}$ concentrations

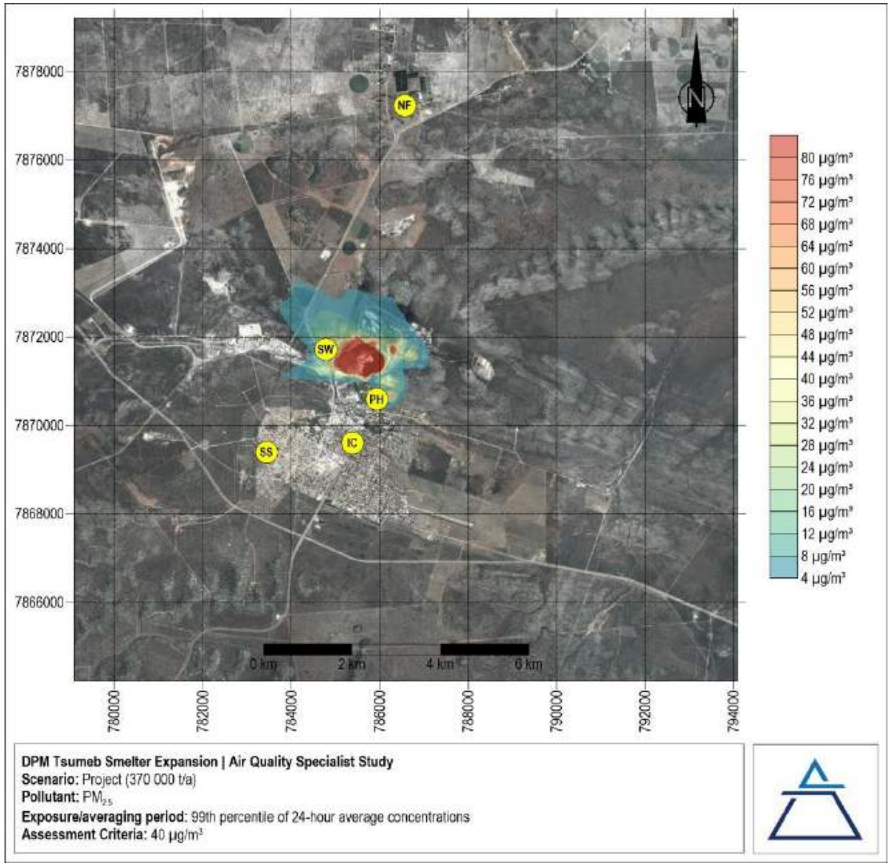


Figure 47: Project scenario, 99th percentile of simulated 24-hour average $PM_{2.5}$ concentrations

6.2.2.4 Simulated Arsenic Concentrations

Simulated base scenario 1-year average arsenic concentrations exceed the EU chronic inhalation reference concentration of 0.006 µg/m³ off-site at the Plant Hill and Sewerage Works sampling locations (Table 18). A more thorough assessment of simulated and sampled arsenic concentrations on human health and cancer risk will be conducted as part of the Community Health Impact Assessment conducted as part of the EIA process for the expansion.

Table 18: Simulated arsenic concentrations at ambient air quality monitoring sites

	1-year average arsenic conc. (µg/m³)
Assessment criteria	*0.006*
Base scenario (240 000 t/a)	
Plant Hill	0.014
Info Centre	0.003
Stadium	0.003
Sewage Works	0.022
Namfo	0.002
Ondundu	0.006
Emdombo	0.006
Private School and Hospital	0.004
Project scenario (370 000 t/a)	
Plant Hill	0.021
Info Centre	0.004
Stadium	0.004
Sewage Works	0.033
Namfo	0.002
Ondundu	0.010
Emdombo	0.009
Private School and Hospital	0.006

6.2.2.5 Simulated Arsenic Fallout Rates

For use in the health risk study, arsenic fallout rates were also simulated. These are graphically presented in Figure 50 and Figure 51 for the base and nominal scenarios, respectively.

6.2.2.6 Simulated H_2SO_4 Concentrations

The dispersion of H_2SO_4 released from the acid plant stack was simulated for the base and project scenarios. 1-year average off-site H_2SO_4 concentrations were well within ambient air quality limits (see Figure 52 and Figure 53). Proposed upgrades to the Tsumeb smelter complex to increase processing capacity are expected to increase ambient H_2SO_4 levels by a factor 1.5.

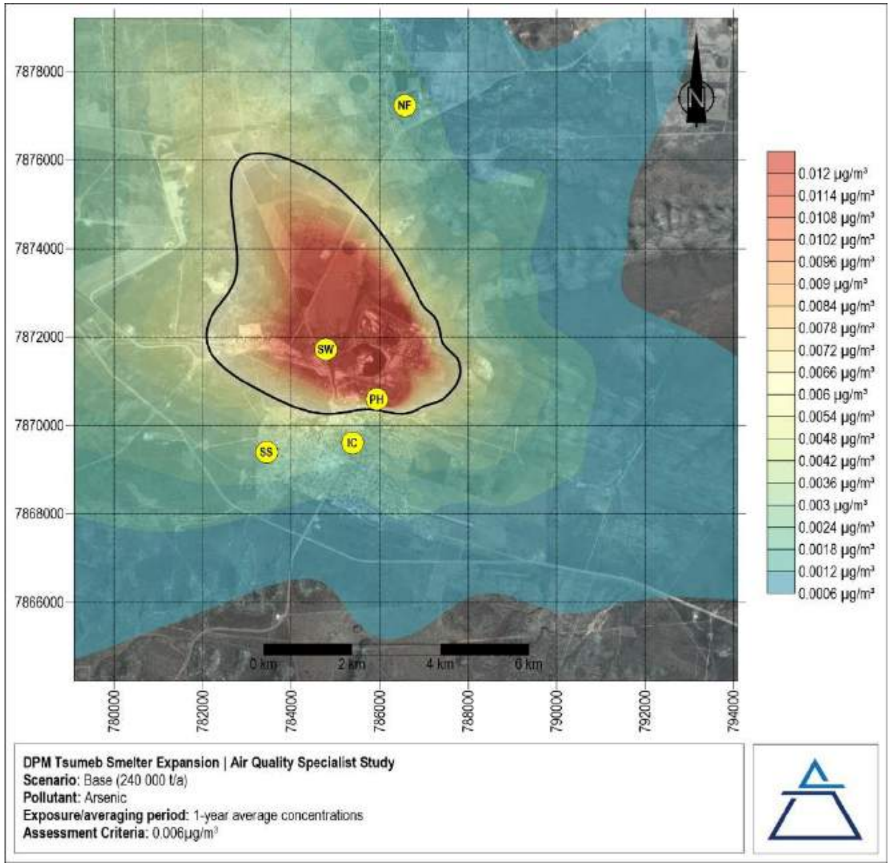


Figure 48: Base scenario, simulated 1-year average arsenic concentrations (The assessment criteria, 0.006 µg/m³, is indicated with a black line)

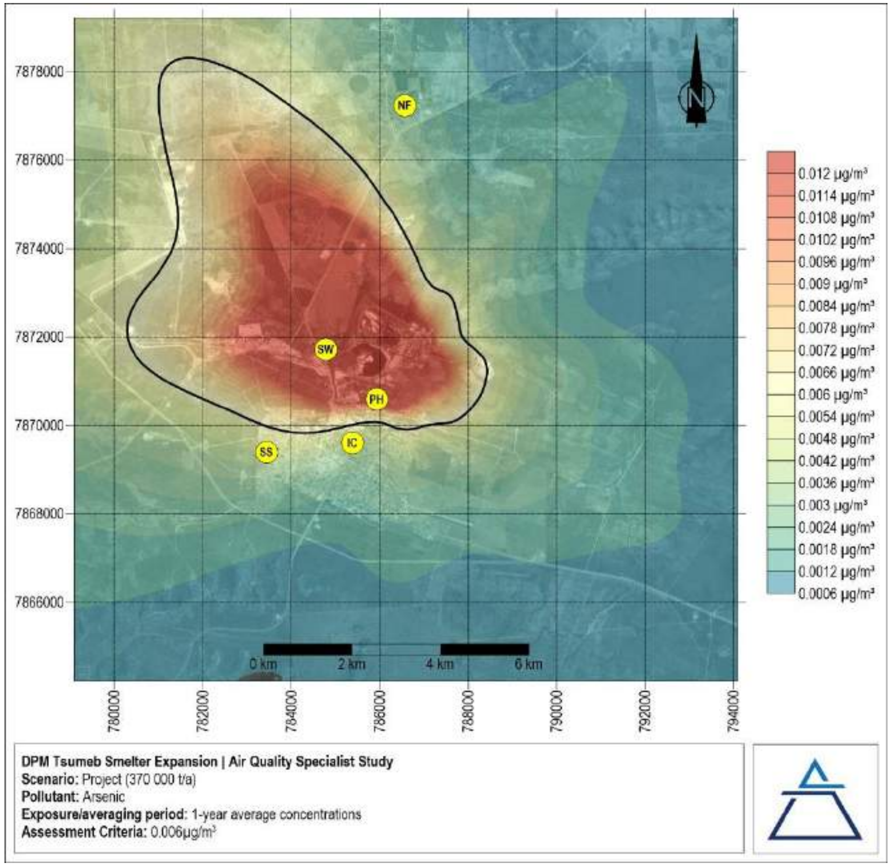


Figure 49: Project scenario, simulated 1-year average arsenic concentrations (The assessment criteria, 0.006 µg/m³, is indicated with a black line)

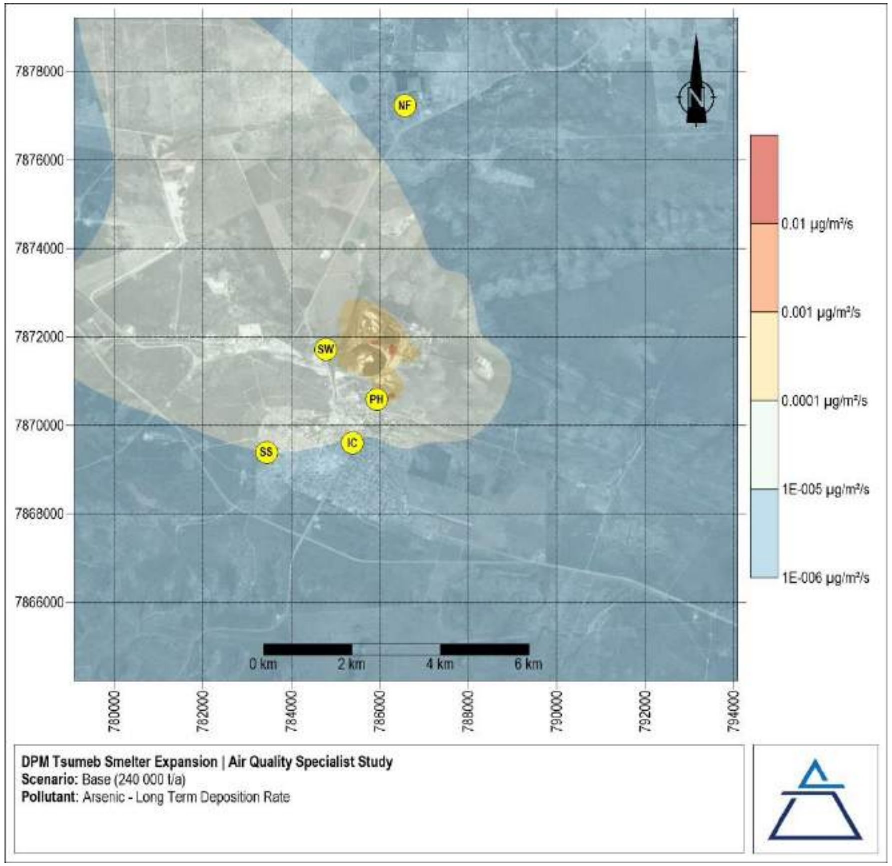


Figure 50: Base scenario, simulated long term arsenic deposition rates

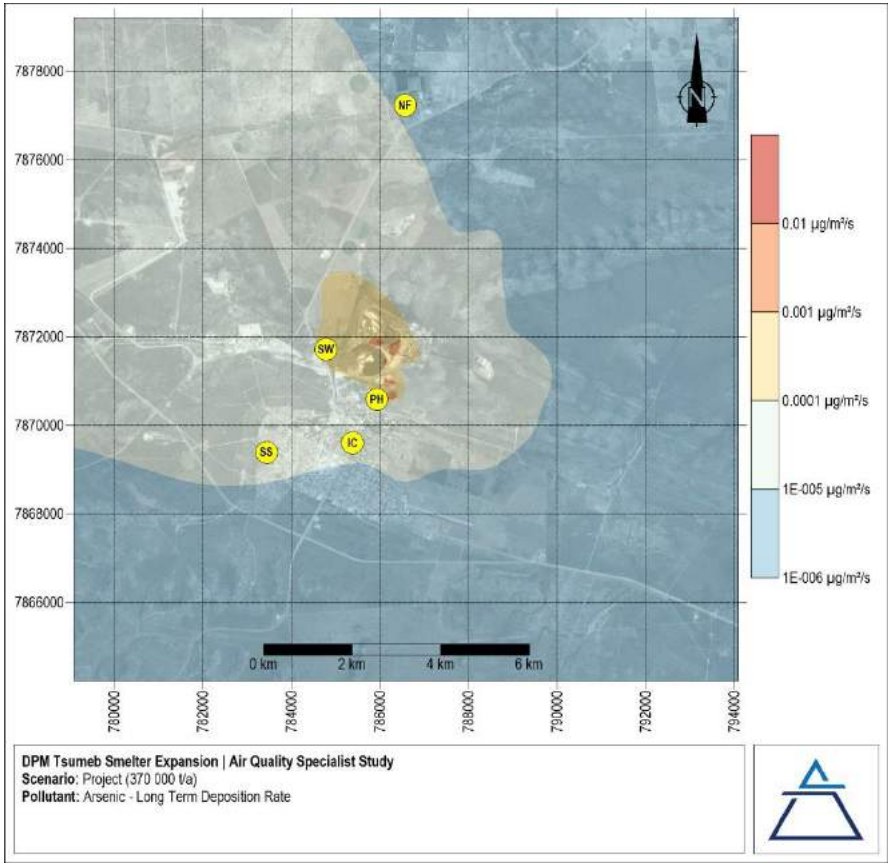


Figure 51: Project scenario, simulated long term arsenic deposition rates

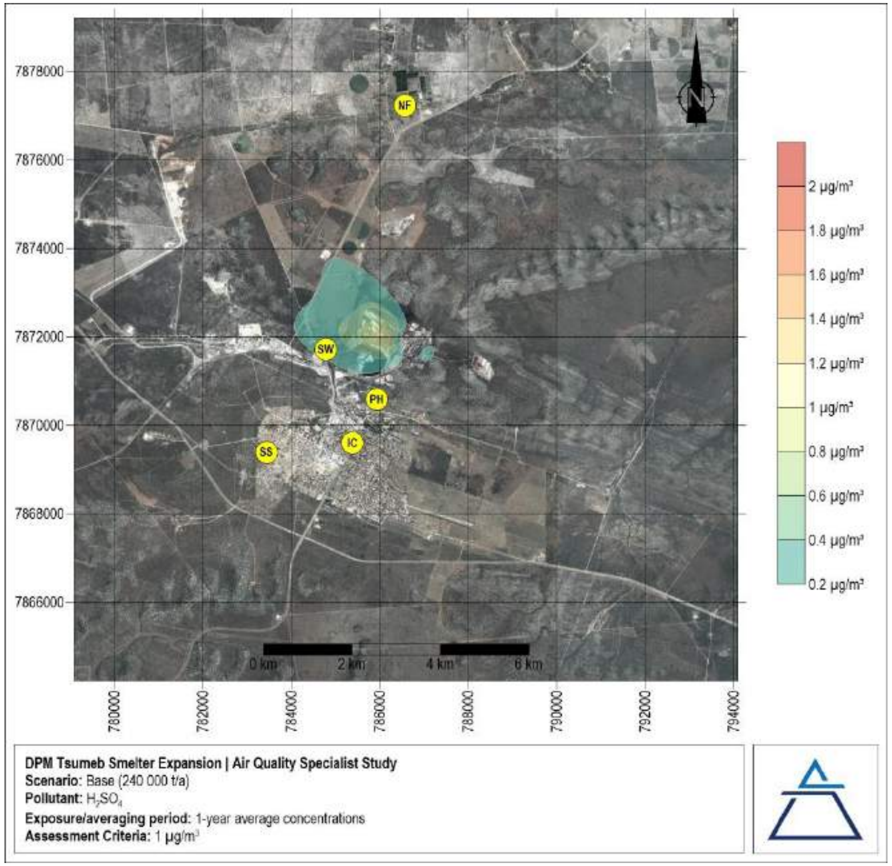


Figure 52: Base scenario, simulated 1-year average H_2SO_4 concentrations

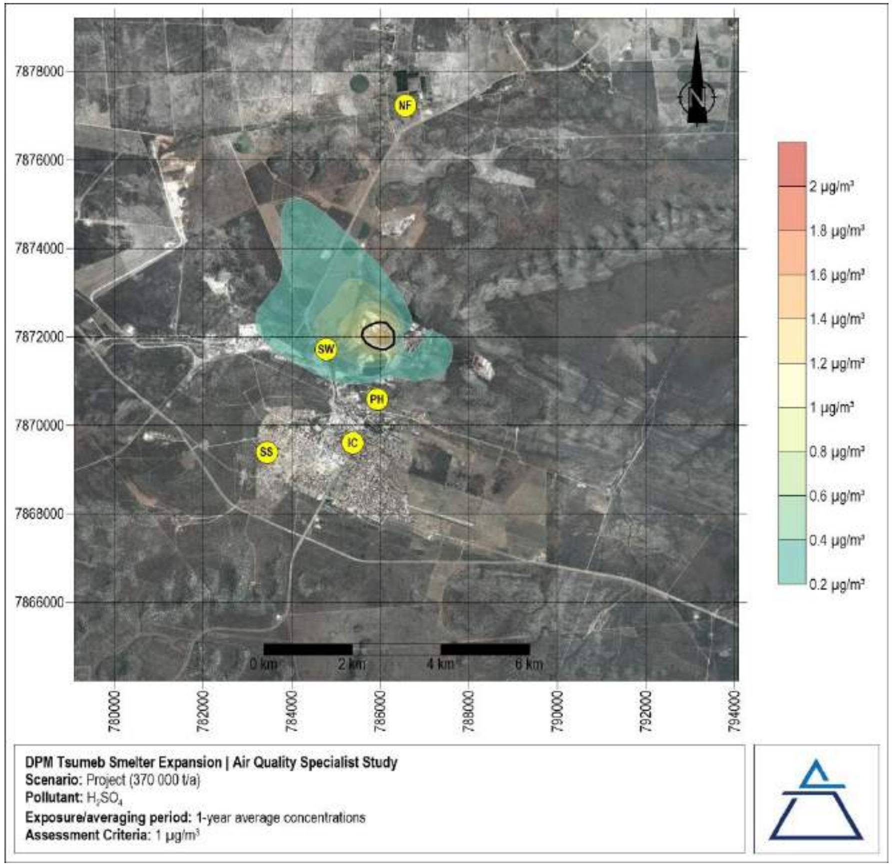


Figure 53: Project scenario, simulated 1-year average H_2SO_4 concentrations

7 Main Findings and Recommendations

An air quality impact assessment was conducted for the proposed upgrades at the DPMT Tsumeb smelter complex to increase copper concentrate processing capacity from 240 000 t/a to 370 000 t/a. The main objective of this study was to determine baseline or current air quality in the area and to quantify the extent to which ambient pollutant levels will change because of proposed upgrades.

A comprehensive information review was conducted to determine key pollutants of concern given smelter activities. From past air quality impact assessments and ambient air quality data, SO_2, PM_{10} and arsenic emissions and impacts were found to be most notable. Although other combustion gases ad trace metals may be released, this assessment focuses on the impacts of SO_2, PM_{10} and arsenic. Given that the impact of H_2SO_4 emissions from the acid plant have not been quantified previously, it was considered in this assessment.

7.1 Main Findings

An air quality impact assessment (AQIA) was conducted for the proposed upgrades at the DPMT Tsumeb smelter complex to increase copper concentrate processing capacity from 240 000 t/a to 370 000 t/a. The main objective of this study was to determine baseline or current air quality in the area and to quantify the extent to which ambient pollutant levels will change because of proposed upgrades. This study was complete by Airshed in 2017. Based on feedback received, Airshed updated the AQIA to include, among others, recent isokinetic stack monitoring results, a $PM_{2.5}$ emissions inventory, an update of the fugitive emissions inventory for all pollutants and the 2017 ambient monitoring results.

A comprehensive information review was conducted to determine key pollutants of concern given smelter activities. From past air quality impact assessments and ambient air quality data, SO_2, $PM_{10,}$ $PM_{2.5}$ and arsenic emissions and impacts were found to be most notable. Although other combustion gases and trace metals may be released, this assessment focuses on the impacts of SO_2, PM_{10}, $PM_{2.5}$ and arsenic. Given that the impact of H_2SO_4 emissions from the acid plant have not been quantified previously, it was considered in the 2017 AQIA as well as this update

In studying the receiving environment, the following was found:

- AQSRs in the project area include towns and scattered farmsteads/homesteads. The closest of these to the smelter complex are residents of Tsumeb and its suburbs to the south, farmhouses, and the Namfo agricultural area to the north. Ambient air quality monitoring stations, Plant Hill, Info Centre and Stadium are representative of receptors within Tsumeb.
- Three additional sensitive receptor locations (Ondundu, Endombo and Private school and hospital) were included in the dispersion modelling scenarios at the request of SLR.
- It was decided to update the dispersion model to rather use meteorological data recorded at the Stadium ambient monitoring station, as data recorded at the Plant Hill station previously used for dispersion modelling simulations has an unacceptably low data availability.
- Based on data collected at the Stadium air quality monitoring station, the area is affected by frequent south-easterly winds. Long term air quality impacts are therefore expected to be the most significant to the north-west of operations.
- The DPMT Tsumeb smelter is the main source of ambient SO_2 and arsenic. SO_2 is however also emitted by vehicles and may be emitted in small quantities at the sewerage plant.
- There are several sources of atmospheric PM in the area. These include the smelter complex, opencast copper mining operations to the west, agricultural activities to the north, paved and unpaved public roadways, open areas

exposed to wind, small scale industrial/commercial activities within and around Tsumeb and transboundary sources.

- An analysis of ambient air quality monitoring at the five DPMT owned and operated stations from 2013 to 2016 indicated:
  - Significant exceedances of SO_2 and PM_{10} ambient air quality limits up to the end of 2015.
  - A notable decrease in SO_2 and PM_{10} levels in 2016 and 2017 due to the commissioning of the acid plant and de-commissioning of the reverb furnace.
  - A notable decrease in PM_{10} levels in 2016 due to the commissioning of the acid plant and de-commissioning of the reverb furnace. Higher PM_{10} concentrations were however recorded in 2017 compared to 2016.
  - A current annual average SO_2 concentration at the complex boundary of between 25 µg/m^3 at Plant Hill and 58.5 µg/m^3 at the sewerage works.
  - An annual average PM_{10} concentration at the complex boundary ranging between 29 and 74 µg/m^3 in 2017.
  - An annual average $PM_{2.5}$ concentration of 27.7 µg/m^3 at the Stadium and 13 µg/m^3 at the Info Centre in 2017.
  - An annual mean arsenic concentration at the complex boundary of approximately 0.35 µg/m^3 in 2017.

The main findings of the impact assessment are as follows:

- SO_2, PM_{10}, $PM_{2.5}$, arsenic and H_2SO_4 emissions from the DPMT Tsumeb smelter complex were quantified.
- SO_2 emissions were calculated using stack testing results and acid plant availabilities provided by DPMT.
- Two operational scenarios were considered:
  - The base scenario is representative of current activities and a concentrate processing rate of 240 000 t/a.
  - The project scenario includes proposed plant upgrades and an increase in concentrate processing rate of 370 000 t/a.
- For SO_2 two acid plant utilization scenarios (75% and 90%) were considered for the base and project scenarios.
- Base scenario SO_2, PM_{10}, $PM_{2.5}$, arsenic and H_2SO_4 emissions were estimated at 16 438 t/a, 348.4 t/a, 219.3 t/a 9.9 t/a and 115.2 t/a respectively. *Note that the SO_2 emission rate above is based on a 90% acid plant utilization.*
- At a processing rate of 370 000 t/a, SO_2, PM_{10}, $PM_{2.5}$, arsenic and H_2SO_4 emissions were estimated to increase to 26 842 t/a, 430.8 t/a, 292.5 t/a, 15.0 t/a and 177.6 t/a respectively.
- The emissions of all pollutants will increase mostly because of increased material throughput and production rates. The increase is expected to be proportional to the increase in the concentrate processing rate.
- The minimum height of the stack used to vent emissions from the baghouse serving the RHF was determined as 70 m. At a release height of 70 m, emissions released will result in ground level pollutant level no more than 25% of the ambient air quality limits.
- Currently, SO_2 concentrations associated with the base scenario, exceed the South African 1-year average assessment criterion of 50 µg/m^3 at the Sewerage Works if the acid plant is 75% utilized. The 24-hour average criterion is exceeded at the Sewerage Works, Plant Hill and the north-eastern part of Tsumeb including at the sensitive receptor locations of Ondundu and the Private School and Hospital. Hourly average concentrations exceed the adopted criterion at the Sewerage Works, Plant Hill and Info Centre as well as at all three the newly included sensitive receptor locations. If the acid plant was 90% utilized (i.e. at least 90% on-line time while the Ausmelt furnace is active) simulated concentrations comply with the annual and daily criteria, but 99th percentile hourly SO_2 concentrations would still be exceeded at the three closest locations (Sewerage Works, Plant Hill and Ondundu).

- With an acid plant utilization of 75%, simulated annual average SO_2 concentrations due to the expanded operations exceed the South African 1-year average assessment criterion of 50 $\mu g/m^3$ only at the Sewerage Works, but daily and hourly 99th percentile concentrations exceed the assessment criteria at almost all sensitive receptor locations. With a 90% (or higher) utilization of the acid plant after the expansion, impacts would be similar or slightly lower on average than current impacts at the sensitive receptor locations. It is therefore recommended that the acid plant utilization be at least 90% after the expansion to ensure compliance with the identified assessment criteria.
- Simulated base scenario ambient PM_{10} and $PM_{2.5}$ concentrations are below air quality criteria in both the long and short-term and, as expected, are below what was measured at ambient air quality stations in 2016. A 10% to 30% increase in ambient PM_{10} concentrations are expected as a result of the expansion.
- Simulated base scenario ambient arsenic concentrations exceed chronic screening criteria off-site at the Plant Hill and Sewerage Works locations.
- Simulated project scenario ambient arsenic concentrations exceed chronic screening criteria off-site at the Plant Hill, Sewerage Works, Ondundu and Emdombo locations.

7.2 Recommendations

Noteworthy improvements in ambient air quality have been observed in and around Tsumeb since 2014. This is especially true for ambient SO_2 and arsenic levels. **Further improvement in management of PM emissions (and specifically the arsenic content thereof) and impacts are however necessary and should be incorporated into the smelter complex's existing air quality management plan**. In addressing PM emissions, arsenic levels will also be reduced. The main objective of any air quality management measure is to ensure that operations result in ambient air concentrations that are within the relevant ambient air quality criteria off-site. The measures below are considered best practice for mitigating especially fugitive emissions and should be implemented or improved upon to account for the increase in emissions resulting from the increase in production and the construction phase of the proposed upgrades. Other recommendations are specifically related to the RHF and monitoring.

7.2.1 Fugitive Dust Control Measures

7.2.1.1 Building Fugitive Emissions

Fugitive emissions escaping primary and secondary fume capture systems at the Ausmelt and converters (and the RHF in future) must be addressed to reduce arsenic emissions and ambient concentrations. Engineering methods to reduce such emissions must be considered. These could include upgrading/retro-fitting secondary extraction systems to more efficiently evacuate fumes from the building, and building enclosure, especially during charging and tapping.

7.2.1.2 Crushing and Screening Operations

Sizing operations at the slag plant (including handling and stockpiling of crusher materials) was observed to be a significant source of fugitive dust at the smelter complex that need to be addressed. Water sprays can have up to 50% control efficiency and hoods with scrubbers up to 75%. If in addition, the crushers and screens were to be enclosed; up to 100% control efficiency can be achieved. Hooding with fabric filters can result in control efficiencies of 83%. It is important that control equipment be maintained and inspected on a regular basis to ensure that the expected control efficiencies are met (ADE, 2011). It is recommended that a method with at least 75% control efficiency be selected for the slag crusher plant.

7.2.1.3 Paved Roads

Although internal roads at the smelter complex are paved, these have been observed to be covered with dust which is re-entrained as vehicles pass. Good housekeeping and minimising windblown dust and spillage is key to minimising re-entrainment.

Mechanical broom sweepers use large, rotating brooms to lift the material from the road onto a conveyor belt, which then discharges the debris into a collection hopper. In the early 1990s, mechanical broom sweeping was discounted as a feasible means of air pollution control on paved roads, with studies having shown that the brushes re-suspend as many particles as they remove (Chow, et al., 1990). Significant recent developments in broom sweeping technology have, however, reinstated these sweepers as a viable dust control alternative to vacuum sweeping.

Commercially available vacuum sweepers use pure vacuum suction, re-generative air suction, or blow-air suction re-circulation. Most vacuum sweepers use a gutter broom to loosen debris from the road surface and direct it to a vacuum nozzle, which sucks it into a hopper. The hopper usually consists of a chamber into which particles are collected by gravitational settling. The air is then exhausted either directly back into the environment, or through a bag-filter or precipitator, or to the collection nozzle for re-circulation (Chow, et al., 1990).

The control efficiency of vacuum and broom sweepers is dependent on: sweeper design and maintenance, the frequency of sweeping, the nature of the area being swept, and the particle size distribution of the dust on the roadway. Until recently, the control efficiency of vacuum sweepers was given as being generally in the range of 0% to 60%. The frequent use of efficiently designed and well maintained vacuum sweepers was found to provide an estimated PM_{10} control efficiency of between 30 and 60 % by studies conducted in the 1980s (Calvert, Brattin, Bhutra, & Ono, 1984) The control efficiency of daily sweeping with a regenerative-air vacuum sweeper was, however, found at that time to have resulted in no detectable reductions in ambient PM_{10} concentrations (Chow, et al., 1990). One of the main reasons for the inefficiency of regenerative-air suction, and similar types of vacuum sweepers, was observed during the study to be due to the insufficient residence time of particles in the hopper collection chamber. The air was found not to be in the chamber for a long enough period to allow for the gravitational settling of particles in the PM_{10} size fraction. Instead small particles were directed back to the pickup head, and a significant portion of the particles are impacted back onto the road.

Developments in vacuum and broom sweepers over the past decade have resulted in significant increases in their PM_{10} control efficiency, with certain of the latest sweepers being shown to have efficiencies of more than 80%. A wide variety of broom and vacuum sweepers are currently available on the market. In selecting a suitable sweeper, it is recommended that close attention be paid to the PM_{10} collection efficiency of the machine.

Factors in addition to PM_{10} control efficiency to be considered in selecting an appropriate sweeper include: the extent of the sweeping path, hopper capacity, water capacity, travel speed, drive-by noise levels and maneuverability. Large hopper, water and sweep path capacities allow for extended sweeping time and maximum productivity.

Vacuum and broom sweepers are routinely used in various industries in which fugitive dust emissions are a problem, including lead and asbestos industries, brickworks, cement factories, and various metallurgical smelters. Such sweepers are either purchased directly by the end user (~60% of cases) or alternatively use is made of contracting companies to supply sweeping services.

7.2.1.4 Unpaved Roads

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

- Measures aimed at reducing the extent of unpaved roads, e.g. paving;
- Traffic control measures aimed at reducing the entrainment of material by restricting traffic volumes and reducing vehicle speeds; and
- Measures aimed at binding the surface material or enhancing moisture retention, such as wet suppression and chemical stabilization (Cowherd, Muleski, & Kinsey, 1988).

The main dust generating factors on unpaved road surfaces include:

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

According to research conducted by the Desert Research Institute at the University of Nevada, an increase in vehicle speed of 10 miles per hour resulted in an increase in PM_{10} emissions of between 1.5 and 3 times. A similar study conducted by Flocchini (Flocchini, Cahill, Matsumura, Carvacho, & Lu, 1994) found a decrease in PM_{10} emissions of 42±35% with a speed reduction from 40 km/hr to 24 km/hr (Stevenson, 2004). The control efficiency obtained by speed reduction can be calculated by varying the vehicle speed input parameter in the predictive emission factor equation given for unpaved roads. An evaluation of control efficiencies resulting from reductions in traffic volumes can be calculated due to the linear relationship between traffic volume, given in terms of vehicle kilometres travelled, and fugitive dust emitted. Similar effects will be achieved by reducing the truck volumes on the roads.

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

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

There is however no cure-all solution but rather a combination of solutions. A cost-effective chemical control programme may be developed through establishing the minimum control efficiency required on a roadway, and evaluating the costs and benefits arising from various chemical stabilization practices. Appropriate chemicals and the most effective relationships between application intensities, reapplication frequencies, and dilution ratios may be considered in the evaluation of such practices. One of the main benefits of chemical stabilisation in conjunction with wet suppression is the management of water resources (MFE, 2001).

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

7.2.1.5 Materials Handling Dust Control Options

Control techniques applicable to materials handling are generally classifiable as source extent reduction, source improvement related to work practices and transfer equipment, and surface treatment. The delivery of raw material fines and handling of baghouse/cooler dusts should be minimised.

Control options available may be summarised as follows:

- Source extent reduction:
    - Mass transfer reduction
- Source improvement:
    - Drop height reduction
    - Wind sheltering
    - Moisture retention
- Surface treatment:
    - Wet suppression
    - Air atomising suppression

The efficiency of these controls may be estimated through the relationships between climatic parameters, material properties and quantities of material transferred demonstrated in the predictive emission factor equation.

Good operational practices frequently represent the **most cost effective and efficient means** of reducing emissions. The variation of the height from which stacking occurs to suit the height of the storage pile would limit drop heights and therefore reduce the potential for the entrainment of fines by the wind.

Wet suppression systems use either liquid sprays or foam to suppress the formation of airborne dust. Emissions are prevented through agglomerate formation by combining fine particulates with larger aggregate or with liquid droplets. The key factors which affect the extent of agglomeration and therefore the efficiency of the system are the coverage of the material by the liquid and the ability of the liquid to "wet' small particles. The only wet suppression systems considered in this section is liquid sprays.

Liquid spray suppression systems may use only water or a combination of water and a chemical surfactant as the wetting agent. Surfactants reduce the surface tension of the water thus allowing particles to more easily penetrate the water particle and reducing the quantity of water needed to achieve the control efficiency required. General engineering guidelines which have been shown to be effective in improving the control efficiency of liquid spray systems are as follows:

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

The control efficiency of pure water suppression can be estimated based on the US EPA emission factor which relates material moisture content to control efficiency. This relationship is illustrated in Figure 54.

It is important to note that the improvements in dust control efficiencies are marginal following increases in material moisture contents by 400%. To obtain control efficiencies of greater than 90%, it would be more feasible and cost effective to consider either alternative systems (e.g. foam suppression) or supplementary methods (e.g. addition of chemical surfactants to water).

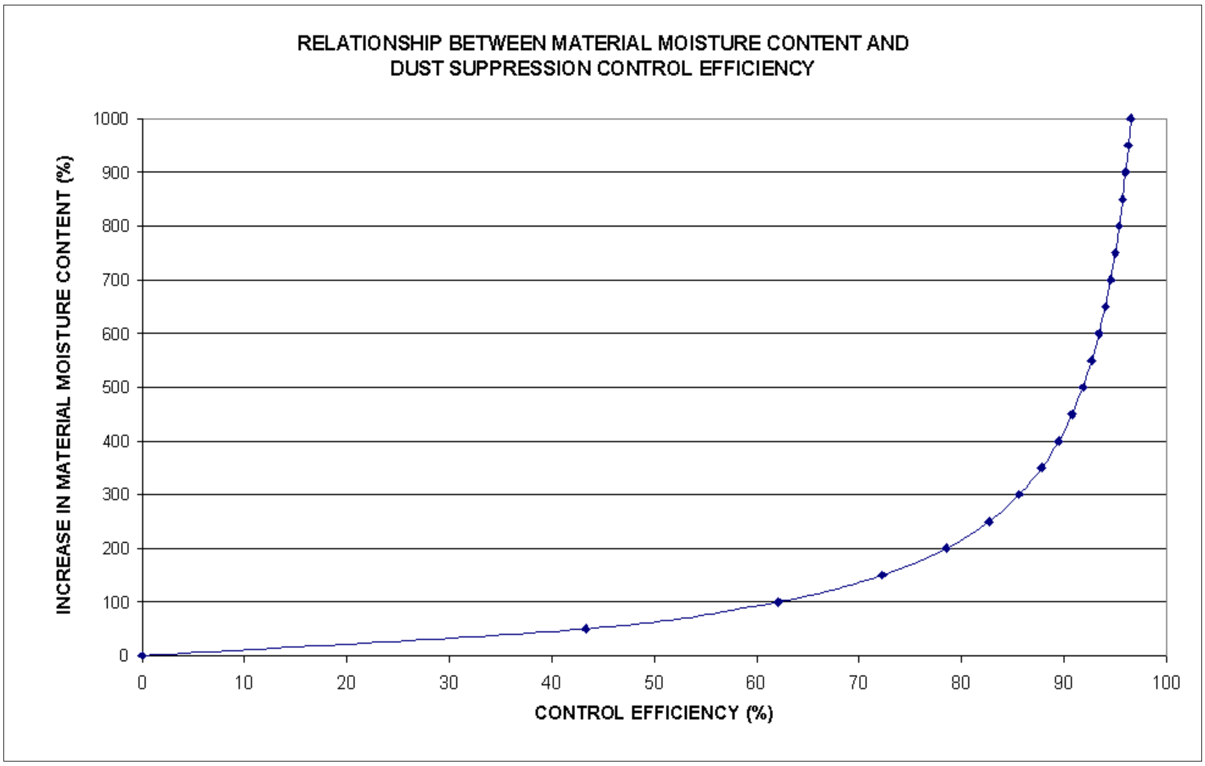


Figure 54: Relationship between the moisture content and the dust control efficiency

Wind sheltering techniques are widely applied for dust minimization during stacking and loading operations, particularly in cases where the application of wet suppression is not a viable alternative. The application of transfer chutes represents one of the most common of such wind sheltering methods.

Transfer chutes can be used at belt-to-belt transfer points. Chutes provide the potential for dust control due to wind sheltering, and prevention of spillages, which could give rise to dust emissions through wind or vehicle entrainment. Spillage, material degradation, conveyor belt damage, blockage and high maintenance costs have been noted as commonly re-occurring problems at transfer chute operating sites. Considerable improvements on conventional transfer chute design over the past few years have, however, resulted in solutions to many of these problems.

Significant developments have been made in the field of air atomising spray systems. These systems use water and compressed air to produce micron sized droplets that can suppress respirable dust without adding any detectable moisture to the process. As such, such systems may be suitable for implementation at transfer points beyond the sampling plant. No information could be obtained on the control efficiency of such spray systems.

7.2.1.6 Options for Reducing Windblown Dust Emissions

Measurements have shown windblown dust as a source of peak ambient PM_{10} levels at the complex boundary under strong wind conditions. There remain several large open areas exposed to wind on-site. These areas include active plant areas, active tailings facilities, active and historical waste disposal areas. As for materials handling, the main techniques adopted to reduce windblown dust potential include source extent reduction, source improvement and surface treatment methods:

- Source extent reduction:
  - Disturbed area reduction.
  - Disturbance frequency reduction.
  - Dust spillage prevention and/or removal.
- Source Improvement:
  - Disturbed area wind exposure reduction, e.g. wind fences and enclosure of source areas.
- Surface Treatment:
  - Wet suppression
  - Chemical stabilisation
  - Covering of surface with less erodible aggregate material
  - Vegetating of open areas

The suitability of the dust control techniques indicated will depend on the specific source to be addressed, and will vary between dust spillage, material storage and open areas. The ADE recommends the following methods for reducing windblown dust:

- Primary rehabilitation - 30%
- Vegetation established but not demonstrated to be self-sustaining. Weed control and grazing control - 40%
- Secondary rehabilitation - 60%
- Re-vegetation - 90%
- Fully rehabilitated (release) vegetation - 100%

7.2.2 The RHF

Emissions from the proposed holding furnace will be extracted and passed through a baghouse before being vented to atmosphere. Both movable and stationary hoods will be employed. It is essential that movable hoods be positioned correctly during all cycles of the process.

It is further recommended that the height of the baghouse stack be at least 70 m above ground level. At a release height of 70 m, emissions released will result in ground level pollutant level no more than 25% of the ambient air quality limits.

7.2.3 The Acid Plant

SO_2 emissions have drastically reduced since the commissioning of the sulphuric acid plant. **It is expected to reduce further as the acid plant's performance and utilization continues to improve**. Ambient levels, post the commissioning of the acid plant, however still frequently exceeded short-term air quality limits. Management and maintenance of systems feeding off-gas to the sulphuric acid plant, and the acid plant itself, is essential to maintaining improvements to SO_2 levels in the area. It will also ensure minimal H_2SO_4 emissions. **A total process shutdown of the Ausmelt furnace and converters is recommended should the acid plant not be operational. If this is not feasible it is recommended that interruptions of the acid plant operations be kept to a minimum between the hours of 11AM and 4PM (**Figure 5**).**

In order to comply with assessment criteria, it is recommended that the **acid plant utilization be at least 90%.**

Continuous monitoring of SO_2 emissions released through the acid plant stack is recommended. This will enable plant operators to monitor plant efficiency and provide the environmental department with a true reflection of SO_2 emissions over time. It can also be used as input to a real time atmospheric dispersion model.

7.2.4 Emissions Monitoring

The following is recommended in terms of emissions monitoring:

- To validate theoretical emission estimates, stack emission testing for the full operation cycle of the proposed RHF furnace must be conducted once the furnace is operational.
- Stack emissions testing on the outlet of the converter baghouse must be conducted over the full converter cycle.
- There is some uncertainty as to the extent of furnace and converter fugitive emissions. Building fugitive emissions measurements must be conducted once the RHF has been commissioned. These emissions need to be updated given the decommissioning of the reverberatory furnace as well as to determine the extent of fugitive emissions from the charging and pouring RHF. It is essential that the arsenic content in particulate matter emissions be determined.
- Continuous emissions monitoring of SO_2 at the acid plant stack is recommended.

7.2.5 Ambient Monitoring

It is recommended that attempts be made to improve data availability on the PM_{10} analysers installed at the DPMT owned and operated ambient monitoring stations. While data availability was adequate in 2017 for the Plant Hill station, data availability at all other stations remain poor.

It is further recommended that DPMT consider extending their network to include one station at the airport and another one between one and two km north-west of the smelter boundary.

8 Impact Significance

The significance of air quality impacts was determined using the methodology adopted by SLR for the ESIA.

The significance of the base/current scenario, which is also representative of the "no-go" option, was found to be *medium* (Figure 55). This assessment is based on measured ambient pollutant levels, simulated ambient pollutant levels, as well as observations made during a specialist site visit. With the air quality management and mitigation measures proposed in place, the significance of current impacts can be reduced to *low to medium*. Of specific importance to the base scenario is the mitigation/management of SO_2 and fugitive dust, especially arsenic containing dusts.

The significance of the project scenario, which is representative of smelter complex operations including upgrades and increased production rates, was found to be *medium* (Figure 55) without mitigation and *low to medium* with mitigation. The expansion project will not change the significance of air quality impacts currently experienced. The impact of *current* activities should therefore have an influence on the approval decision of the *expansion project*, unless it is mitigated.

Figure 55: Impact significance of the base (current) scenario

Impact of **base (current) operations** at DPMT Tsumeb smelter on the atmospheric environment.	**Unmitigated assessment**						**Mitigation/management measures**	**Mitigated assessment**					
	Severity	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**		**Severity**	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**
Potential for health impacts associated with SO_2, PM_{10}, $PM_{2.5}$, arsenic and H_2SO_4 **Severity:** Negative impacts associated with SO_2, PM_{10} and arsenic are currently *moderate*, since ambient measurements and simulations show exceedances of assessment criteria at AQSR's. With mitigation, impact severity may be reduced to *low to moderate*. **Duration** would be for the life of the project and is thus considered *medium term* as per the impact rating guidelines provided. **Spatial scale:** Impacts would be experienced on a local scale. The rating is considered *moderate* without mitigation and *low to moderate* with mitigation. **Consequence:** Based on the above assessment, consequence is *medium* in the unmitigated case and *low to medium* in the mitigated case. **Probability:** Probability of occurrence is *definite*. **Significance:** Summarising the above assessment, the overall significance is rated as *medium*. The impact of current activities should have an influence on the approval decision of the expansion project, unless it is mitigated. After mitigation, the significance will reduce to *low to medium*.	M	M	M	M	H	M	**Objective:** Minimise impact on AQSRs by ensuring ambient air quality limits are not exceeded off-site. **Actions:** Improve fugitive dust management measures to reduce PM and arsenic emissions. Measures must specifically include: • Engineering methods to reduce building fugitive emissions; • Proper handling and disposal of arsenic containing dusts at the waste disposal site; • Good housekeeping on plant and road areas to reduce fine material re-entrainment by wind and vehicles; • Enclosure, extraction and fabric filters on slag plant crusher section. SO_2 emissions have drastically reduced since the commissioning of the sulphuric acid plant. Management and maintenance of systems feeding off-gas to the sulphuric acid plant, and the acid plant itself, is essential to maintaining improvements to SO_2 levels in the area. It will also ensure minimal H_2SO_4 emissions. Acid plant efficiency to be improved from 76% to 93%. A total process shutdown is recommended should the acid plant not be operational.	M	M	L/M	L/M	H	M

Figure 56: Impact significance of the project scenario

Impact of **project (370 000 t/a) operations** at DPMT Tsumeb smelter on the atmospheric environment.	**Unmitigated assessment**						**Mitigation/management measures**	**Mitigated assessment**					
	Severity	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**		**Severity**	**Duration**	**Spatial Scale**	**Consequence**	**Probability**	**Significance**
Potential for health impacts associated with SO_2, PM_{10}, $PM_{2.5}$, arsenic and H_2SO_4 **Severity:** Negative impacts will be *moderate*, since exceedance of assessment criteria at AQSR's will occur given current performance levels of air quality management plan and systems. The proposed expansion will increase ambient air pollutant levels. With mitigation, impact severity may be reduced to *low to moderate*. **Duration** would be for the life of the project and is thus considered *medium term* as per the impact rating guidelines provided. **Spatial scale:** Impacts would be experienced on a local scale. The rating is considered *moderate* without mitigation and *low to moderate* with mitigation. **Consequence:** Based on the above assessment, consequence is *medium* in the unmitigated case and *low to medium* in the mitigated case. **Probability:** Probability of occurrence is *definite*. **Significance:** Summarising the above assessment, the overall significance is rated as *medium*. The impact of activities should have an influence on the approval decision of the expansion project, unless it is mitigated. After mitigation, the significance would reduce to *low to medium*.	M	M	M	M	H	M	**Objective:** Minimise impact on AQSRs by ensuring ambient air quality limits are not violated off-site. ***Additional*** **actions:** Acid plant utilization of 90%. The RHF baghouse stack must be at least 70 m high. Fume capture and extraction systems at the RHF must be maintained and operated to specifications to ensure minimal fugitive emissions during charging, holding and pouring cycles. Improve fugitive dust management measures to minimise PM_{10} and arsenic emissions which will increase proportionally to increased production rates. As for the base scenario, measures must specifically include: • Engineering methods to minimise building fugitive emissions. • Proper handling and disposal of arsenic containing dusts at the waste disposal site; • Good housekeeping on plant and road areas to reduce fine material re-entrainment by wind and vehicles; • Enclosure, extraction and fabric filters on slag plant crusher section.	M	M	L/M	L/M	H	M

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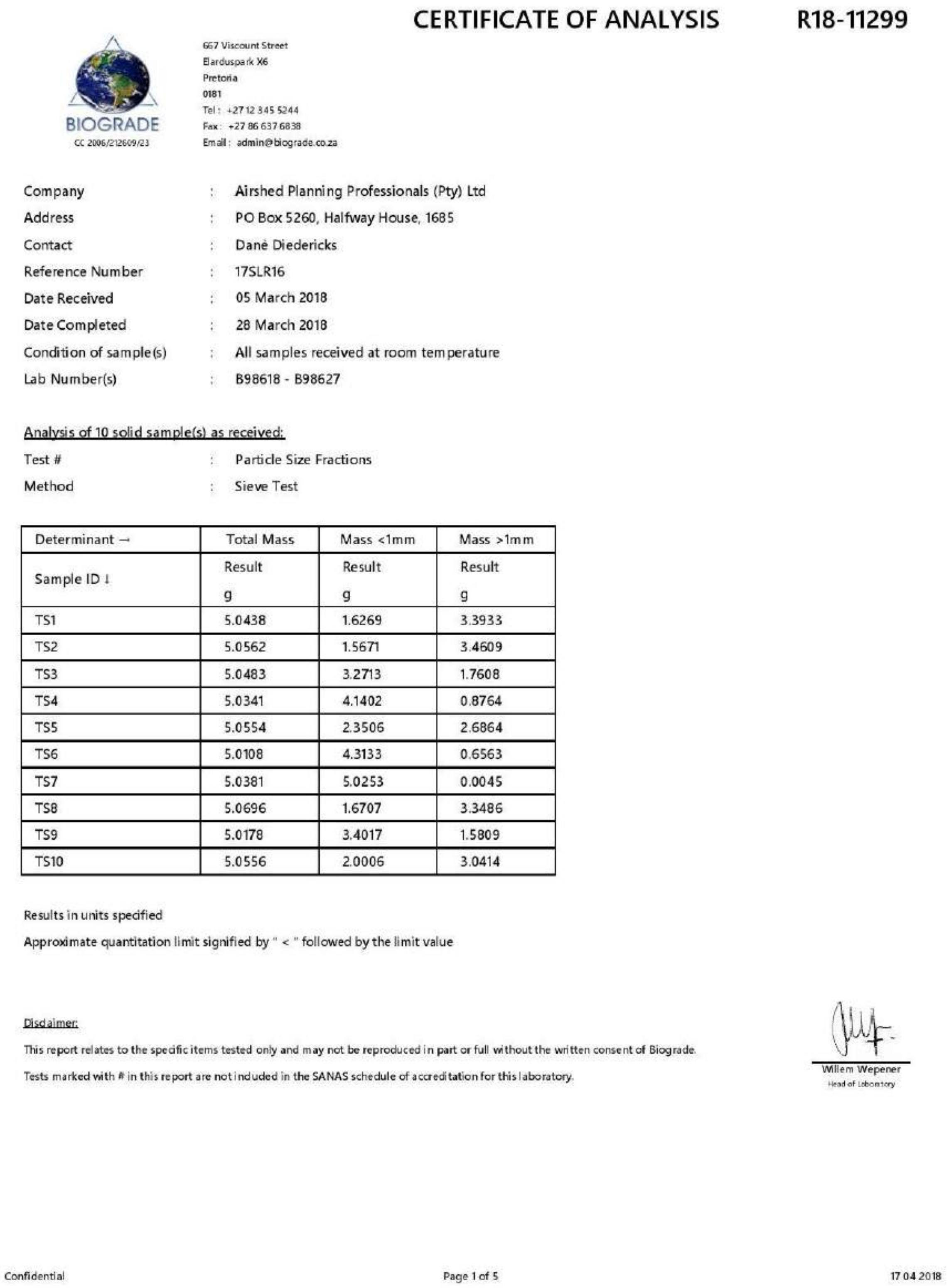
10 Appendix A – Laboratory Results



CERTIFICATE OF ANALYSIS R18-11299

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Company : Airshed Planning Professionals (Pty) Ltd
Address : PO Box 5260, Halfway House, 1685
Contact : Danè Diedericks
Reference Number : 17SLR16
Date Received : 05 March 2018
Date Completed : 28 March 2018
Condition of sample(s) : All samples received at room temperature
Lab Number(s) : B98618 - B98627

Analysis of 10 solid sample(s) as received:

Test # : Particle Size Fractions
Method : Sieve Test

Determinant →	Total Mass	Mass <1mm	Mass >1mm
Sample ID ↓	Result g	Result g	Result g
TS1	5.0438	1.6269	3.3933
TS2	5.0562	1.5671	3.4609
TS3	5.0483	3.2713	1.7608
TS4	5.0341	4.1402	0.8764
TS5	5.0554	2.3506	2.6864
TS6	5.0108	4.3133	0.6563
TS7	5.0381	5.0253	0.0045
TS8	5.0696	1.6707	3.3486
TS9	5.0178	3.4017	1.5809
TS10	5.0556	2.0006	3.0414

Results in units specified

Approximate quantitation limit signified by " < " followed by the limit value

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Head of Laboratory

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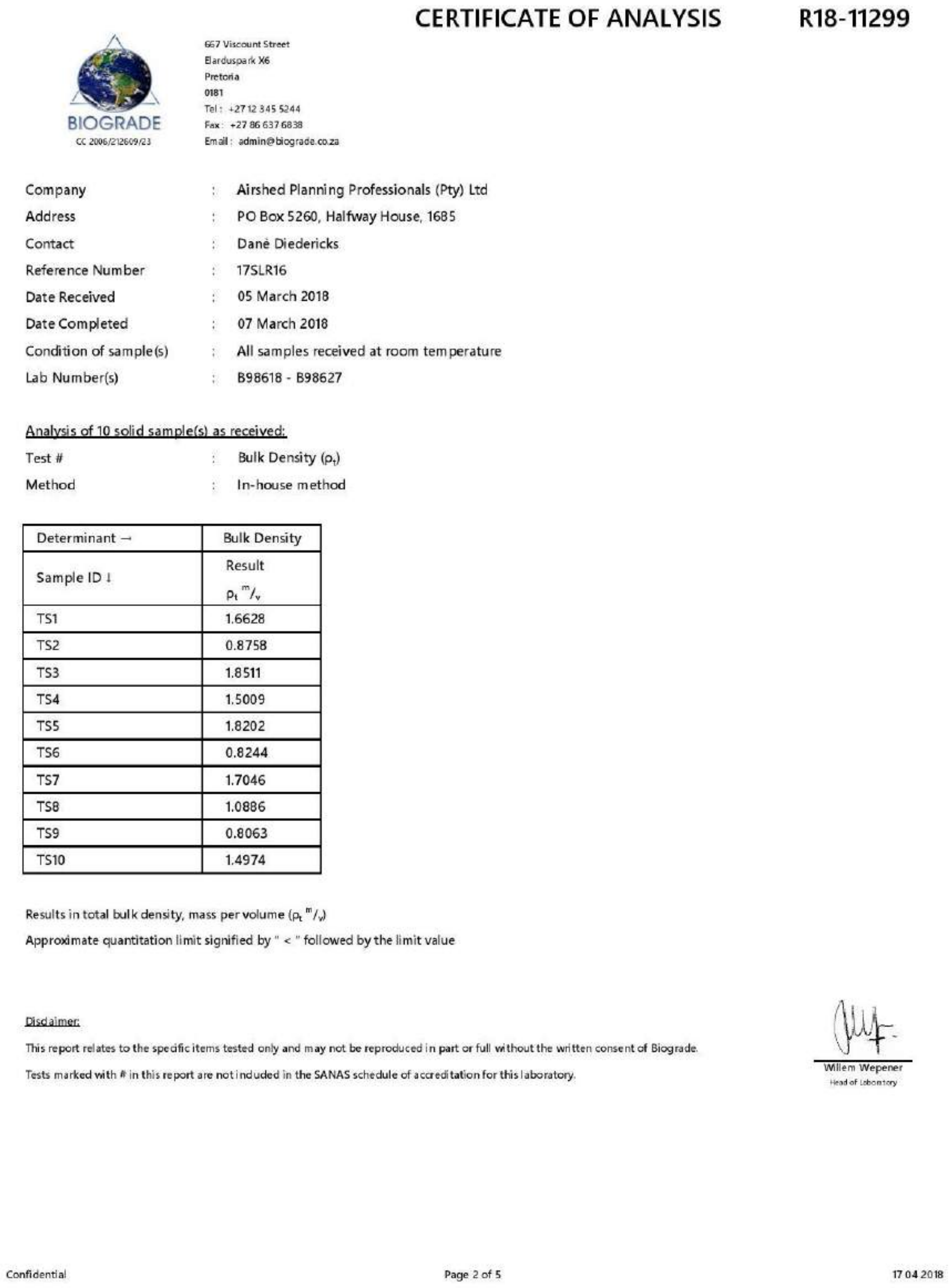

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Company : Airshed Planning Professionals (Pty) Ltd
Address : PO Box 5260, Halfway House, 1685
Contact : Danė Diedericks
Reference Number : 17SLR16
Date Received : 05 March 2018
Date Completed : 07 March 2018
Condition of sample(s) : All samples received at room temperature
Lab Number(s) : B98618 - B98627

Analysis of 10 solid sample(s) as received:

Test # : Bulk Density (ρ_t)
Method : In-house method

Determinant →	Bulk Density
Sample ID ↓	Result $\rho_t \, {}^{m}/_{v}$
TS1	1.6628
TS2	0.8758
TS3	1.8511
TS4	1.5009
TS5	1.8202
TS6	0.8244
TS7	1.7046
TS8	1.0886
TS9	0.8063
TS10	1.4974

Results in total bulk density, mass per volume ($\rho_t \, {}^{m}/_{v}$)

Approximate quantitation limit signified by " < " followed by the limit value

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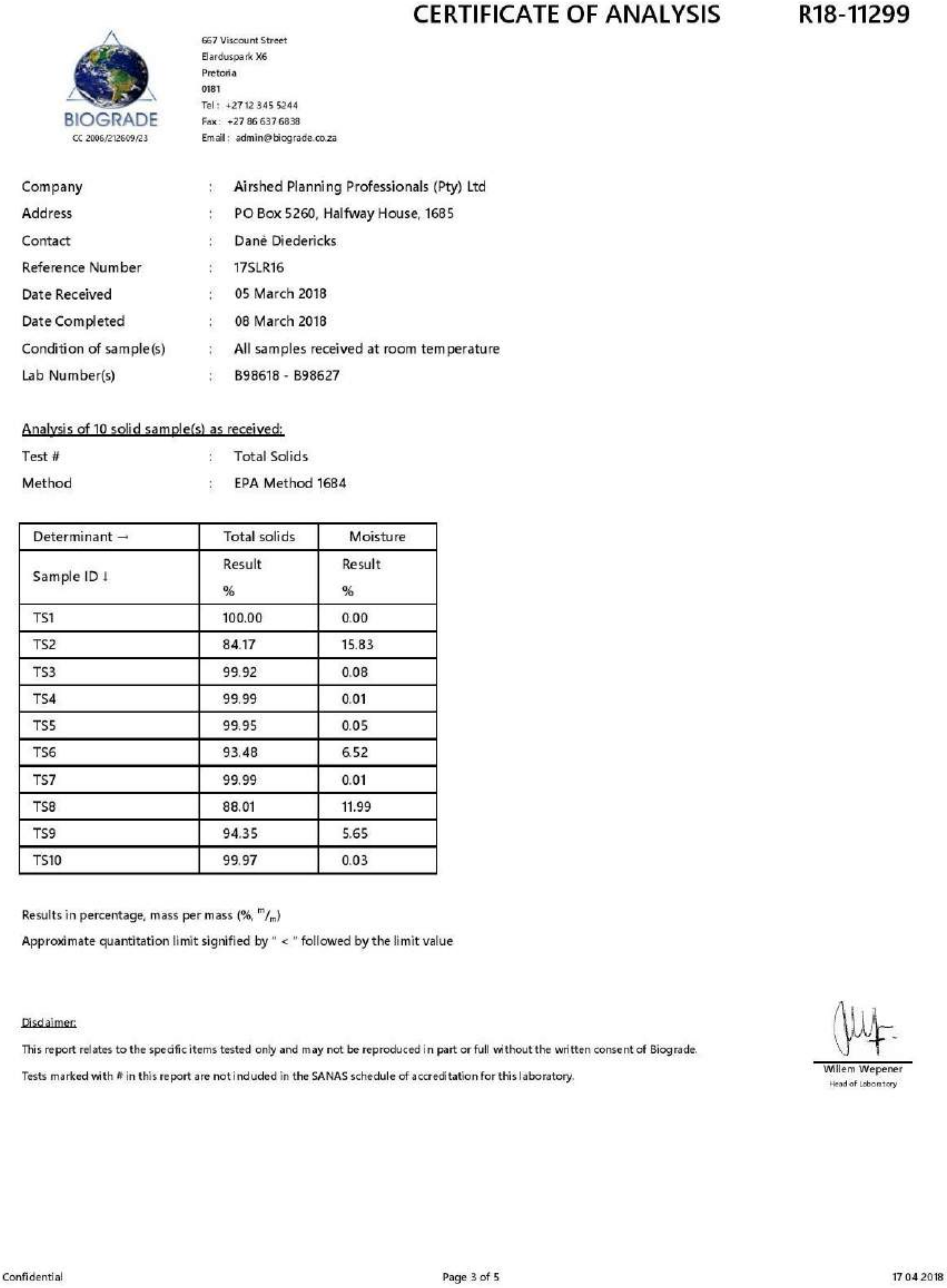

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Company	:	Airshed Planning Professionals (Pty) Ltd
Address	:	PO Box 5260, Halfway House, 1685
Contact	:	Danè Diedericks
Reference Number	:	17SLR16
Date Received	:	05 March 2018
Date Completed	:	08 March 2018
Condition of sample(s)	:	All samples received at room temperature
Lab Number(s)	:	B98618 - B98627

Analysis of 10 solid sample(s) as received:

Test # : Total Solids
Method : EPA Method 1684

Determinant →	Total solids	Moisture
Sample ID ↓	Result %	Result %
TS1	100.00	0.00
TS2	84.17	15.83
TS3	99.92	0.08
TS4	99.99	0.01
TS5	99.95	0.05
TS6	93.48	6.52
TS7	99.99	0.01
TS8	88.01	11.99
TS9	94.35	5.65
TS10	99.97	0.03

Results in percentage, mass per mass (%, $^{m}/_{m}$)

Approximate quantitation limit signified by " < " followed by the limit value

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Willem Wepener
Head of Laboratory

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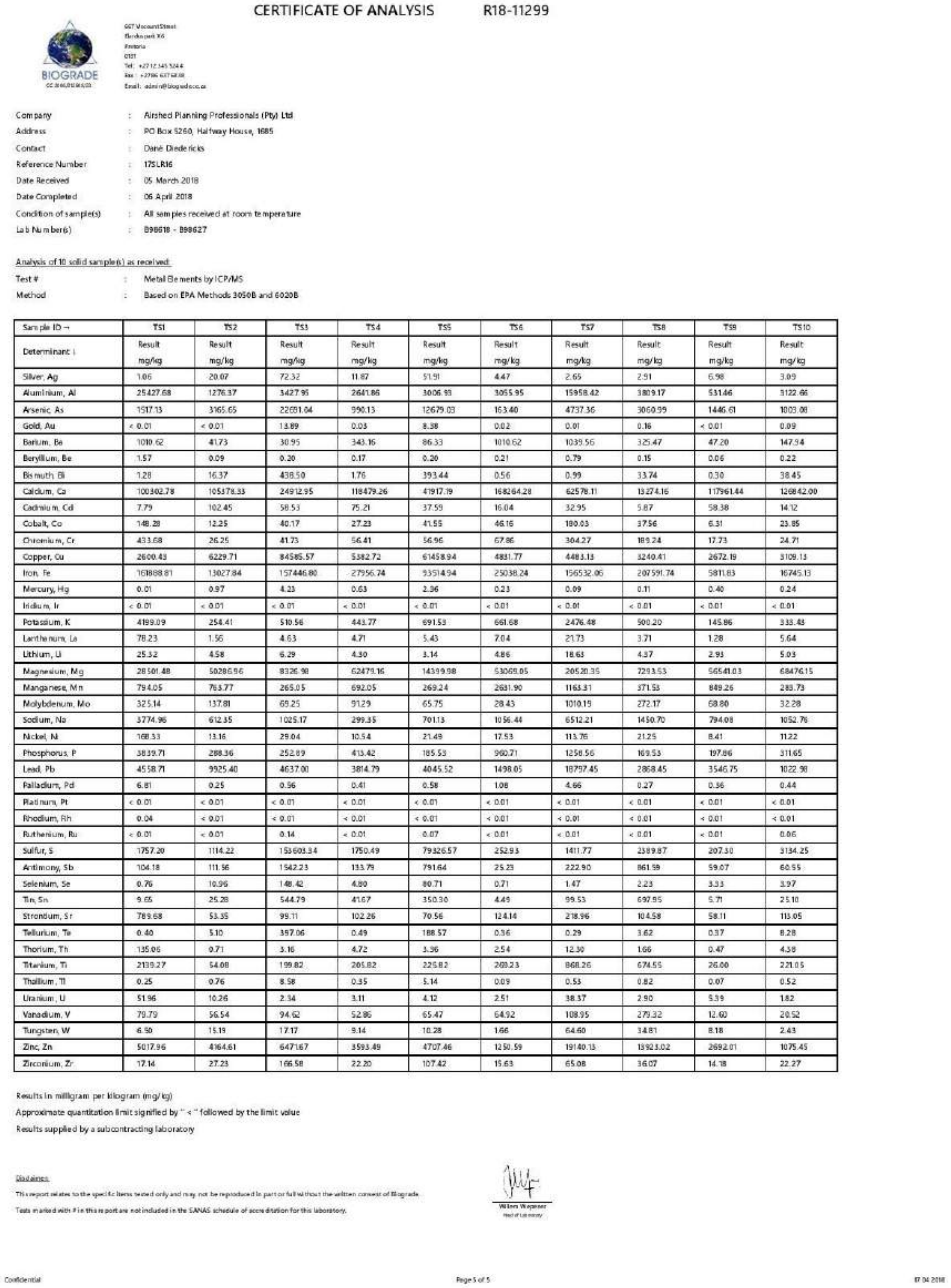

BIOGRADE

CERTIFICATE OF ANALYSIS R18-11299

Company : Airshed Planning Professionals (Pty) Ltd
Address : PO Box 5260, Halfway House, 1685
Contact : Dané Diedericks
Reference Number : 17SLR16
Date Received : 05 March 2018
Date Completed : 06 April 2018
Condition of sample(s) : All samples received at room temperature
Lab Number(s) : B98618 - B98627

Analysis of 10 solid sample(s) as received:

Test # : Metal Elements by ICP/MS
Method : Based on EPA Methods 3050B and 6020B

Sample ID →	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8	TS9	TS10
Determinant ↓	Result mg/kg	Result mg/kg	Result mg/kg	Result mg/kg	Result mg/kg	Result mg/kg	Result mg/kg	Result mg/kg	Result mg/kg	Result mg/kg
Silver, Ag	1.06	20.07	72.32	11.87	51.91	4.47	2.65	2.91	6.98	3.09
Aluminium, Al	25427.68	1276.37	3427.95	2641.86	3006.93	3055.95	15958.42	3809.17	531.46	3122.66
Arsenic, As	1517.13	3165.65	22681.04	990.13	12679.03	163.40	4737.36	3060.99	1446.61	1003.08
Gold, Au	< 0.01	< 0.01	13.89	0.03	8.38	0.02	0.01	0.16	< 0.01	0.09
Barium, Ba	1010.62	41.73	30.95	343.16	86.33	1010.62	1039.56	325.47	47.20	147.94
Beryllium, Be	1.57	0.09	0.20	0.17	0.20	0.21	0.79	0.15	0.06	0.22
Bismuth, Bi	1.28	16.37	438.50	1.76	393.44	0.56	0.99	33.74	0.30	38.45
Calcium, Ca	100302.78	105378.33	24912.95	118479.26	41917.19	168264.28	62578.11	13274.16	117961.44	126842.00
Cadmium, Cd	7.79	102.45	58.53	75.21	37.59	16.04	32.95	5.87	58.38	14.12
Cobalt, Co	148.28	12.25	40.17	27.23	41.55	46.16	180.03	37.56	6.31	23.85
Chromium, Cr	433.68	26.25	41.73	56.41	56.96	67.86	304.27	189.24	17.73	24.71
Copper, Cu	2600.43	6229.71	84585.57	5382.72	61458.94	4831.77	4483.13	3240.41	2672.19	3109.13
Iron, Fe	161888.81	13027.84	157446.80	27956.74	93514.94	25038.24	156532.06	207591.74	5811.83	16745.13
Mercury, Hg	0.01	0.97	4.23	0.63	2.36	0.23	0.09	0.11	0.40	0.24
Iridium, Ir	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Potassium, K	4199.09	254.41	510.56	443.77	691.53	661.68	2476.48	900.20	145.86	333.43
Lanthanum, La	78.23	1.56	4.63	4.71	5.43	7.04	21.73	3.71	1.28	5.64
Lithium, Li	25.32	4.58	6.29	4.30	3.14	4.86	18.63	4.37	2.93	5.03
Magnesium, Mg	28501.48	50286.96	8326.98	62479.16	14399.98	53069.05	20520.35	7293.53	56541.03	68476.15
Manganese, Mn	794.05	763.77	265.05	692.05	269.24	2631.90	1163.31	371.53	849.26	283.73
Molybdenum, Mo	325.14	137.81	69.25	91.29	65.75	28.43	1010.19	272.17	68.80	32.28
Sodium, Na	3774.96	612.35	1025.17	299.35	701.13	1056.44	6512.21	1450.70	794.08	1052.76
Nickel, Ni	168.33	13.16	29.04	10.54	21.49	17.53	113.76	21.25	8.41	11.22
Phosphorus, P	3839.71	288.36	252.89	413.42	185.53	960.71	1258.56	169.53	197.86	311.65
Lead, Pb	4558.71	9925.40	4637.00	3814.79	4045.52	1498.05	18797.45	2868.45	3546.75	1022.98
Palladium, Pd	6.81	0.25	0.56	0.41	0.58	1.08	4.66	0.27	0.36	0.44
Platinum, Pt	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Rhodium, Rh	0.04	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Ruthenium, Ru	< 0.01	< 0.01	0.14	< 0.01	0.07	< 0.01	< 0.01	< 0.01	< 0.01	0.06
Sulfur, S	1757.20	1114.22	153603.34	1750.49	79326.57	252.93	1411.77	2389.87	207.30	3134.25
Antimony, Sb	104.18	111.56	1542.23	133.79	791.64	25.23	222.90	861.59	59.07	60.55
Selenium, Se	0.76	10.96	148.42	4.80	80.71	0.71	1.47	2.23	3.33	3.97
Tin, Sn	9.65	25.28	544.79	41.67	350.30	4.49	99.53	697.95	5.71	25.10
Strontium, Sr	789.68	53.35	99.11	102.26	70.56	124.14	218.96	104.58	58.11	113.05
Tellurium, Te	0.40	5.10	397.06	0.49	188.57	0.36	0.29	3.62	0.37	8.28
Thorium, Th	135.06	0.71	3.16	4.72	3.36	2.54	12.30	1.66	0.47	4.38
Titanium, Ti	2139.27	54.08	199.82	205.82	225.82	269.23	868.26	674.55	26.00	221.05
Thallium, Tl	0.25	0.76	8.58	0.35	5.14	0.09	0.53	0.82	0.07	0.52
Uranium, U	51.96	10.26	2.34	3.11	4.12	2.51	38.37	2.90	5.39	1.82
Vanadium, V	79.79	56.54	94.62	52.86	65.47	64.92	108.95	279.32	12.60	20.52
Tungsten, W	6.50	15.19	17.17	9.14	10.28	1.66	64.60	34.81	8.18	2.43
Zinc, Zn	5017.96	4164.61	6471.67	3593.49	4707.46	1250.59	19140.13	13923.02	2692.01	1075.45
Zirconium, Zr	17.14	27.23	166.58	22.20	107.42	15.63	65.08	36.07	14.18	22.27

Results in milligram per kilogram (mg/kg)

Approximate quantitation limit signified by " < " followed by the limit value

Results supplied by a subcontracting laboratory

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Measurement Details

Sample Name Average of 'B98619'
SDS 3388
SOP File Name Default + 60us.msop

Measurement Details

Measurement Date Time 04/04/2018 15:04:29
Analysis Date Time 04/04/2018 15:04:29
Original Record Number 59

Analysis

Particle Name Default 1.0
Dispersant Name Water
Particle Absorption Index 1,000
Weighted Residual 0,43 %
Analysis Model General Purpose

Analysis

Particle Refractive Index 1,520
Dispersant Refractive Index 1,330
Laser Obscuration 7,59 %
Scattering Model Mie
Analysis Sensitivity Normal

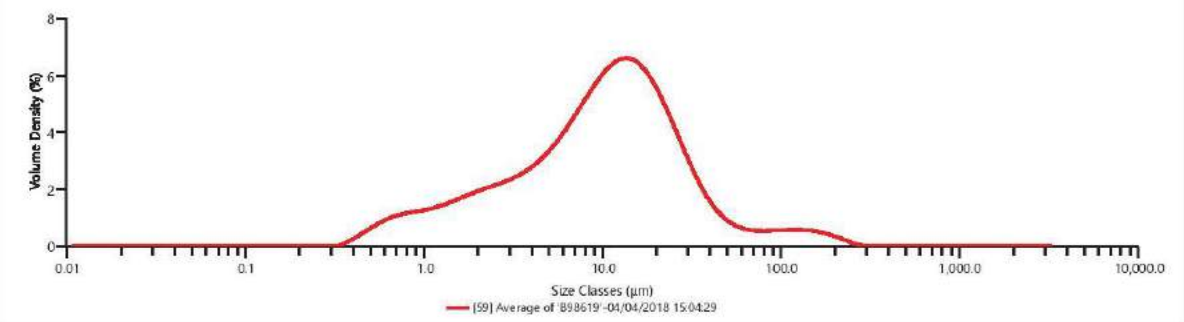
Result

Concentration 0,0039 %
Uniformity 1,204
Specific Surface Area 1348 m²/kg
D [3,2] 4,24 µm
D [4,3] 17,3 µm

Result

Span 2,940
Result Units Volume
Dv (10) 1,62 µm
Dv (50) 10,4 µm
Dv (90) 32,2 µm

Frequency (compatible)



Result

Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under
0,0100	0,00	0,0995	0,00	0,991	5,35	9,86	47,86	98,1	97,24	976	100,00
0,0114	0,00	0,113	0,00	1,13	6,42	11,2	53,06	111	97,71	1110	100,00
0,0129	0,00	0,128	0,00	1,28	7,57	12,7	58,51	127	98,19	1260	100,00
0,0147	0,00	0,146	0,00	1,45	8,82	14,5	64,05	144	98,66	1430	100,00
0,0167	0,00	0,166	0,00	1,65	10,20	16,4	69,50	163	99,10	1630	100,00
0,0189	0,00	0,188	0,00	1,88	11,71	18,7	74,65	186	99,48	1850	100,00
0,0215	0,00	0,214	0,00	2,13	13,32	21,2	79,32	211	99,76	2100	100,00
0,0244	0,00	0,243	0,00	2,42	15,03	24,1	83,39	240	99,94	2390	100,00
0,0278	0,00	0,276	0,00	2,75	16,84	27,4	86,77	272	100,00	2710	100,00
0,0315	0,00	0,314	0,00	3,12	18,75	31,1	89,46	310	100,00	3080	100,00
0,0358	0,00	0,357	0,00	3,55	20,80	35,3	91,50	352	100,00	3500	100,00
0,0407	0,00	0,405	0,14	4,03	23,02	40,1	93,00	400	100,00		
0,0463	0,00	0,460	0,44	4,58	25,46	45,6	94,07	454	100,00		
0,0526	0,00	0,523	0,94	5,21	28,18	51,8	94,84	516	100,00		
0,0597	0,00	0,594	1,62	5,92	31,24	58,9	95,42	586	100,00		
0,0679	0,00	0,675	2,44	6,72	34,71	66,9	95,91	666	100,00		
0,0771	0,00	0,767	3,35	7,64	38,64	76,0	96,35	756	100,00		
0,0876	0,00	0,872	4,33	8,68	43,03	86,4	96,79	859	100,00		

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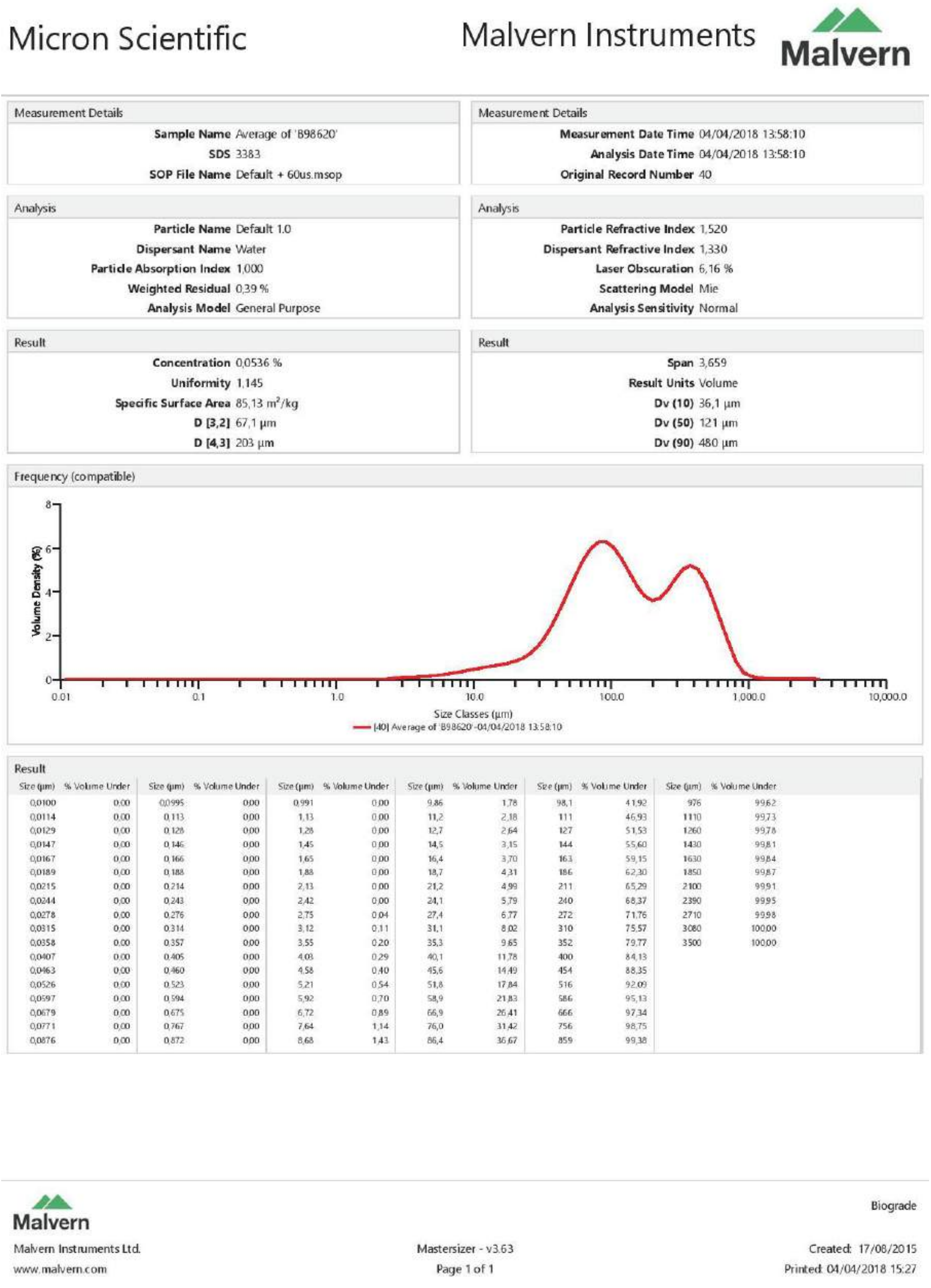

Micron Scientific

Malvern Instruments

Measurement Details	
Sample Name	Average of 'B98620'
SDS	3383
SOP File Name	Default + 60us.msop

Measurement Details	
Measurement Date Time	04/04/2018 13:58:10
Analysis Date Time	04/04/2018 13:58:10
Original Record Number	40

Analysis	
Particle Name	Default 1.0
Dispersant Name	Water
Particle Absorption Index	1,000
Weighted Residual	0,39 %
Analysis Model	General Purpose

Analysis	
Particle Refractive Index	1,520
Dispersant Refractive Index	1,330
Laser Obscuration	6,16 %
Scattering Model	Mie
Analysis Sensitivity	Normal

Result	
Concentration	0,0536 %
Uniformity	1,145
Specific Surface Area	85,13 m^2/kg
D [3,2]	67,1 µm
D [4,3]	203 µm

Result	
Span	3,659
Result Units	Volume
Dv (10)	36,1 µm
Dv (50)	121 µm
Dv (90)	480 µm

Frequency (compatible)

Result

Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under
0,0100	0,00	0,0995	0,00	0,991	0,00	9,86	1,78	98,1	41,92	976	99,62
0,0114	0,00	0,113	0,00	1,13	0,00	11,2	2,18	111	46,93	1110	99,73
0,0129	0,00	0,128	0,00	1,28	0,00	12,7	2,64	127	51,53	1260	99,78
0,0147	0,00	0,146	0,00	1,45	0,00	14,5	3,15	144	55,60	1430	99,81
0,0167	0,00	0,166	0,00	1,65	0,00	16,4	3,70	163	59,15	1630	99,84
0,0189	0,00	0,188	0,00	1,88	0,00	18,7	4,31	186	62,30	1850	99,87
0,0215	0,00	0,214	0,00	2,13	0,00	21,2	4,99	211	65,29	2100	99,91
0,0244	0,00	0,243	0,00	2,42	0,00	24,1	5,79	240	68,37	2390	99,95
0,0278	0,00	0,276	0,00	2,75	0,04	27,4	6,77	272	71,76	2710	99,98
0,0315	0,00	0,314	0,00	3,12	0,11	31,1	8,02	310	75,57	3080	100,00
0,0358	0,00	0,357	0,00	3,55	0,20	35,3	9,65	352	79,77	3500	100,00
0,0407	0,00	0,405	0,00	4,03	0,29	40,1	11,78	400	84,13		
0,0463	0,00	0,460	0,00	4,58	0,40	45,6	14,49	454	88,35		
0,0526	0,00	0,523	0,00	5,21	0,54	51,8	17,84	516	92,09		
0,0597	0,00	0,594	0,00	5,92	0,70	58,9	21,83	586	95,13		
0,0679	0,00	0,675	0,00	6,72	0,89	66,9	26,41	666	97,34		
0,0771	0,00	0,767	0,00	7,64	1,14	76,0	31,42	756	98,75		
0,0876	0,00	0,872	0,00	8,68	1,43	86,4	36,67	859	99,38		

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Measurement Details

Sample Name Average of 'B98621'
SDS 3384
SOP File Name Default + 60us.msop

Measurement Details

Measurement Date Time 04/04/2018 14:08:47
Analysis Date Time 04/04/2018 14:08:47
Original Record Number 44

Analysis

Particle Name Default 1.0
Dispersant Name Water
Particle Absorption Index 1,000
Weighted Residual 1,27 %
Analysis Model General Purpose

Analysis

Particle Refractive Index 1,520
Dispersant Refractive Index 1,330
Laser Obscuration 1,19 %
Scattering Model Mie
Analysis Sensitivity Normal

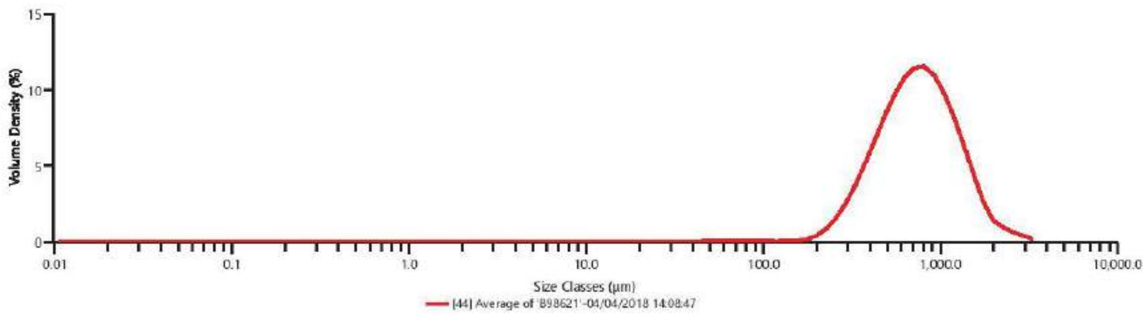
Result

Concentration 0,1003 %
Uniformity 0.440
Specific Surface Area 9,123 m²/kg
D [3,2] 626 µm
D [4,3] 834 µm

Result

Span 1,382
Result Units Volume
Dv (10) 374 µm
Dv (50) 742 µm
Dv (90) 1400 µm

Frequency (compatible)



Result

Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under
0,0100	0,00	0,0995	0,00	0,991	0,00	9,86	0,00	98,1	0,40	976	70,36
0,0114	0,00	0,113	0,00	1,13	0,00	11,2	0,00	111	0,43	1110	78,64
0,0129	0,00	0,128	0,00	1,28	0,00	12,7	0,00	127	0,45	1260	85,58
0,0147	0,00	0,146	0,00	1,45	0,00	14,5	0,00	144	0,47	1430	90,99
0,0167	0,00	0,166	0,00	1,65	0,00	16,4	0,00	163	0,51	1630	94,81
0,0189	0,00	0,188	0,00	1,88	0,00	18,7	0,00	186	0,62	1850	97,02
0,0215	0,00	0,214	0,00	2,13	0,00	21,2	0,00	211	0,92	2100	98,16
0,0244	0,00	0,243	0,00	2,42	0,00	24,1	0,00	240	1,59	2390	98,96
0,0278	0,00	0,276	0,00	2,75	0,00	27,4	0,00	272	2,84	2710	99,50
0,0315	0,00	0,314	0,00	3,12	0,00	31,1	0,00	310	4,89	3080	99,84
0,0358	0,00	0,357	0,00	3,55	0,00	35,3	0,00	352	7,97	3500	100,00
0,0407	0,00	0,405	0,00	4,03	0,00	40,1	0,00	400	12,24		
0,0463	0,00	0,460	0,00	4,58	0,00	45,6	0,00	454	17,82		
0,0526	0,00	0,523	0,00	5,21	0,00	51,8	0,04	516	24,72		
0,0597	0,00	0,594	0,00	5,92	0,00	58,9	0,10	586	32,81		
0,0679	0,00	0,675	0,00	6,72	0,00	66,9	0,17	666	41,85		
0,0771	0,00	0,767	0,00	7,64	0,00	76,0	0,25	756	51,45		
0,0876	0,00	0,872	0,00	8,68	0,00	86,4	0,33	859	61,13		

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Measurement Details

Sample Name Average of 'B98622'
SDS 3387
SOP File Name Default + 60us.msop

Measurement Details

Measurement Date Time 04/04/2018 14:40:41
Analysis Date Time 04/04/2018 14:40:41
Original Record Number 55

Analysis

Particle Name Default 1.0
Dispersant Name Water
Particle Absorption Index 1,000
Weighted Residual 0,43 %
Analysis Model General Purpose

Analysis

Particle Refractive Index 1,520
Dispersant Refractive Index 1,330
Laser Obscuration 5,84 %
Scattering Model Mie
Analysis Sensitivity Normal

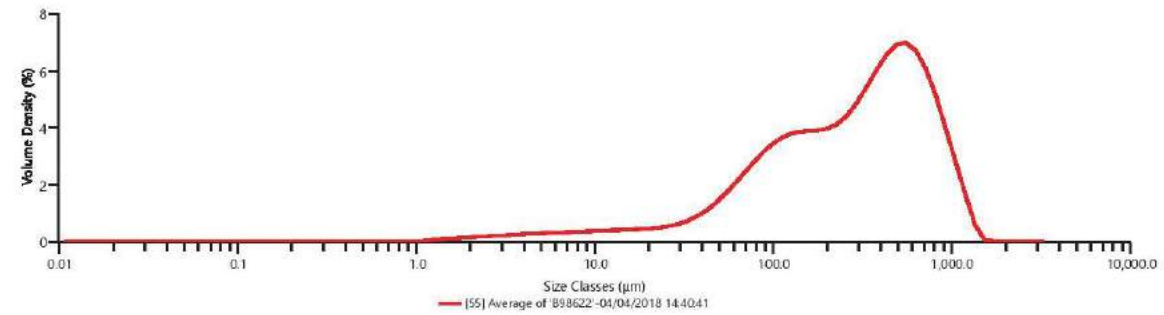
Result

Concentration 0,0475 %
Uniformity 0,790
Specific Surface Area 88,50 m²/kg
D [3,2] 64,6 μm
D [4,3] 369 μm

Result

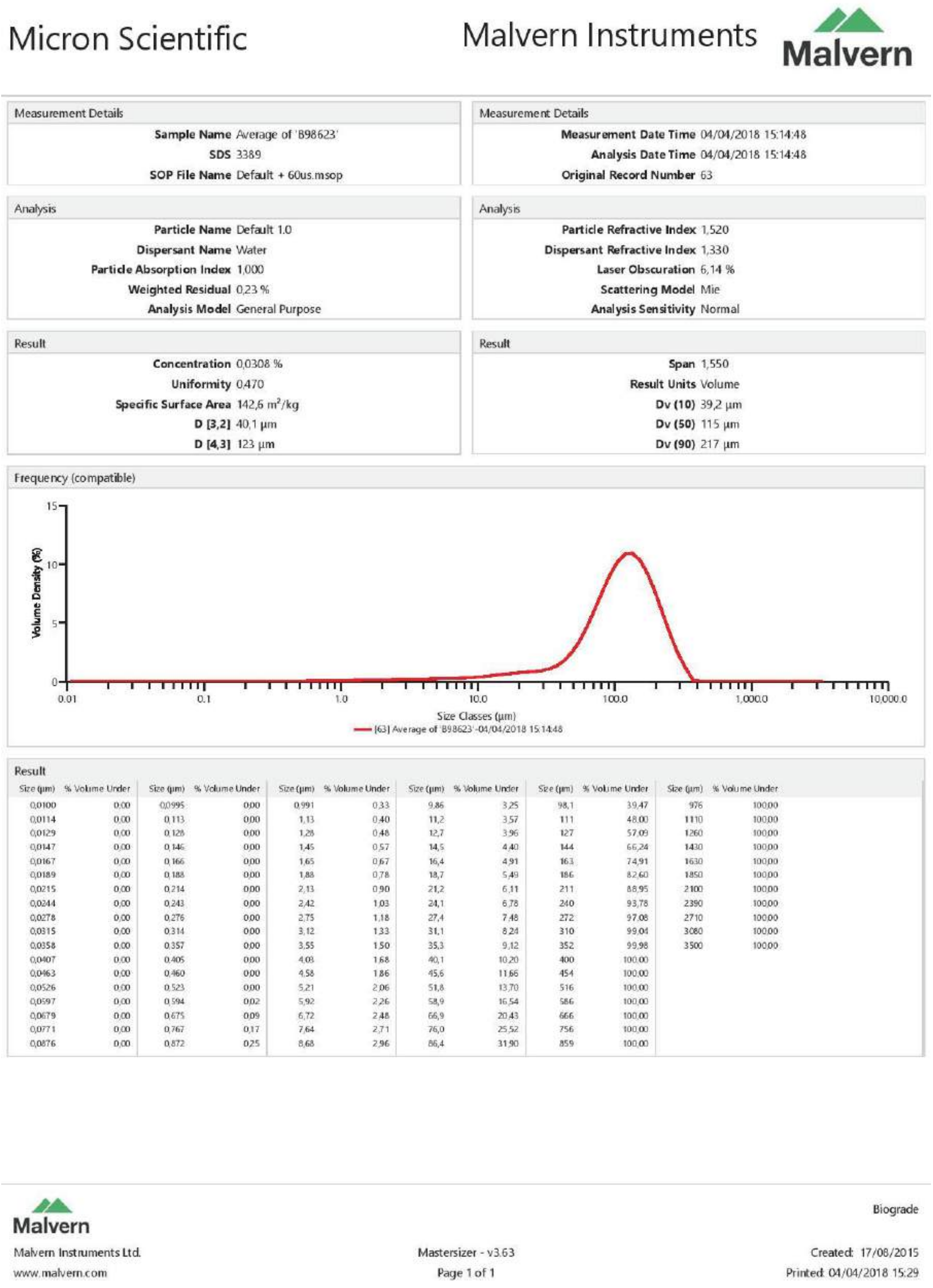
Span 2,477
Result Units Volume
Dv (10) 51,8 μm
Dv (50) 303 μm
Dv (90) 801 μm

Frequency (compatible)



Result

Size (μm)	% Volume Under	Size (μm)	% Volume Under	Size (μm)	% Volume Under	Size (μm)	% Volume Under	Size (μm)	% Volume Under	Size (μm)	% Volume Under
0,0100	0,00	0,0995	0,00	0,991	0,00	9,86	3,14	98,1	20,52	976	95,74
0,0114	0,00	0,113	0,00	1,13	0,00	11,2	3,46	111	23,49	1110	98,13
0,0129	0,00	0,128	0,00	1,28	0,04	12,7	3,78	127	26,61	1260	99,54
0,0147	0,00	0,146	0,00	1,45	0,11	14,5	4,11	144	29,82	1430	100,00
0,0167	0,00	0,166	0,00	1,65	0,20	16,4	4,46	163	33,06	1630	100,00
0,0189	0,00	0,188	0,00	1,88	0,31	18,7	4,82	186	36,31	1850	100,00
0,0215	0,00	0,214	0,00	2,13	0,43	21,2	5,19	211	39,61	2100	100,00
0,0244	0,00	0,243	0,00	2,42	0,57	24,1	5,59	240	43,03	2390	100,00
0,0278	0,00	0,276	0,00	2,75	0,73	27,4	6,03	272	46,69	2710	100,00
0,0315	0,00	0,314	0,00	3,12	0,91	31,1	6,54	310	50,72	3080	100,00
0,0358	0,00	0,357	0,00	3,55	1,10	35,3	7,14	352	55,21	3500	100,00
0,0407	0,00	0,405	0,00	4,03	1,31	40,1	7,89	400	60,21		
0,0463	0,00	0,460	0,00	4,58	1,53	45,6	8,82	454	65,68		
0,0526	0,00	0,523	0,00	5,21	1,76	51,8	10,00	516	71,46		
0,0597	0,00	0,594	0,00	5,92	2,01	58,9	11,46	586	77,31		
0,0679	0,00	0,675	0,00	6,72	2,28	66,9	13,24	666	82,94		
0,0771	0,00	0,767	0,00	7,64	2,55	76,0	15,35	756	88,05		
0,0876	0,00	0,872	0,00	8,68	2,84	86,4	17,79	859	92,37		



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Measurement Details

Sample Name	Average of 'B98623'
SDS	3389
SOP File Name	Default + 60us.msop

Measurement Details

Measurement Date Time	04/04/2018 15:14:48
Analysis Date Time	04/04/2018 15:14:48
Original Record Number	63

Analysis

Particle Name	Default 1.0
Dispersant Name	Water
Particle Absorption Index	1,000
Weighted Residual	0,23 %
Analysis Model	General Purpose

Analysis

Particle Refractive Index	1,520
Dispersant Refractive Index	1,330
Laser Obscuration	6,14 %
Scattering Model	Mie
Analysis Sensitivity	Normal

Result

Concentration	0,0308 %
Uniformity	0,470
Specific Surface Area	142,6 m²/kg
D [3,2]	40,1 µm
D [4,3]	123 µm

Result

Span	1,550
Result Units	Volume
Dv (10)	39,2 µm
Dv (50)	115 µm
Dv (90)	217 µm

Frequency (compatible)

Result

Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under
0,0100	0,00	0,0995	0,00	0,991	0,33	9,86	3,25	98,1	39,47	976	100,00
0,0114	0,00	0,113	0,00	1,13	0,40	11,2	3,57	111	48,00	1110	100,00
0,0129	0,00	0,128	0,00	1,28	0,48	12,7	3,96	127	57,09	1260	100,00
0,0147	0,00	0,146	0,00	1,45	0,57	14,5	4,40	144	66,24	1430	100,00
0,0167	0,00	0,166	0,00	1,65	0,67	16,4	4,91	163	74,91	1630	100,00
0,0189	0,00	0,188	0,00	1,88	0,78	18,7	5,49	186	82,60	1850	100,00
0,0215	0,00	0,214	0,00	2,13	0,90	21,2	6,11	211	88,95	2100	100,00
0,0244	0,00	0,243	0,00	2,42	1,03	24,1	6,78	240	93,78	2390	100,00
0,0278	0,00	0,276	0,00	2,75	1,18	27,4	7,48	272	97,08	2710	100,00
0,0315	0,00	0,314	0,00	3,12	1,33	31,1	8,24	310	99,04	3080	100,00
0,0358	0,00	0,357	0,00	3,55	1,50	35,3	9,12	352	99,98	3500	100,00
0,0407	0,00	0,405	0,00	4,08	1,68	40,1	10,20	400	100,00		
0,0463	0,00	0,460	0,00	4,58	1,86	45,6	11,66	454	100,00		
0,0526	0,00	0,523	0,00	5,21	2,06	51,8	13,70	516	100,00		
0,0597	0,00	0,594	0,02	5,92	2,26	58,9	16,54	586	100,00		
0,0679	0,00	0,675	0,09	6,72	2,48	66,9	20,43	666	100,00		
0,0771	0,00	0,767	0,17	7,64	2,71	76,0	25,52	756	100,00		
0,0876	0,00	0,872	0,25	8,68	2,96	86,4	31,90	859	100,00		

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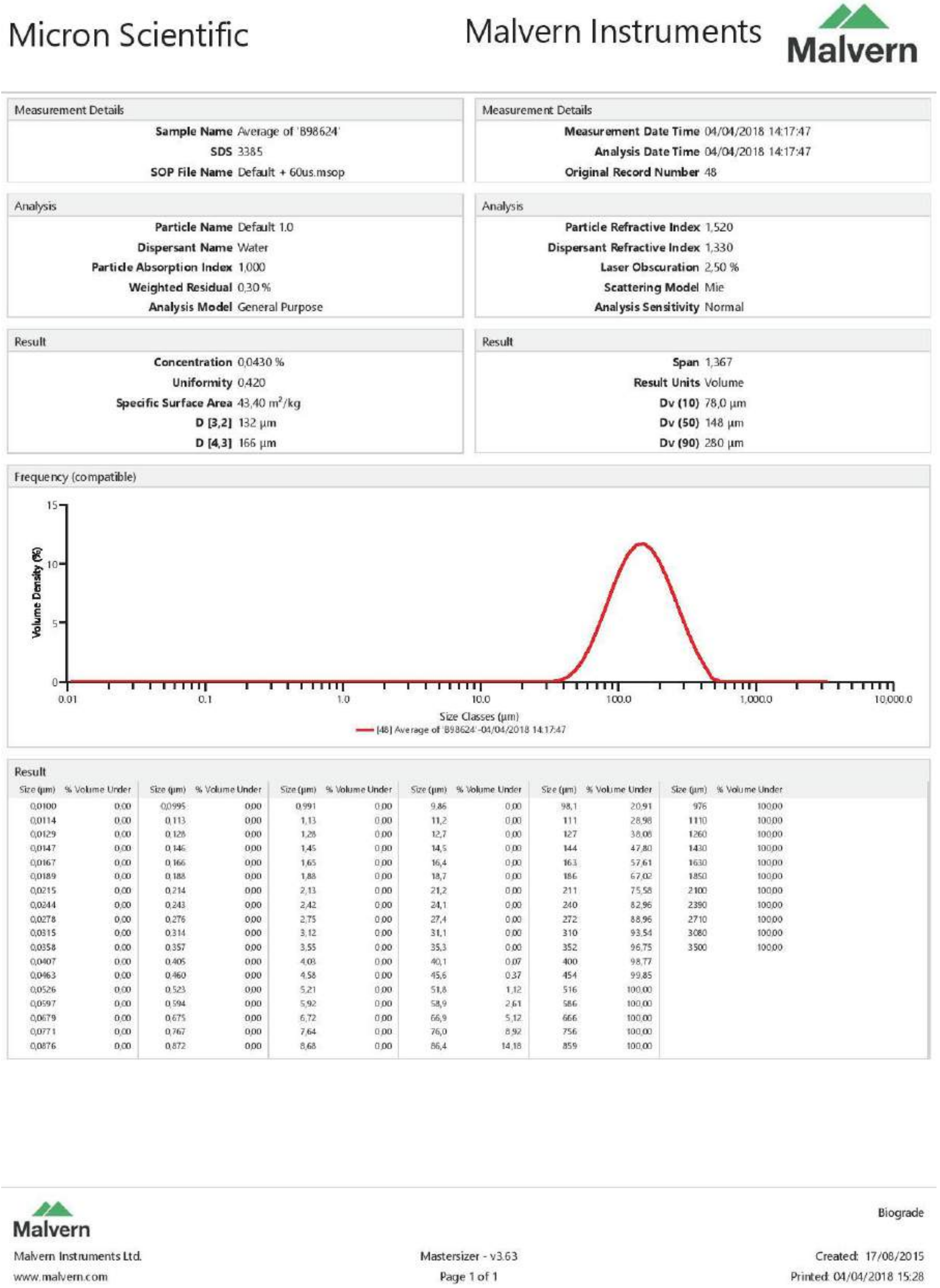

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Measurement Details

Sample Name Average of 'B98624'
SDS 3385
SOP File Name Default + 60us.msop

Measurement Details

Measurement Date Time 04/04/2018 14:17:47
Analysis Date Time 04/04/2018 14:17:47
Original Record Number 48

Analysis

Particle Name Default 1.0
Dispersant Name Water
Particle Absorption Index 1,000
Weighted Residual 0,30 %
Analysis Model General Purpose

Analysis

Particle Refractive Index 1,520
Dispersant Refractive Index 1,330
Laser Obscuration 2,50 %
Scattering Model Mie
Analysis Sensitivity Normal

Result

Concentration 0,0430 %
Uniformity 0,420
Specific Surface Area 43,40 m²/kg
D [3,2] 132 µm
D [4,3] 166 µm

Result

Span 1,367
Result Units Volume
Dv (10) 78,0 µm
Dv (50) 148 µm
Dv (90) 280 µm

Frequency (compatible)

Result

Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under
0,0100	0,00	0,0995	0,00	0,991	0,00	9.86	0,00	98,1	20,91	976	100,00
0,0114	0,00	0,113	0,00	1,13	0,00	11,2	0,00	111	28,98	1110	100,00
0,0129	0,00	0,128	0,00	1,28	0,00	12,7	0,00	127	38,08	1260	100,00
0,0147	0,00	0,146	0,00	1,45	0,00	14,5	0,00	144	47,80	1430	100,00
0,0167	0,00	0,166	0,00	1,65	0,00	16,4	0,00	163	57,61	1630	100,00
0,0189	0,00	0,188	0,00	1,88	0,00	18,7	0,00	186	67,02	1850	100,00
0,0215	0,00	0,214	0,00	2,13	0,00	21,2	0,00	211	75,58	2100	100,00
0,0244	0,00	0,243	0,00	2,42	0,00	24,1	0,00	240	82,96	2390	100,00
0,0278	0,00	0,276	0,00	2,75	0,00	27,4	0,00	272	88,96	2710	100,00
0,0315	0,00	0,314	0,00	3,12	0,00	31,1	0,00	310	93,54	3080	100,00
0,0358	0,00	0,357	0,00	3,55	0,00	35,3	0,00	352	96,75	3500	100,00
0,0407	0,00	0,405	0,00	4,03	0,00	40,1	0,07	400	98,77		
0,0463	0,00	0,460	0,00	4,58	0,00	45,6	0,37	454	99,85		
0,0526	0,00	0,523	0,00	5,21	0,00	51,8	1,12	516	100,00		
0,0597	0,00	0,594	0,00	5,92	0,00	58,9	2,61	586	100,00		
0,0679	0,00	0,675	0,00	6,72	0,00	66,9	5,12	666	100,00		
0,0771	0,00	0,767	0,00	7,64	0,00	76,0	8,92	756	100,00		
0,0876	0,00	0,872	0,00	8,68	0,00	86,4	14,18	859	100,00		

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Measurement Details

Sample Name Average of 'B98625'
SDS 3390
SOP File Name Default + 60us.msop

Measurement Details

Measurement Date Time 04/04/2018 15:24:47
Analysis Date Time 04/04/2018 15:24:47
Original Record Number 67

Analysis

Particle Name Default 1.0
Dispersant Name Water
Particle Absorption Index 1,000
Weighted Residual 0,39 %
Analysis Model General Purpose

Analysis

Particle Refractive Index 1,520
Dispersant Refractive Index 1,330
Laser Obscuration 12,90 %
Scattering Model Mie
Analysis Sensitivity Normal

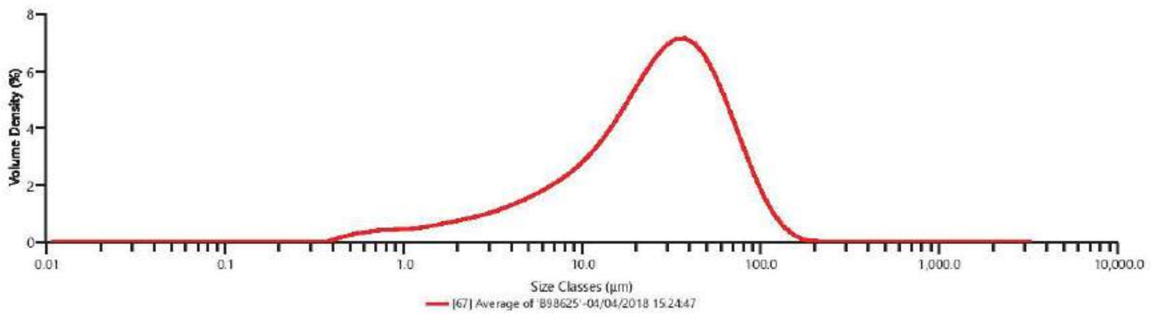
Result

Concentration 0,0151 %
Uniformity 0,750
Specific Surface Area 619,2 m²/kg
D [3,2] 9,23 µm
D [4,3] 32,8 µm

Result

Span 2,415
Result Units Volume
Dv (10) 4,53 µm
Dv (50) 26,7 µm
Dv (90) 69,1 µm

Frequency (compatible)



Result

Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under
0,0100	0,00	0,0995	0,00	0,991	1,89	9,86	20,20	98,1	97,23	976	100,00
0,0114	0,00	0,113	0,00	1,13	2,26	11,2	22,64	111	98,54	1110	100,00
0,0129	0,00	0,128	0,00	1,28	2,66	12,7	25,40	127	99,33	1260	100,00
0,0147	0,00	0,146	0,00	1,45	3,11	14,5	28,53	144	99,75	1430	100,00
0,0167	0,00	0,166	0,00	1,65	3,61	16,4	32,08	163	99,94	1630	100,00
0,0189	0,00	0,188	0,00	1,88	4,17	18,7	36,11	186	99,98	1850	100,00
0,0215	0,00	0,214	0,00	2,13	4,78	21,2	40,61	211	100,00	2100	100,00
0,0244	0,00	0,243	0,00	2,42	5,46	24,1	45,60	240	100,00	2390	100,00
0,0278	0,00	0,276	0,00	2,75	6,20	27,4	51,01	272	100,00	2710	100,00
0,0315	0,00	0,314	0,00	3,12	7,02	31,1	56,76	310	100,00	3080	100,00
0,0358	0,00	0,357	0,00	3,55	7,93	35,3	62,71	352	100,00	3500	100,00
0,0407	0,00	0,405	0,00	4,03	8,96	40,1	68,69	400	100,00		
0,0463	0,00	0,460	0,12	4,58	10,10	45,6	74,51	454	100,00		
0,0526	0,00	0,523	0,30	5,21	11,37	51,8	79,97	516	100,00		
0,0597	0,00	0,594	0,56	5,92	12,78	58,9	84,89	586	100,00		
0,0679	0,00	0,675	0,85	6,72	14,35	66,9	89,13	666	100,00		
0,0771	0,00	0,767	1,18	7,64	16,10	76,0	92,60	756	100,00		
0,0876	0,00	0,872	1,53	8,68	18,03	86,4	95,29	859	100,00		

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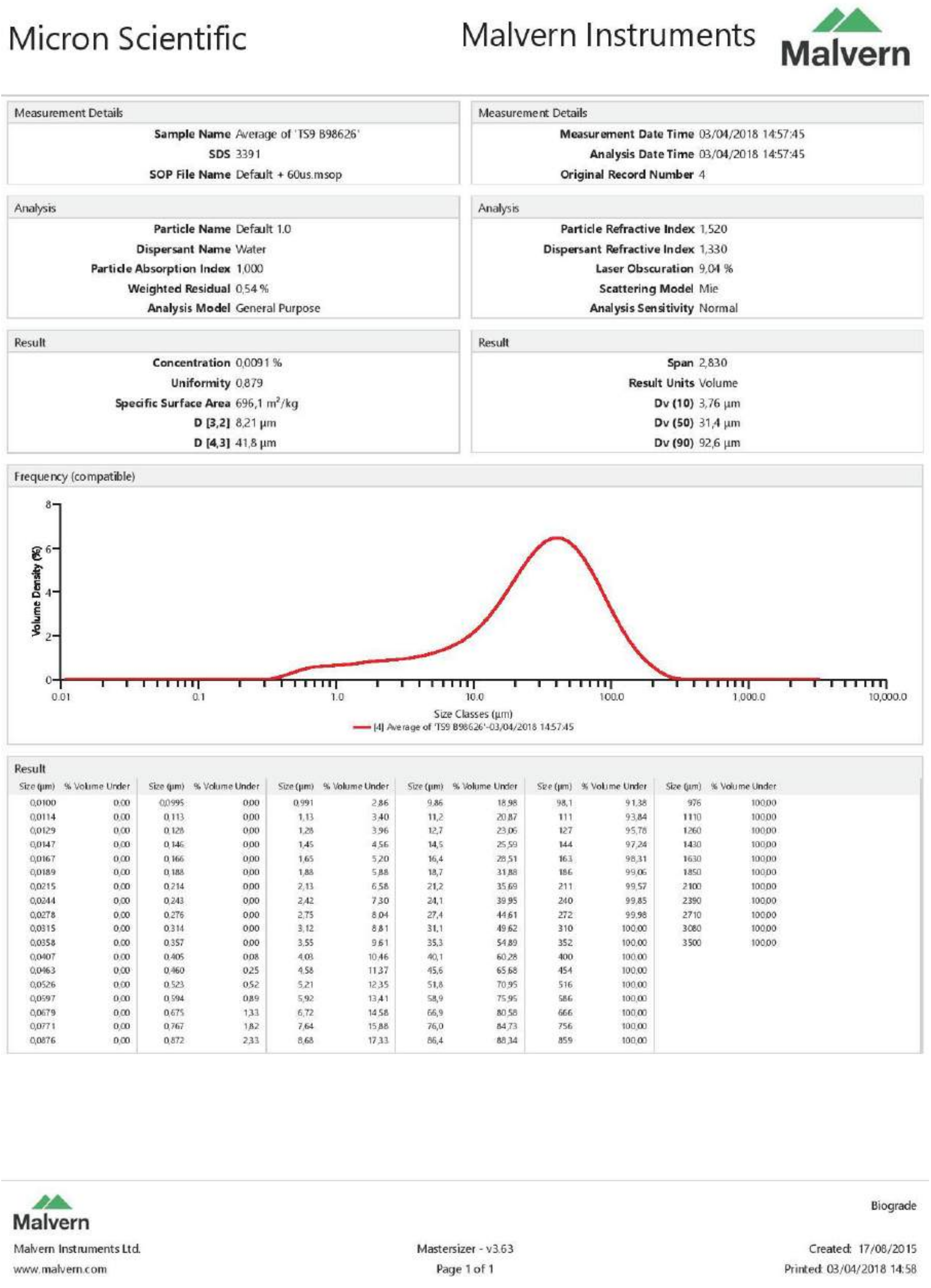

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Measurement Details

Sample Name Average of 'TS9 B98626'
SDS 3391
SOP File Name Default + 60us.msop

Measurement Details

Measurement Date Time 03/04/2018 14:57:45
Analysis Date Time 03/04/2018 14:57:45
Original Record Number 4

Analysis

Particle Name Default 1.0
Dispersant Name Water
Particle Absorption Index 1,000
Weighted Residual 0,54 %
Analysis Model General Purpose

Analysis

Particle Refractive Index 1,520
Dispersant Refractive Index 1,330
Laser Obscuration 9,04 %
Scattering Model Mie
Analysis Sensitivity Normal

Result

Concentration 0,0091 %
Uniformity 0,879
Specific Surface Area 696,1 m²/kg
D [3,2] 8,21 µm
D [4,3] 41,8 µm

Result

Span 2,830
Result Units Volume
Dv (10) 3,76 µm
Dv (50) 31,4 µm
Dv (90) 92,6 µm

Frequency (compatible)

Result

Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under
0,0100	0,00	0,0995	0,00	0,991	2,86	9,86	18,98	98,1	91,38	976	100,00
0,0114	0,00	0,113	0,00	1,13	3,40	11,2	20,87	111	93,84	1110	100,00
0,0129	0,00	0,128	0,00	1,28	3,96	12,7	23,06	127	95,78	1260	100,00
0,0147	0,00	0,146	0,00	1,45	4,56	14,5	25,59	144	97,24	1430	100,00
0,0167	0,00	0,166	0,00	1,65	5,20	16,4	28,51	163	98,31	1630	100,00
0,0189	0,00	0,188	0,00	1,88	5,88	18,7	31,88	186	99,06	1850	100,00
0,0215	0,00	0,214	0,00	2,13	6,58	21,2	35,69	211	99,57	2100	100,00
0,0244	0,00	0,243	0,00	2,42	7,30	24,1	39,95	240	99,85	2390	100,00
0,0278	0,00	0,276	0,00	2,75	8,04	27,4	44,61	272	99,98	2710	100,00
0,0315	0,00	0,314	0,00	3,12	8,81	31,1	49,62	310	100,00	3080	100,00
0,0358	0,00	0,357	0,00	3,55	9,61	35,3	54,89	352	100,00	3500	100,00
0,0407	0,00	0,405	0,08	4,03	10,46	40,1	60,28	400	100,00		
0,0463	0,00	0,460	0,25	4,58	11,37	45,6	65,68	454	100,00		
0,0526	0,00	0,523	0,52	5,21	12,35	51,8	70,95	516	100,00		
0,0597	0,00	0,594	0,89	5,92	13,41	58,9	75,95	586	100,00		
0,0679	0,00	0,675	1,33	6,72	14,58	66,9	80,58	666	100,00		
0,0771	0,00	0,767	1,82	7,64	15,88	76,0	84,73	756	100,00		
0,0876	0,00	0,872	2,33	8,68	17,33	86,4	88,34	859	100,00		

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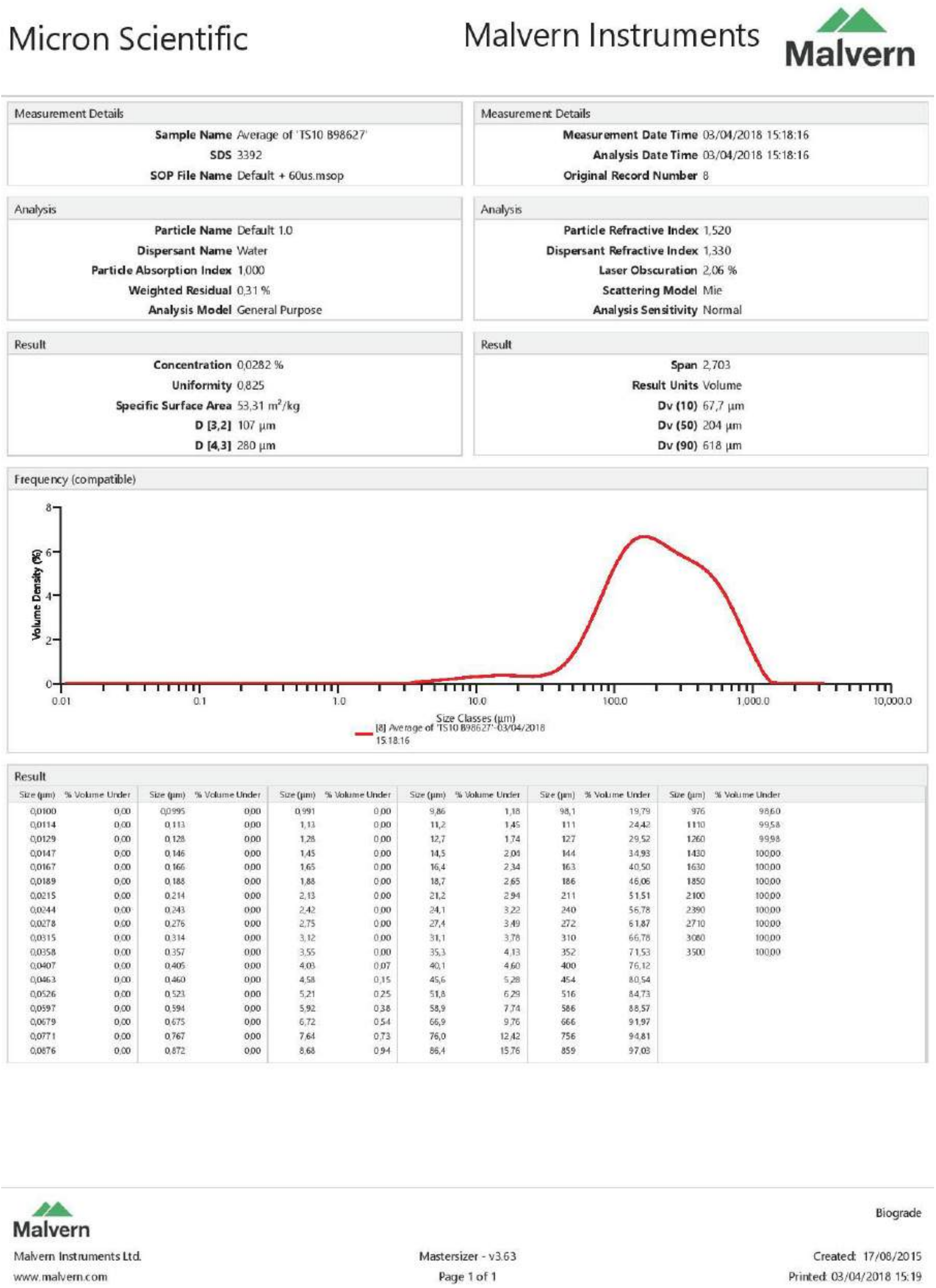

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Measurement Details

Sample Name Average of 'TS10 B98627'
SDS 3392
SOP File Name Default + 60us.msop

Measurement Details

Measurement Date Time 03/04/2018 15:18:16
Analysis Date Time 03/04/2018 15:18:16
Original Record Number 8

Analysis

Particle Name Default 1.0
Dispersant Name Water
Particle Absorption Index 1,000
Weighted Residual 0,31 %
Analysis Model General Purpose

Analysis

Particle Refractive Index 1,520
Dispersant Refractive Index 1,330
Laser Obscuration 2,06 %
Scattering Model Mie
Analysis Sensitivity Normal

Result

Concentration 0,0282 %
Uniformity 0,825
Specific Surface Area 53,31 m²/kg
D [3,2] 107 µm
D [4,3] 280 µm

Result

Span 2,703
Result Units Volume
Dv (10) 67,7 µm
Dv (50) 204 µm
Dv (90) 618 µm

Frequency (compatible)

Result

Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under	Size (µm)	% Volume Under
0,0100	0,00	0,0995	0,00	0,991	0,00	9,86	1,18	98,1	19,79	976	98,60
0,0114	0,00	0,113	0,00	1,13	0,00	11,2	1,45	111	24,42	1110	99,58
0,0129	0,00	0,128	0,00	1,28	0,00	12,7	1,74	127	29,52	1260	99,98
0,0147	0,00	0,146	0,00	1,45	0,00	14,5	2,04	144	34,93	1430	100,00
0,0167	0,00	0,166	0,00	1,65	0,00	16,4	2,34	163	40,50	1630	100,00
0,0189	0,00	0,188	0,00	1,88	0,00	18,7	2,65	186	46,06	1850	100,00
0,0215	0,00	0,214	0,00	2,13	0,00	21,2	2,94	211	51,51	2100	100,00
0,0244	0,00	0,243	0,00	2,42	0,00	24,1	3,22	240	56,78	2390	100,00
0,0278	0,00	0,276	0,00	2,75	0,00	27,4	3,49	272	61,87	2710	100,00
0,0315	0,00	0,314	0,00	3,12	0,00	31,1	3,78	310	66,78	3080	100,00
0,0358	0,00	0,357	0,00	3,55	0,00	35,3	4,13	352	71,53	3500	100,00
0,0407	0,00	0,405	0,00	4,03	0,07	40,1	4,60	400	76,12		
0,0463	0,00	0,460	0,00	4,58	0,15	45,6	5,28	454	80,54		
0,0526	0,00	0,523	0,00	5,21	0,25	51,8	6,29	516	84,73		
0,0597	0,00	0,594	0,00	5,92	0,38	58,9	7,74	586	88,57		
0,0679	0,00	0,675	0,00	6,72	0,54	66,9	9,76	666	91,97		
0,0771	0,00	0,767	0,00	7,64	0,73	76,0	12,42	756	94,81		
0,0876	0,00	0,872	0,00	8,68	0,94	86,4	15,76	859	97,03		

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