



Atmospheric Impact Report: Sasol Sasolburg Operations

Project done on behalf of **Sasol South Africa (Pty) Ltd.**

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Report No: 16SAS01 | **Date:** February 2017



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Report Details

Report number	16SAS01
Status	Draft
Report Title	Atmospheric Impact Report: Sasol Sasolburg Operations
Date	February 2017
Client	Sasol South Africa (Pty) Ltd
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Revision Record

Revision Number	Date	Reason for Revision
Rev 0	December 2016	Draft for client review
Rev 1	February 2017	Updated with client comments

Preface

Sasol's Sasolburg Operations (SO) is required to comply with the Minimum Emission Standards, which came into effect in terms of Section 21 of the National Environment Management: Air Quality Act (Act No 39 of 2004) on 1 April 2010 and subsequently replaced by GN893, of 22 November 2013. These standards require the operations to comply with "existing plant" limits by 1 April 2015, and with more stringent "new plant" limits by 1 April 2020. Technical investigations were conducted by SO to establish feasibility and practicality of improving its existing process plants operations in order to comply with the standards as set out in the Minimum Emission Standards. Guided by the technical investigations, SO requested postponement to comply with the Minimum Emission Standards in 2014. This was granted in February 2015, however for certain of the activities only a three year postponement was granted. Based on this as well as information associated with current roadmaps, the Employer intends to request an extension of the original postponement granted for the three year period to allow for the implementation of technical solutions. In support of the submissions and to fulfil the requirements for these applications stipulated in the Air Quality Act and the Minimum Emission Standards, air quality studies are required to substantiate the motivations for the postponement application.

At the Sasolburg facility, SO is responsible to supply utilities as well as reformed and synthesis gas to the other Sasol Business Units operating on the site. Apart from coal-fired steam stations supplying steam and electricity, natural gas is reformed in two auto thermal reformers (ATRs) with oxygen at high temperature to produce synthesis gas (syngas). This syngas is distributed to Sasol Wax, to produce a range of waxes and paraffins, and to Sasol Solvents, to produce methanol, butanol and acrylates. Tail gases from various gas units are used in the ammonia plant to produce ammonia which in turn is used to produce nitric acid, ammonium nitrate and ammonium nitrate-based explosives and fertilisers.

The main air pollutants from SO are sulfur dioxide (SO₂) and oxides of nitrogen (NO_x), and particulates. Other minor pollutants to consider, include ammonia (NH₃), hydrochloric acid (HCl), hydrogen fluoride (HF), dioxins/furans and metals.

Airshed Planning Professionals (Pty) Ltd (hereafter referred to as Airshed) was appointed by SO to provide independent and competent services for the compilation of an Atmospheric Impact Report as set out in the Draft Regulations and detailing the results of the dispersion model runs. The tasks to be undertaken consisted of:

- 1) Review of emissions inventory for the identified point sources and identification of any gaps in the emissions inventory. Where possible, it is preferable that gaps be estimated using an agreed emission estimation technique. No emission factors may be used without the written consent from Sasol that the emission factors are deemed acceptable. Should measurements be required, Sasol will source the required information.
- 2) Prepare meteorological input files for use in one or more dispersion models to cover all applicable Sasol sites. Sasol will provide surface meteorological data and ambient air quality data from the Sasol ambient air quality monitoring stations. Surface meteorological data for three years, as required by the Dispersion Modelling Guidelines for Level 3 Assessments, is available for ambient air quality monitoring stations situated in both Sasolburg and Secunda.
- 3) Preparation of one or more dispersion models set up with SO's emissions inventory capable of running various scenarios for each of the point sources as specified by SO. The intent is to model delta impacts of the various emission scenarios against an acceptable emissions baseline.
- 4) Airshed will validate the dispersion model based on an acceptable and agreed approach. The validation methodology must be agreed between the SO and Airshed. It is anticipated that each point source identified above will require 3 scenarios per component per point source to be modelled, in order to establish the delta impacts against the baselines. i.e.:
 - a. Baseline – modelling is conducted based on the current inventory and impacts

- b. Future – modelling must be conducted based on the legislative requirement as stipulated within the Listed Activities and Minimum Emission Standards (for both 2015 and 2020 standards).
 - c. Alternative emission limits – the actual SO proposed reductions, where applicable and different from the other 3 emission scenarios.
- 5) Comparison of dispersion modelling results with the National Ambient Air Quality Standards (NAAQS).
- 6) A report detailing the methodology used and model setup must be compiled for purposes of a peer review, which Sasol will contract independently.
- 7) Interactions with Environmental Assessment Practitioner (EAP) to provide all necessary inputs into the EAP's compilation of documentation in support of Sasol's postponement applications. Airshed will attend all Public Participation meetings scheduled by the EAP to address any queries pertaining to the dispersion model.

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Abbreviations

AAA	Acrylic acid and acrylate
AEL	Atmospheric Emission Licence
AIR	Atmospheric Impact Report
AQA	Air quality act
AQMS	Air quality monitoring stations
As	Arsenic
ATR	Auto Thermal Reformer
APCS	Air pollution control systems
ARM	Ambient Ratio Method
ASG	Atmospheric Studies Group
BPIP	Building Profile Input Program
CH₄	Methane
Cl₂	Chlorine
Co	Cobalt
CO	Carbon monoxide
CO₂	Carbon dioxide
Cr	Chromium
Cu	Copper
DEA	Department of Environmental Affairs
EDC	1,2-dichloroethane
g	Gram
g/s	Gram per second
HCl	Hydrogen chloride
HCN	Hydrogen cyanide
HNO₃	Nitric acid
H₂	Hydrogen
H₂O	Water
H₂S	Hydrogen Sulfide
HSP	High Sulfur Pitch
IP	Intellectual property
IPCC	Intergovernmental Panel on Climate Change
kV	Kilo volt
LMo	Monin-Obukhov length
m	Meter
m²	Meter squared
m³	Meter cubed
MES	Minimum Emission Standards
MIBK	Methyl isobutyl ketone
Mn	Manganese
m/s	Meters per second
N₂	Nitrogen
NAAQS	National Ambient Air Quality Standards (as a combination of the NAAQ Limit and the allowable frequency of exceedance)
NaCN	Sodium cyanide

NaOH	Sodium hydroxide
NAP	Nitric Acid Plant
NEMA	National Environmental Management Act
NEMAQA	National Environmental Management Air Quality Act
NH₃	Ammonia
Ni	Nickel
NO	Nitrogen oxide
NO₂	Nitrogen dioxide
NO_x	Oxides of nitrogen
O₃	Ozone
OH	Hydroxyles
OLM	Ozone Limiting Method
PBL	Planetary boundary layer
Pb	Lead
PM	Particulate matter
PM₁₀	Particulate matter with diameter of less than 10 µm
PM_{2.5}	Particulate matter with diameter of less than 2.5 µm
ppb	Parts per billion
PVC	Polyvinyl chloride
RNO₃	Organic nitrates
Sb	Antimony
SO₂	Sulfur dioxide ⁽¹⁾
SO₃	Sulfur trioxide ⁽¹⁾
SO₄	Sulfates
SO_x	Oxides of sulfur ⁽¹⁾
SSBR	Sasol Slurry Bed Reactor
TEOS	Tetraethyl Orthosilicate
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
V	Vanadium
VOC	Volatile organic compound
WRF	The Weather Research and Forecasting Mesoscale Model
yr	Year
Z₀	Roughness length
µ	micro
°C	Degrees Celsius

Note:

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

Glossary

Advection	Transport of pollutants by the wind
Airshed	An area, bounded by topographical features, within which airborne contaminants can be retained for an extended period
Algorithm	A mathematical process or set of rules used for calculation or problem-solving, which is usually undertaken by a computer
Alternative Emission Limit	Ceiling or maximum emission limit requested by Sasol, with which it commits to comply
Assessment of environmental effects	A piece of expert advice submitted to regulators to support a claim that adverse effects will or will not occur as a result of an action, and usually developed in accordance with section 88 of the Resource Management Act 1991
Atmospheric chemistry	The chemical changes that gases and particulates undergo after they are discharged from a source
Atmospheric dispersion model	A mathematical representation of the physics governing the dispersion of pollutants in the atmosphere
Atmospheric stability	A measure of the propensity for vertical motion in the atmosphere
Building wakes	Strong turbulence and downward mixing caused by a negative pressure zone on the lee side of a building
Calm / stagnation	A period when wind speeds of less than 0.5 m/s persist
Cartesian grid	A co-ordinate system whose axes are straight lines intersecting at right angles
Causality	The relationship between cause and effect
Complex terrain	Terrain that contains features that cause deviations in direction and turbulence from larger-scale wind flows
Configuring a model	Setting the parameters within a model to perform the desired task
Convection	Vertical movement of air generated by surface heating
Convective boundary layer	The layer of the atmosphere containing convective air movements
Data assimilation	The use of observations to improve model results – commonly carried out in meteorological modelling
Default setting	The standard (sometimes recommended) operating value of a model parameter
Diagnostic wind model (DWM)	A model that extrapolates a limited amount of current wind data to a 3-D grid for the current time. It is the 'now' aspect, and makes the model 'diagnostic'.
Diffusion	Clean air mixing with contaminated air through the process of molecular motion. Diffusion is a very slow process compared to turbulent mixing.
Dispersion	The lowering of the concentration of pollutants by the combined processes of advection and diffusion
Dispersion coefficients	Variables that describe the lateral and vertical spread of a plume or a puff
Dry deposition	Removal of pollutants by deposition on the surface. Many different processes (including gravity) cause this effect.
Sasolburg Operations (SO)	Sasol South Africa (Pty) Limited operating through its Sasolburg Operations,

Atmospheric Impact Report: Sasol Sasolburg Operations

1 ENTERPRISE DETAILS

1.1 Enterprise Details

The details of Sasol's Sasolburg Operations (SO) are summarised in Table 1-1. The contact details of the responsible person, the emission control officer, are provided in Table 1-2.

Table 1-1: Enterprise details

Enterprise Name	Sasol South Africa (Pty) Ltd, through its Sasolburg Operations
Trading as	n/a
Type of Enterprise	1968/013914/07
Company Registration Number	Sasol 1 Site 1 Klasie Havenga Street Sasolburg 1947
Registered Address	PO Box 1 Sasolburg 1947
Telephone Number (General)	016 960 1111
Fax Number (General)	016 920 2338
Company Website	www.sasol.com
Industry Type/Nature of Trade	Petrochemical industry
Land Use Zoning as per Town Planning Scheme	Industrial
Land Use Rights if Outside Town Planning Scheme	n/a

Table 1-2: Contact details of responsible person

Responsible Person Name:	Louis Fourie
Responsible Person Post:	Senior Vice President: Sasolburg Operations
Telephone Number:	016 960 8001
Cell Phone Number:	
Fax Number:	011 219 2438
E-mail Address:	louis.fourie@sasol.com
After Hours Contact Details:	083 632 5975
Name of VP SHE Sasolburg Operations:	Kaas de Boer

1.2 Location and Extent of the Plant

Table 1-3: Location and extent of the plant

Physical Address of the Plant	Sasol 1 Site 1 Klasie Havenga Street Sasolburg 1947
Description of Site (Where no Street Address)	Subdivision 6 of 2 of Driefontein No- 2 and certain subdivisions of the farm Saltberry Plain, Roseberry Plain Flerewarde and Antrim and subdivision 5 of 4 of Montrose, District of Sasolburg, Free State.
Coordinates of Approximate Centre of Operations	Sasol 1 Site: Latitude: S 26.82678 Longitude: E 27.84206
Extent	15.51 km ²
Elevation Above Sea Level	1 498 m
Province	Free State
Metropolitan/District Municipality	Fezile Dabi District Municipality
Local Municipality	Metsimaholo
Designated Priority Area	Vaal Triangle Priority Area

1.3 Atmospheric Emission Licence and other Authorisations

The following authorisations, permits and licences related to air quality management are applicable:

- Atmospheric Emission License:
 - FDDM-MET-2011-01
 - FDDM-MET-2013-18
 - FDDM-MET-2013-19
 - FDDM-MET-2013-21
 - FDDM-MET-2013-22
 - FDDM-MET-2013-23-P1
 - FDDM-MET-2013-24
- Other: None

2 NATURE OF THE PROCESS

2.1 Listed Activities

A summary of listed activities currently undertaken at SO is provided in Table 2-1.

Table 2-1: Listed activities

Category of Listed Activity	Subcategory of listed activity	Listed activity name	Description of the Listed Activity
1	1.1	Solid Fuel Combustion installations	Solid fuels (excluding biomass) combustion installations used primarily for steam raising or electricity generation
2	2.1	Petroleum Industry	Petroleum industry, the production of gaseous and liquid fuels as well as petrochemicals from crude oil, coal, gas or biomass
	2.4	Petroleum Industry (Storage and handling of petroleum products)	All permanent immobile liquid storage facility on a single site with a combined storage capacity of greater than 1000 m ³
3	3.1	Carbonization and Coal Gasification	Combustion installations not primarily used for steam raising or electricity generation.
4	4.1	Metallurgical industry	Drying of minerals including ore.
6	6.1	Organic Chemical Industry	<p>The production, or use in production of organic chemicals not specified elsewhere including acetylene, ecetic, maleic or phthalic anhydride or their acids, carbon disulphide, pyridine, formaldehyde, acetaldehyde, acrolein and its derivatives, acrylonitrile, amines and synthetic rubber. The production of organometallic compounds, organic dyes and pigments, surface-active agents.</p> <p>The polymerisation or co-polymerisation of any unsaturated hydrocarbons, substituted hydrocarbon (including Vinyl chloride).</p> <p>The manufacture, recovery or purification of acrylic acid or any ester of acrylic acid.</p> <p>The use of toluene di-isocyanate or other di-isocyanate of comparable volatility; or recovery of pyridine.</p> <p>All permanent immobile liquid storage facilities at a single site with a combined storage capacity of greater than 1 000 m³.</p>
7	7.1	Inorganic chemicals industry	The use of ammonia in the manufacturing of ammonia
	7.2		The primary production of nitric acid in concentrations exceeding 10%
	7.3		The manufacturing of ammonium nitrate and its processing into fertilisers
	7.4		Manufacturing activity involving the production, use or recovery of antimony, beryllium, cadmium, chromium, cobalt, lead, mercury, selenium, thallium and their salts
8	8.1	Thermal treatment of hazardous and general	Facilities where general and hazardous waste are treated by the application of heat (Applicable: Capacity of Incinerator > 10 kg/hour)

Category of Listed Activity	Subcategory of listed activity	Listed activity name	Description of the Listed Activity
		waste	

2.2 Process Description

A description on the process units operating at SO is provided below.

Steam Stations

SO operates two steam/power stations. Pulverised coal is fired in boilers which are used for steam and power generation. All the steam and the majority of the power generated at these stations are used for Sasol's purposes, however Sasol do supply Eskom with electricity directly into the national grid to alleviate the pressure on the national grid, for which Steam Station 1 is critical. Emissions include combustion gases; sulfur dioxide (SO₂), nitrogen oxide (NO), nitrogen dioxide (NO₂), particulate matter (PM), carbon dioxide (CO₂) and carbon monoxide (CO).

Auto Thermal Reformers

SO operates two Auto Thermal Reformers (ATR) on the Sasol One facility. Natural gas is reformed in the ATRs to form the building blocks of the Fischer Tropsch process. The heat required in the ATRs is obtained from the Fired Heaters which is fired with process tail gas, except during startup when they are fired with natural gas. Emissions from the two Fired Heaters are combustion gas products, such as NO, NO₂, CO and CO₂. No sulfur compounds are present.

Rectisol

SO operates a Rectisol plant on the Sasol One Site. The purpose of the Rectisol plant is "dew point correction" and "CO₂" removal. Due to the high concentration of methane and other hydrocarbons, the gas from the first two stages are sent to the flare and those from the last three stages are sent to atmosphere through the Steam Station 1 Stacks. Emissions include hydrocarbons specifically with high concentrations of CO₂ emitted from the Steam Station 1 stacks.

Thermal Oxidation

SO operates a thermal oxidation unit where various waste streams from various business units are thermally oxidized. The thermal oxidation facility consists of three incinerators, namely: the caustic; old HSO; and, new HSP incinerators. As part of the oxidation process, heat is recovered by means of steam, which supplements the steam supply to the plants from the Steam Stations. The B6930 incinerator has a bag house for particulate emission control, whilst the caustic incinerator has a caustic scrubber for both SO₂ and PM emission control.

Benfield

SO operates a Benfield unit as part of the ammonia plant on the Sasol One Site. The Benfield unit consists of a CO₂ absorber column where CO₂ is removed from the process gas stream using the benfield solution. The benfield solution is regenerated in the desorber column where the CO₂ is desorbed to the atmosphere.

Nitric acid plant (NAP)

A nitric acid plant is operational at the Sasol Bunsen Street site. Ammonia is piped from the cold storage area to the nitric acid plant where it is reacted with oxygen to produce oxides of nitrogen (NO_x), as an intermediate product, which is fed to a catalyst to selectively convert NO to NO₂. The NO₂ is fed to a series of absorption columns where nitric acid is formed. The exhaust vent from the second tower, which contains NO₂, and N₂O is sent to the de-NO_x reactor, where the gas is reduced over a catalyst to nitrogen and oxygen, which is released to atmosphere.

Ammonium Nitrate solution

SO operates an ammonium nitrate solution plant. This plant is integrated into the NAP plant. The nitric acid from the NAP plant is reacted with ammonia in a reactor to form the ammonium nitrate solution.

Ammonium Nitrate Prill

SO also operates an ammonium nitrate prill unit on the Sasol One Site. Aqueous ammonium nitrate is combined with off spec prill in a dissolving tank and then concentrated by means of parallel evaporators. The concentrated liquor is then fed to the top of the prill tower where after it is sprayed through the prill nozzles to obtain a desired diameter. The spheres fall inside the prill tower through counter current air flow which cools the droplet and forming the prill. The upward air flow is passed through three scrubbers at the top of the prill plant before it is vented to atmosphere. The prill is fed to drying, cooling and screening units where off spec prill is recycled to the dissolving tank whilst the on spec prill is packaged as the final product. The air used for drying is passed through a scrubber before being vented to atmosphere. Emissions are particulates coming from the scrubbers on top of the Prill tower as well as from the drying scrubbers.

Ammonia

Nitrogen from the Air Products plant on site is combined with hydrogen from the Rectisol stream to form ammonia in the ammonia plant. Inert gasses and hydrogen are vented to ammonia flare and combustion gasses (CO₂, CO, NO₂ and NO) are vented to atmosphere from the super heater.

SCCM

Step 1: Support Modification

Aluminium oxide powder is unloaded from bags and fed to the support modification reactor. The reactor also receives metered streams of tetraethyl orthosilicate (TEOS) and organic solvent (ethanol). In the reactor, the ethanol evaporates and leaves an ethoxysilicate coating on the alumina particles. This coating will promote adhesion of the active components of the catalyst during subsequent process stages.

The reactor has a nitrogen blanket, a screw agitator and is heated by a hot oil jacket. During the process volatile organic compounds (VOC) (mainly ethanol) are removed from the reactor under vacuum through a cooling tower condenses. After passing through a gas liquid separator and a knock out vessel, vapours are incinerated in the VOC incinerator while all liquid residues are collected in the spent ethanol tank.

At the exit the main product, modified support powder, proceeds directly to the next process stage (calcination) or is collected on tote bins if required.

Step 2: Calcination

A hopper receives modified support powder from the support modification reactor. The powder is fed into a calciner, which is heated by a gas burner. Ethanol groups from TEOS are removed under air at elevated temperatures from the calciner. At the calciner exit the product (roasted modified support powder) passes through a water cooler and can be stored for use or collected in a tote bin. Vapours from the hoppers and the calciner are fed to the VOC incinerator.

Step 3: Impregnation

In the first impregnation reactor the calcinated modified support powder (from bins) is treated with impregnation liquid. This liquid is prepared in a mixing tank by diluting a cobalt nitrate solution with demineralised water and adding a metal promoter solution (platinum). The process objective is to absorb cobalt and platinum (the active catalyst components) onto the silica

coated alumina particles that make up the modified support powder (and ultimately the catalyst). The final product from impregnation reactor is a moist impregnated powder.

The impregnation reactor is heated by a hot oil jacket and has a screw agitator. Aqueous vapours are removed from the reactor under vacuum through a cooling water condenser. The condensate is routed to the chemical sewer while clean vapours are released to the atmosphere.

Step 4: Calcination

Moist impregnated powder feeds directly from the impregnated reactor into a fluidised bed calciner. The nitrate salts in the powder are converted into oxides under release of NO_x. Preheated air acts as the fluidising medium which carries the nitrous vapours to the DeNO_x unit. This unit is also fed with an anhydrous ammonia solution and is equipped with a gas burner. It facilitates a two-step catalytic reduction of NO_x with ammonia (NH₃) to nitrogen and water. Calcinated impregnated powder is fed catalytic reduction fed to a sieve where it is separated according to particle size. On specification, product is collected into a tote bin.

Step 5 and 6: Impregnation and Calcination

The next two steps are a second impregnation and calcination. Both the impregnation and calcination steps are repeated in a separate process section which is identical to steps 3 and 4. Key differences are the composition of impregnation liquid and this impregnation process is also known as adsorption. Most process equipment is duplicated.

Step 7: Reduction

Following the two-step adsorption and calcinations process, the cobalt and platinum oxides are reduced to active metals under release of water and ammonia. Initially the product is fed from bins into a purge hopper where all oxygen is removed. The powder then enters a fluidised bed reduction reactor, which represents the final step in converting the powder into a catalyst. Hydrogen is used as a reduction medium and nitrogen is used for purging. The hydrogen flow is compressed and heated prior to injection into the reactor.

After passing through the fluidised bed the gas stream is cooled in two steps. The coolers utilise water and a water/glycol mixture respectively. After removal of water and ammonia in an adsorption dryer, the regenerated reduction gas is fed into the compressor suction and recirculated. A regenerated gas bleed-off is located between the water cooler and water glycol chiller. Water and ammonia removed from the gas is routed to the chemical sewer.

Step 8: Coating

Having passed the reduction step the product can be considered as an active catalyst which needs to be protected against oxidative degradation (it would auto-ignite under atmospheric conditions) to accomplish this protection the catalyst feeds directly from the reduction reactor into the coating tank where it is suspended in molten wax. Wax consists of synthetic paraffins and is melted in the wax melt tank.

Wax volatiles from the wax melt tank and coating tank are routed to a separate dedicated wax scrubber where they stripped with water. Stripper water from the wax melt tank scrubber is routed to the storm water drain, while stripper water from the coating tank scrubber is routed to the chemical sewer as it may contain metals. Clean gas from both scrubbers is released to atmosphere. Both tanks and transfer lines have jackets with hot oil for heating.

Step 9: Packaging

Finished product (active catalyst suspended in wax) runs through to the drum filling station using a nitrogen purge, to package the product for distribution and use.

Phenol, Cresol and TNPE plants

The Phenol, cresol and TNPE plants extract and purifies a range of phenolic products from tar acid containing feed streams sourced from Sasol Synfuels Operations. Various process chemicals are used to extract the tar acids and to remove impurities where-after phenol, cresols and xylenols are recovered via distillation. Waste generated by the processes are either incinerated or treated at the Sasol Bio-works. All relieve valves and vents are connected to the plant's flare system and normal combustion products are emitted (CO₂, CO, NO, NO₂ and water (H₂O)). The fuel gas furnace emits combustion gas products and SO₂ and sulfur trioxide (SO₃) are emitted from the oxides of sulfur (SO_x) scrubber.

Solvents

All vents and hydrocarbon emissions from Solvents are sent to the flare with the exception of a few units which vent hydrocarbons to atmosphere which has been quantified.

Methanol High Purity

Gas and hydrogen is reacted in a synthesis reactor at Sasol Waxes where crude methanol is produced. The distillation of the crude methanol into high purity methanol takes place at Sasol Solvents, through atmospheric distillation. The purification is accomplished through degassing and the removal of low and high boiling point by-products.

Methanol Technical Grade

The methanol extracted from the reaction water (Chemical water treatment plant) is purified to methanol technical grade through a process of atmospheric distillation. The purification is accomplished through the removal of low and high boiling point by-products.

Chemical Water Recovery

Chemicals are recovered from the reaction water from the Sasol Waxes synthesis processes, as well as purge streams from Butanol and by-products from HP methanol, TG methanol, MIBK and FTDR. Recovery of chemicals takes place through a process of atmospheric distillation and degassing.

Methyl Iso Butyl Ketone (MIBK 1 and 2)

DMK (acetone) is converted over a palladium impregnated resin ion-exchange catalyst in the presence of hydrogen to MIBK via a single stage process. The reactor product is worked up and purified through a series of distillation columns. All impurities and co-products are removed through the distillation processes.

Solvents Blending Plant

Raw material from Secunda, Sasolburg and outside suppliers, transported via road tankers to the blending plant, are stored in on-site storage tanks. The raw products, mixed according to customers specifications, are supplied to the customer via road tankers or drums.

Heavy Alcohol Plant

Raw material from Secunda (Sabutol bottoms) is distilled through a single step distillation column into 2 final products, i.e. pentylol and hexylol. No by-products are removed in the process.

Solvents Mining Chemicals Plant

Raw material from Secunda, Sasolburg and outside suppliers, transported via road tankers to the blending plant, are stored in on-site storage tanks. The raw products, mixed according to customers specifications, are supplied to the customer via road tankers or drums.

AAA/Butanol

Sasol operates an Acrylic Acid and Acrylate (AAA) as well as a Butanol plant on the Sasol Midland Site.

Butanol

Synthesis gas is fed to a cold box separation phase where impurities are removed from the syngas. The impurities are recycled back into the gas loop and vented into an elevated flare. The purified syngas as well as propylene are fed into a series of reactive distillation units to produce n-butanol and i-butanol as the final product. All columns are vented to the flare.

AAA

Acrylic acid is manufactured by reacting propylene with air through a series of reactors and a distillation / purification process. The crude Acrylic Acid is fed to three processes. It can be purified to form Glacial Acrylic Acid, it can be reacted with n-Butanol to produce Butyl Acrylate or it can be reacted with Ethanol to produce Ethyl Acrylate. All vents from the AAA plant goes through high temperature incinerator to eliminate any Acrylates entering the atmosphere, especially due to the odorous nature of Ethyl Acrylate.. Off gasses from the catalytic destruction unit and the vapour combustion unit contains CO₂, CO, NO and NO₂.

LOC

Liquid bulk storage contains/stores the various products produced on site. It is coupled to the loading bay which is covered to the vapour combustion. Drum, road and rail loading takes place. The fugitive organic vapour emitted during loading of road bulk haul trucks are extracted from the tanker hoods and incinerated at the vapour combustion unit. Emissions are normal combustion gasses such as CO₂, CO and H₂O. No sulfur components are present.

Polymers

Ethylene

SO operates a monomers production unit where ethylene is produced to be used within the polyethylene and polyvinylchloride manufacturing plants. Ethane is piped to Sasolburg from Secunda where it enters the cracker units where the ethane is cracked to ethylene. Once cracked the ethylene/ethane gas mixture goes through a quenching, scrubbing and drying phase where after the gas is hydrogenated to convert acetylene to ethylene. After this the gas is purified by means of distillation process where light and heavy components as well as unreacted ethane are removed. The ethylene is then stored in the ethylene tank to be distributed to the polythene and vinyl chloride monomer plants. Hydrocarbon off-gasses are sent to the plant's main flare where it is converted to CO₂, CO and H₂O. The cracking unit emits traces of hydrogen sulphide (H₂S) from the caustic scrubber.

Polyethylene

SO operates two polyethylene plants on the Sasol Midland Site, namely the Poly 2 and Poly 3 plants.

Poly 2: The Poly 2 process involves the manufacture of linear low density polyethylene in a fluidized bed gas phase reactor. The materials used for the manufacture comprise ethylene which is the main component, hexene/butene as a density modifier, hydrogen as a melt index modifier, isopentane for temperature control, a silica based Ziegler Natta catalyst (manufacture in house in the catalyst plant, a catalyst activator and nitrogen for reactor pressure control. The feeds enter the reactor where the reaction process takes place and polymer together with some unreacted gas is transferred to the degassing bin for separation of hydrocarbons from the polymer. The liquid hydrocarbons (hexene, isopentane) is recovered in the monomer recovery section of the plant and recycled back to the reactor for re-use. The polymer pneumatically transferred from the degassing bin and is stored in intermediate storage silos and thereafter pelletised at the extruder. At the extruder, virgin polymer is mixed with additives, is melted and is thereafter cut it into pellets in an underwater cutter. This polymer pellets are thereafter dried and cooled before being pneumatically conveyed to the Pack Silos from which it is

bagged at the packline and stored in the warehouse. Emergency venting occurs through the plant flare system where ethylene is converted to CO₂, CO and H₂O.

Poly 3: The Poly 3 plant produces medium and low density polyethylene. The ethylene is fed to a reactor where initiator and modifier depending on which grade (LDPE or MDPE) is added and the polymerization reaction take place. The excess ethylene is recycled and the polyethylene is separated, extruded, dried and transferred to degassing silos where the excess ethylene is purged out with air. After degassing the product is transferred for packaging. Emergency venting occurs through the plant flare system where ethylene is converted to CO₂, CO and H₂O.

Chlorine

Sasol also operates a chlorine, hydrochloric acid, sodium hydroxide and sodium hypochlorite production facility on the Sasol Midlands Site. Salt is conveyed to a dissolving tank where the salt is dissolved up to a specific brine concentration. After several purification steps, the brine solution is fed to the chloro-caustic cells where chlorine, hydrogen and aqueous sodium hydroxide is manufactured. The chlorine manufactured is stored, reacted with sodium hydroxide to create sodium hypochlorite or reacted with hydrogen to create hydrochloric acid in the hydrogen chloride (HCl) burners. The hydrogen is either used at the HCl burners to manufacture HCl or sent to the VCM plant as a fuel gas. The hydrochloric acid produced in the HCl burners is stored and sold as a final product. Scrubbers and outlets might contain traces of HCl and chlorine (Cl₂).

Vinyl Chloride Monomer

Sasol operates a Vinyl Chloride Monomer (VCM) production facility on the Sasol Midland Site. The facility uses two different reactions for the manufacturing of the intermediate 1,2-dichloroethane (EDC). The first is the direct chlorination of ethylene to produce EDC. The second is the oxychlorination step where ethylene, oxygen, hydrogen and HCl react to produce crude EDC and water. The water is separated after the oxychlorination reactor and the crude EDC is sent to the EDC purification unit. The water stream is fed to the water recovery unit for purification before being exported to the Sasol Polymers Chlorine Plant for brine make up. EDC from the purification step is fed to the EDC cracker together with EDC from the direct chlorination step. In the EDC cracking unit EDC is cracked to VCM and HCl after which the cracked stream is fed to the VCM purification unit. Here the VCM and HCl are separated and HCl is recycled to the oxychlorination unit. The VCM is sent to storage in two spheres at the PVC Plant. By products from the EDC Purification Unit and plant vent gasses are incinerated and the recovered dilute hydrochloric acid exported to the Sasol Polymers Hydrochloric Acid Plant.

Polyvinyl Chloride

Sasol operates a Polyvinyl chloride plant on the Sasol Midland Site. VCM from the VCM plant storage spheres is suspended in water whilst the reaction is brought up to the desired temperature. The polymerization reaction takes place and the polyvinyl chloride (PVC) is formed. The reactor is discharged into a blow down vessel which feeds into the stripper, where unreacted VCM is recovered from the slurry and recycled. The PVC/water mixture is then fed to the slurry stock tank and then to the centrifuge where the PVC is separated. Once the PVC is separated, it is dried, screened and pneumatically fed to the storage area for packaging. The unreacted VCM is recovered by liquefaction and stored for reuse. The incompressible tail gas from the latter unit is fed to the incinerator at the VCM Plant.

Cyanide

Sasol, furthermore, operates a Cyanide manufacturing plant on the Sasol Midland Site. Methane (CH₄) rich natural gas reacts with NH₃ in a fluidized coke bed reactor to form a hydrogen cyanide (HCN) rich synthesis gas. The energy required for the endothermic reactor is supplied by a set of six graphite electrodes connected to a 6.6kV electrical supply. The synthesis gas and large coke particles leaving the reactor are transferred through a cyclone where the particles are separated from the gas. After the cyclone, the gas is cooled and fed to fabric filters where any carbon soot entrained in the synthesis gas is removed. The "polished" gas is then fed to a pair of sodium hydroxide (NaOH) absorbers installed in series. Here the HCN reacts with the NaOH to form sodium cyanide (NaCN), which is the final product. The exhaust gasses from the second

NaOH absorber is fed into a NaOH vent scrubber after which it is emitted to atmosphere via an elevated stack. Emissions contain mainly hydrogen, particulates from the bag houses and are measured for traces of HCN.

Wax

Sasol Wax operates a catalyst manufacturing plant as well as two wax production units namely the Sasol Slurry Bed Reactor (SSBR) and the Arge Reactors. In the catalyst preparation plant metals are dissolved in nitric acid and then precipitated after which the catalyst is dried and activated, where after it is ready for use. NO_x is emitted from one and particulates are emitted from three stacks at the Catalyst plant.

The SSBR and Arge reactors are fed with the active catalyst and synthesis gas to produce hydrocarbons. The hydrocarbons are worked up via hydrogenation, distillation and oxidation to liquid final products. The products are blended, solidified and packed. Organics and combustion gasses (CO₂, CO, H₂O, NO and NO₂) are emitted from various furnaces within the process. Hydrocarbons could be sent to the factory main flare system where the organics are converted to CO₂, CO and H₂O before being emitted to atmosphere.

2.3 Unit Processes

All unit processes for the SO complex are listed in Table 2-2. The listed activity for which the postponement is applied is indicated as bold text. Sasol's Sasolburg Operations also operates various activities including water treatment facilities, fine ash dams, research activities and various distillation and processing units that are not included in the Listed Activities and Minimum Emissions Standards (MES). The site is a gas plant and as such continuous emissions are limited to predominantly combustion gases where flares have been installed as safety mechanisms.

Table 2-2: Unit processes at Sasol Sasolburg

Unit Process	Function of Unit Process	Batch or Continuous Process
SO		
<i>ATR</i>		
Auto Thermal reformers	Convert natural gas to reform gas	Continuous
Membrane separators	Purification of reformed gas	Continuous
Flares	Destruction of gas	Batch
Rectisol	CO ₂ removal and dew point correction	Continuous
<i>Thermal oxidation</i>		
B6993 Spent Caustic Incinerator	The incineration of spent caustic solution and off specification solvent products including MIBK by-products in a down fired incinerator.	Continuous
Spent Caustic Storage - F6903	Intermediate storage	Batch
Hydrocarbon Solvents - F6963 A/B F6927 B	Intermediate storage	Batch
Sodium Carbonate - F6954	Intermediate storage	Batch
Caustic - F6959 / F6975	Intermediate storage	Batch
B6930 High Sulfur Pitch Incinerator	The incineration of High Sulfur Pitch, Organic solvents and High Organic waters in a limestone fluidized bed unit.	Continuous
HSP Storage tanks - F6926 / F6990	Intermediate storage	Batch
HOW tank - F6938	Intermediate storage	Batch
BFW tank - F6939	Intermediate storage	Batch
B6990 Chemical Incinerator	The incineration of heavy oils, off-specification waxes, Sasol spent catalyst, funda filter cake, slop solvents and high	Continuous

Unit Process	Function of Unit Process	Batch or Continuous Process
	organic waste.	
Product tank	Intermediate storage	Batch
<i>Steam Stations</i>		
Fuel oil tanks	Holding fuel	Continuous
Coal bunkers/silos	Holding coal	Continuous
15 Boilers	Steam production	Continuous
Feed water tanks	Holding water	Continuous
Resins (HCL, caustic)	Holding chemicals	Continuous
NH ₃ tank	Holding ammonia	Continuous
Blow down tank		Continuous
<i>Nitric Acid (NAP)</i>		
NO reactor	Reaction of NH ₃ and air to form NO	Continuous
Absorber columns	Absorption of NO ₂ to HNO ₃	Continuous
De-NOx reactor	Reduction of NOx to O ₂ and N ₂	Continuous
<i>Ammonium Nitrate</i>		
AN reactor	Reaction to form ammonium nitrate	Continuous
Neutralizer	pH correction	Continuous
AN solution tank	Storage of AN solution	Continuous
<i>Prillan</i>		
Wet section	Concentration of ammonium NH ₄ OH solution	Continuous
Dry section	Drying of prilled NH ₄ OH	Continuous
Storage	Storage of prilled NH ₄ OH	Continuous
<i>Ammonia</i>		
CO ₂ capture	Remove moisture from the CO ₂ stream	Continuous
CO-shift	Reacts CO + steam to form H ₂	Continuous
Benfield	Removal of CO ₂ from the process stream	Continuous
PSA	Production of LPH ₂	Continuous
Deoxo	N ₂ purification	Continuous
Ammonia synthesis	Production of NH ₃	Continuous
BFW	Demineralized water	Continuous
SCCM		
<u>Step 1</u>		
Storage tanks/Bags	Containing raw materials for the support modification step	Continuous
Reactor	Allow chemical reactions	Batch
VOC destruction unit	Destroying VOC vapours	Continuous
<u>Step 2</u>		
Hoppers	Temporally storage of the support powder	Continuous
Calciner	Calcinations of the raw materials	Continuous

Unit Process	Function of Unit Process	Batch or Continuous Process
Water cooler	Cooling the roasted the roasted support powder for storage	Continuous
<u>Step 3</u>		
Mixing tank	Mixing cobalt nitrate, water and metal promoter	Batch
Heated reactor	Impregnating support powder with the metals and subsequent partial drying	Batch
<u>Step 4</u>		
Fluidised bed calciner	Oxidising of the impregnated support powder	Batch
DeNO _x unit	Catalytic destruction of NO _x fumes	Continuous
Sieve	Sizing of the particles	Continuous
Reverse pulse jet cartridge filters	Removing of dust particulates	Continuous
<u>Step 5</u>		
Mixing tank	Mixing cobalt nitrate, water and metal promoter	Batch
Heated reactor	Impregnating support powder with the metals and subsequent partial drying	Batch
<u>Step 6</u>		
Fluidised bed calciner	Oxidising of the impregnated support powder	Batch
DeNO _x unit	Catalytic destruction of NO _x fumes	Continuous
Sieve	Sizing of the particles	Continuous
Reverse pulse jet cartridge filters	Removing of dust particulates	Continuous
<u>Step 7</u>		
Purge Hopper	Remove oxygen	Batch
Reduction Reactor	Activation step on the catalyst	Batch
Coolers	Cooling activated catalyst	Batch
<u>Step 8</u>		
Tank	Wax coating of the activated analyst	Continuous
Scrubber	Removal of wax vapours emanating from the coating tank	Continuous
<u>Step 9</u>		
Packaging unit	Package of the activated catalyst for distribution	Continuous
<u>Vent System</u>		
Vent system	Removing dust particles from step 1,4,6, and 7 hoppers off hoppers gas	Continuous
Phenol, Cresol and TNPE		
Phenol producing column	Process NBF DTA material for phenol production	Continuous
Feedstock storage	Hold feed material	Batch
Rundown tanks	Hold product phenol	Batch
Final product tanks	Hold final product phenol	Batch
Product Stabiliser tanks	Hold chemicals	Batch
Tempered water system	Hold and provide condensate to phenol unit	Continuous
Relief system	Relief system in high pressure cases	Batch
HP steam	Provide heat to phenol unit reboilers/heater	Continuous
HOW Storage tanks	Holding high organic effluent materials	Batch

Unit Process	Function of Unit Process	Batch or Continuous Process
Sand Filtration	Filter solids from HOW water	Continuous
Extraction	Extract phenolics from the high organic wastewater	Continuous
C stream distillation	Recover butyl acetate (solvent)	Continuous
Stripping section	Strip out butyl acetate from final effluent	Continuous
Crude tar acids storage	Hold tar acids extracted from high organic effluent	Batch
Separators	Remove tar and oil from high organic stream	Continuous
Storage tanks	Holding raw materials – Formalin, Caustic Soda, O-cresol, Water	Batch
Atmospheric and Vacuum Dehydration	Removal of water from crude resin by heating	Batch
	Stripping of unreacted o-cresol from crude resin by direct steam injection under vacuum conditions	
Pastillising	Pastillising of resin to form final product	Batch
Buffer storage	Intermediate storage of resin before pastillising	Batch
Feed storage tanks	Holding raw materials as buffer between Secunda and Sasolburg	Batch
Drying and N-base removal	Removing excess water from the feed followed by a process step to remove unwanted nitrogen base compounds from the feed	Continuous
Phenol production	Phenol produced from cleaned-up cresol feed	Continuous
Phenol removal	Remaining phenol in bottom product from above unit has to be removed	Continuous
Product Splitter	Separates cresol products from feed based on boiling points differences	Continuous
Intermediate feed product storage	Between units products are temporarily stored to minimize the whole production train to be affected if one unit experiences problems	Batch / Continuous
Final product tanks	Bulk storage before shipment to customer	Batch / Continuous
Loading facility	Road tanker loading of intermediate or final products	Batch
Loading facility	Road tanker loading of pitch type material for transport to incineration plant	Batch
Incineration	Heavy product from the above nitrogen base removal is incinerated	Continuous
Solvents		
<i>Solvents – All plants</i>		
Off-loading facility	Off-loading raw material to holding tank	Batch
Loading Facilities	Loading final product	Batch
Final product tanks	Holding product	Batch
<i>Solvents – AAA/Butanol</i>		
Oxidation	Raw material to crude product	Continuous
Distillation	Purification of crude product	Continuous
Esterification	Reaction of crude product with specific alcohol	Continuous
Refrigeration unit - NH ₃	Cooling in process	Continuous
Cryogenic separation	Conditioning of synthesis gas	Continuous
Chemical Dosing	In-process requirement	Continuous
Flare system	Process gas	Continuous
Off gas incineration	Incineration of process and tank waste gas	Continuous
Catalytic combustion	VOC combustion	Continuous

Unit Process	Function of Unit Process	Batch or Continuous Process
<u>Solvents – MIBK 1 and 2</u>		
Raw material tank	Holding raw materials	Continuous
Compression	Preparation of raw material	Continuous
High pressure Reaction	Production of raw product	Continuous
Refrigeration Unit	Preparation of vapour (H ₂) emissions to flare	Continuous
Distillation	Fractionation of product to desired spec.	Continuous
Prover tanks	Stores MIBK while being analysed before being pumped to final storage tank	Batch
Catalyst Loading Facilities	Loading and washing of catalyst for D551 A&B	Batch
<u>Solvents – Methanol</u>		
Synthesis	Converting gas and hydrogen to crude methanol	Continuous
Raw crude methanol tank	Holding raw materials	Continuous
Prover product tanks	Holding product	Batch
Atmospheric distillation	Distill methanol from crude	Continuous
Caustic dosing	Corrosion control and neutralization of acids	Continuous
<u>Solvents – Methanol TG</u>		
Atmospheric distillation	Distill methanol in reaction water to Technical grade purity	Continuous
Prover tanks	Storage of Methanol TG	Continuous
<u>Solvents – E1204</u>		
Prover tanks	Holding product	Continuous
Atmospheric distillation	Distill Pentylol and Hexylol from Sabutol Bottoms	Continuous
<u>Solvents – Chemical Recovery (S500) Alcohol distillation</u>		
Degassing	Dissolved gases are removed from chemical water	Continuous
Feed storage	Reaction water Storage to E501	Continuous
Atmospheric distillation	Removal of water and other light components from chemical water	Continuous
Scrubbing	Vapours are scrubbed of acids	Continuous
<u>Solvents – Blending plant</u>		
Raw material	Feed for blends	Batch
Blending tanks	To blend formulations according to customer requirements	Batch
Storage	Final Products	Batch
<u>Solvents – Mining Chemicals plant</u>		
Raw material	Feed for blends	Batch
Blending tanks	To blend formulations according to customer requirements	Batch
Storage	Final Products	Batch
LOC		
Vapour combustion unit	Destruction of organic vapours from the loading racks	Batch
Various storage tanks	Storage of liquid products	Continuous
Polymers		
<u>Poly 2</u>		

Unit Process	Function of Unit Process	Batch or Continuous Process
<u>Feed Streams:</u>		
Knock-out drum	Knock out oil entrainment in supply ethylene	Continuous
Ethylene Compression	Compression of supply ethylene from supply pressure to reaction pressure	Continuous
Hydrogen Storage	Acceptance of supply high pressure hydrogen from air products line	Continuous
Raw material offloading	Offloading of rail cars / isocontainers into storage tanks before use in catalyst and LLDPE manufacturing	Batch
<u>Catalyst Plant:</u>		
Dehydration	Preparation of silica for use in the manufacture of catalyst	Batch
Catalyst Preparation	Manufacture of Ziegler Natta, silica based catalyst for the polyethylene manufacture process	Batch
Catalyst Storage	Storage of catalyst manufactured and transfer to reactor catalyst feeders	Batch
Catalyst Deactivation	Deactivation of out of specification catalyst	Batch
Purification	Purification of feed streams to remove trace poisons before use in the Catalyst and LLDPE manufacturing processes	Continuous and batch
Reaction	Produce polyethylene in the fluidized bed reactor	Continuous
<u>Degassing:</u>		
Degassing Bin	Degassing of reactor polymer to remove hydrocarbons from polymer and screen polymer to prevent conveying line blockages	Continuous
Monomer recovery	Knock out hydrocarbons from degassing bin vent via a compressor and fridge system – recycle liquid hydrocarbons to the reactor	Continuous
Flare	Flaring of hydrocarbons not recovered at the monomer recovery unit	Continuous
	Flaring of reactor inventory during reactor shutdown / purging	- Batch
<u>Blending:</u>		
Intermediate storage	Intermediate storage and feed of reactor polymer to the extruder	Batch
Extruder	Mixing of reactor polymer with additives and pelletising	Batch
Packline	Bagging of polymer into 25kg bags and 1.25ton semi bulk bags	Batch
Warehouse	Storage of polymer before being transported to customers	Batch
<u>Poly 3</u>		
<u>Ethylene Feed</u>		
Knock-out drum	Knock-out oils and wax formation in feed line	Continuous
Compressors	Compress Ethylene to required reaction pressure	Continuous
Reactor	Produce Polyethylene	Continuous
Separators	Separate Ethylene from Polyethylene	Continuous
<u>Recycle unit</u>		
Knock-out drums	Knock-out oils and wax formation	Continuous
Heat exchangers	Cool down ethylene	Continuous
<u>Off-loading Area</u>		
Buffer Tank	Isododecane used as flushing agent	Batch
Buffer Tank	Compressor Lubrication Oil (Polybutene & Polyglycol)	Batch
Storage tank (iso-tanker)	Contain Propionaldehyde used as modifier solvent	Batch
Extrusion	Pelletise polymer	Continuous

Unit Process	Function of Unit Process	Batch or Continuous Process
Pellet transfer and degassing	Transfer pellets and degas product	Continuous
Waste oil and initiator	Disposal of waste oil and initiator	Batch
Flare system	Flaring ethylene or propylene	Batch
<u>VCM and PVC</u>		
Reactor	VCM Plant Unit 1100 – manufacture of 1,2-dichloroethane (EDC) from ethylene and chlorine.	Continuous
Cracker	VCM Plant Unit 1400 – cracking of EDC to form vinyl chloride monomer (VCM) and hydrogen chloride (HCl)	Continuous
Reactor	VCM Plant Unit 1200 – manufacture of EDC by oxyhydrochlorination of ethylene	Continuous
Incinerator	VCM Plant Unit 1600 – by-product hydrochloric acid recovery from mixed gaseous and liquid plant streams from both the VCM and PVC Plants.	Continuous
Scrubber	VCM Plant Unit 1500 Safety Scrubber – removal of HCl from gaseous vent streams during incinerator off-line time.	Batch
Cold flare	VCM Plant Unit 1500 Cold Flare – vent gaseous streams of VCM and HCl diluted with steam and nitrogen during emergencies and gas clearing in preparation for maintenance shutdown.	Batch
Tanks – spheres	PVC Plant Storage Spheres – storage of VCM	Continuous / Batch
Reactors	PVC Plant Reaction Unit – manufacture of poly (vinyl chloride) (PVC) from VCM	Batch
Separation - recovery	PVC Plant Vinyl Chloride Recovery Unit – recovery of unreacted VCM from the manufacture of PVC	Continuous
Drying	PVC Plant Drying Unit – remove moisture from raw PVC polymer	Continuous
Separation - recovery	PVC Plant Multigrade Recovery Unit – recovers PVC polymer from effluent water streams	Batch
<u>Monomers</u>		
Ethylene unit 4600	Cracking of ethane and propane Separation of ethylene & ethane from C2 rich gas	Continuous
Ethylene storage tank	Storage of final product	Continuous
Ethane storage sphere	Storage of furnace feed material	Continuous
Propylene storage sphere and bullets	Storage of final product	Continuous
Cracker system	Cracking of ethane or propane to ethylene (This unit operation include boiler feed water, dilution steam, crack gas quench, MEA, Caustic and fuelgas)	Continuous
Cooling water system	Used as cooling medium	Continuous
Loading bay facility	Loading of ethylene road tanker	Batch
Feed gas preparation	Ethane saturator	Continuous
Compression	Crack gas compression as well as ethylene and propylene compression	Continuous
Flare system	Flaring of off-spec product during upset conditions as well as over-pressure protection (3 flares: Ground flare; elevated flare and tank flare)	Continuous
Cold separation	This unit operation include de-ethaniser, C3-recovery, secondary feed gas drying, cold separation, de-methaniser, ethylene cycle, C2-splitter and ethane system	Continuous
Liquefaction	This unit operation include propylene refrigeration, ethylene distribution and storage	Batch
Pre-cooling and drying	Propylene system, pre-cooling, acetylene removal, primary feed gas drying	Continuous
Utilities	Plant air, instrument air, LP nitrogen, de-oxo nitrogen, fire steam, 38bar HP steam, 4.5bar MP steam & 1.5bar LP steam, drinking water, condensate & fire water system	Continuous / Batch
DCS system	Digital Control System for plant operation	Continuous

Unit Process	Function of Unit Process	Batch or Continuous Process
<u>Cyanide</u>		
Water	Process make up water	Batch
Nitrogen	Plant purging, bag house pulsing and coke feed	Continuous
Caustic	Diluted caustic for the production of sodium cyanide	Batch
Ammonia	For the production of hydrogen cyanide gas	Continuous
Sodium cyanide	Primary and secondary absorption	Batch
Sodium cyanide	Crude Tanks	Batch
Sodium cyanide	Final storage	Batch
Natural gas	Piped in for the production of hydrogen cyanide gas	Continuous
Bag house	Filtering of hydrogen cyanide gas	Continuous
Absorbers	Absorbing HCN gas into caustic	Continuous
Back up scrubbers	Final separation of HCN gas from waste gas stream	Continuous
Stack and seal pot	Exhausting waste gas mainly hydrogen into atmosphere	Continuous
Press filter	Filtration of crude sodium cyanide	Batch
Nash compressors	Recycle hydrogen system into process	When required
Loading facility	Dispatch of final product	Continuous
<u>Chlorine</u>		
Chlorine production	To produce chlorine, hydrogen, sodium hydroxide	Continuous
Calcium Chloride	Produce calcium chloride	Batch
Hydrochloric Acid	Hydrochloric acid	Continuous
Tank farm	Storage and dispatch of caustic soda, hydrochloric acid and sulfuric acid.	Continuous
Wax		
<u>Sasol Wax – Production</u>		
Reactors	Production of hydrocarbons	Continuous
Distillation column	Separation of hydrocarbons	Continuous
Packaging	Solidification of wax to get required products	Continuous
Bagging	Packaging of products	Continuous
Mixing and blending	Production of catalyst	Batch
Hoppers	Storage of sodium carbonate	Batch
<u>Sasol Wax – Catalyst preparation</u>		
Dissolving reactors	To produce a metal solution	Batch
Precipitation reactors	To precipitate the catalyst slurry from precursor solutions	Batch
Calcination	To strengthen the catalyst particles	Continuous
Driers	To dry the catalyst to the correct moisture content	Continuous
Evaporators	To concentrate the by-product solution from the precipitation area	Continuous
Crystallisers	To crystallise a salt slurry solution	Continuous
Drier	To dry the salt crystals	Continuous
Storage tanks	Storage for nitric acid, potassium silicate, and caustic soda.	Batch

3 TECHNICAL INFORMATION

Raw material consumption for the listed activities applying for MES postponement at SO is tabulated in Table 3-1. For completeness, the raw materials used by all process are included in Appendix C1 (Table C-1), unless the information is intellectual property (IP) or otherwise sensitive due to competition law. Pollution abatement technologies employed at SO for the listed activities applying for MES postponement are provided in Table 3-2 (all appliance and abatement equipment in use at SO is provided in Appendix C; Table C-2).

3.1 Raw Materials Used and Production Rates

Table 3-1: Raw materials used in the listed activities seeking MES postponement

Raw Material Type	Design Consumption Rate (Volume)	Units (quantity/period)
Thermal oxidation		
Spent Caustic	3.5	tonnes/h
Organic Solvents	1.5	tonnes/h
High Sulfur Pitch	2.5	tonnes/h
Organic Solvents	1	tonnes/h
Limestone	3	tonnes/h
Organic waste water	2	tonnes/h
Off- specification waxes	60	tonnes/month
Sasol spent catalyst	204	tonnes/month
High sulfur pitch	730	tonnes/month
Funda filter cake	220	tonnes/month
Polyethylene wax	80	tonnes/month
Other solid waste	150	tonnes/month
High organic waste	400	tonnes/month
Fuel Gas	1000	Nm ³ /h

3.2 Appliances and Abatement Equipment Control Technology

Table 3-2: Appliances and abatement equipment control technology

Appliance name	Appliance type/description	Appliance function/purpose
Spent Caustic Incinerator B6993		
Scrubber	Venturi scrubber	Scrubbing of flue gasses to remove particulates and SO ₂
New High Sulfur Pitch (HSP) Incinerator B6930		
Fluidized bed	Limestone fluidized bed	Removal of SO ₂
Bag house	Bag house	Particulate removal

4 ATMOSPHERIC EMISSIONS

The establishment of a comprehensive emission inventory for the listed activities seeking postponement formed the basis for the assessment of the air quality impacts from SO on the receiving environment.

Point source parameters are provided in Table 4-1. A locality map indicating the position of SO in relation to surrounding residential and industrial areas is included as Figure 4-1. For completeness, the details for all point sources at SO are provided in Appendix C1; Table C-3 and Table C-4.

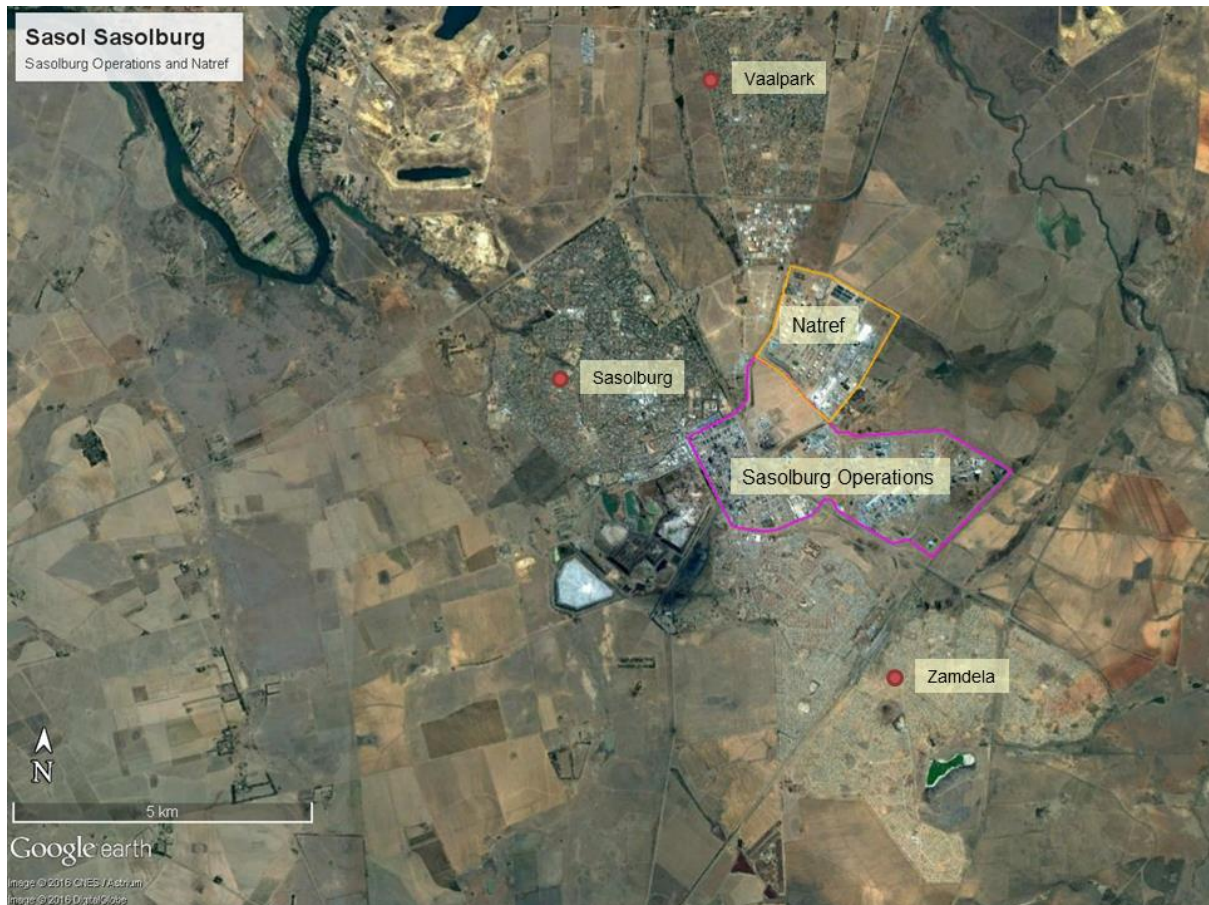


Figure 4-1: Locality map of SO in relation to surrounding residential and industrial areas

4.1 Point Source Parameters

Table 4-1: Point source parameters

Point Source number	Industry name	Source name	Latitude (decimal degrees)	Longitude (decimal degrees)	Height of Release Above Ground (m)	Height Above Nearby Building (m) (a)	Diameter at Stack Tip / Vent Exit (m)	Actual Gas Exit Temperature (°C)	Actual Gas Volumetric Flow (m³/hr)	Actual Gas Exit Velocity (m/s)	Continuous or batch
<i>Baseline point sources</i>											
I1	Solvents	AAA: ST6010	-26.82300	27.86800	20		0.95	790	16 331	6.4	Continuous
I2		Butanol ST1040	-26.82328	27.86682	25		1.5	123	80 349	12.63	Continuous
I3	ATR Phenosolvan	Fired Heater ATR A Train	-26.82631	27.84055	65	52	3.32	190	794 710	25.5	Continuous
I4		Fired Heater ATR B Train	-26.82668	27.84077	65	52	3.32	190	769 778	24.7	Continuous
I5	Prillan Plant	J 4062 A Dust scrubber	-26.82900	27.84100	22	9	1	29	106 311	37.6	Continuous
I6		J 4062 B Dust scrubber	-26.82900	27.84100	22		1	28	92 372	32.67	Continuous
I7		J4063 A	-26.82900	27.84100	85		1.5	21	89 700	14.1	Continuous
I8		J4063 B	-26.82900	27.84100	85		1.5	23	94 599	14.87	Continuous
I9		J4063 C	-26.82900	27.84100	85		1.5	23	66 607	10.47	Continuous
I10	Sasol Polymers - Monomers (excluding flares)	Steam cracker furnaces, B002a,b	-26.83199	27.84400	20	10	1.8	417	54 049	5.9	Continuous
I11		Steam cracker furnaces, B003 and MEA	-26.83190	27.84395	26	16	1.2	200	34 608	8.5	Continuous
I12	Merisol (excluding flares)	Fuel gas furnace	-26.83023	27.84743	40		0.11	99	164	4.8	Continuous
I13		Phenol Plant	-26.82387	27.84063	30		0.2	29	26	0.23	Continuous
I14		SOx scrubber on N-base units	-26.83000	27.84700	12		0.11	300	1 687	49.3	Continuous
I15	Sasol Wax	Oven B 4701	-26.83078	27.84631	26		1	409	18 378	6.5	Continuous
I16		Oven B 4702	-26.83079	27.84625	26		1	320	18 661	6.6	Continuous
I17		Oven B 4801	-26.83081	27.84639	26		1.25	165	23 856	5.4	Continuous
I18		Oven B 4802	-26.83076	27.84648	26		1.25	285	30 925	7	Continuous
I19		Oven L 4234 Catalyst washout	-26.83109	27.84242	45	8	0.5	61	9 613	13.6	Continuous
I20		Cat Prep Salt Plant	-26.83108	27.84210	15	(b)	0.2	35	1 312	11.6	Continuous
I21		Cat prep SBR	-26.83131	27.84264	15	(b)	0.5	58	6 030	8.53	Continuous

Point Source number	Industry name	Source name	Latitude (decimal degrees)	Longitude (decimal degrees)	Height of Release Above Ground (m)	Height Above Nearby Building (m) (a)	Diameter at Stack Tip / Vent Exit (m)	Actual Gas Exit Temperature (°C)	Actual Gas Volumetric Flow (m³/hr)	Actual Gas Exit Velocity (m/s)	Continuous or batch
I22		Cat Prep FBR	-26.83109	27.84244	15		0.6	61	15 879	15.6	Continuous
I23	Steam station	SS1 Boiler 4	-26.82217	27.84073	75		2.5	160	235 030	13.3	Continuous
I24		SS1 Boiler 5&6	-26.82235	27.84037	75		2.5	160	458 751	25.96	Continuous
I25		SS1 Boiler 7&8	-26.82248	27.84009	75		2.5	160	478 543	27.08	Continuous
I26		SS2 Boiler 9-15	-26.82217	27.84884	145		7.8	160	1 746 014	10.15	Continuous
I27		VCM incinerator	-26.82999	27.87300	30		0.36	134	8 329	22.73	Continuous
I28	Vinyl business - VCM (excluding autoclaves)	VCM Cracker	-26.82999	27.87300	40		1.71	390	26 457	3.2	Continuous
I29		PVC Dryer stack North (A)	-26.82787	27.87330	35		1.8	63	131 917	14.4	Continuous
I30		PVC Dryer stack South (B)	-26.82791	27.87336	35		1.8	55	141 352	15.43	Continuous
I31		HCl Burner stacks (3 sources)	-26.82546	27.84039	15	2	0.16	30	203	2.8	Continuous
I35	SGEPP – Engines	Bay 1 (stack 1 - 6)	-26.81964	27.84770	27		1.2	301	114 613	28.15	Continuous
I36			-26.81964	27.84770	27		1.2	346	107 284	26.35	Continuous
I37			-26.81964	27.84770	27		1.2	341	144 946	35.6	Continuous
I38			-26.81964	27.84770	27		1.2	345	134 970	33.15	Continuous
I39			-26.81964	27.84770	27		1.2	325	116 445	28.6	Continuous
I40			-26.81964	27.84770	27		1.2	338	135 581	33.3	Continuous
I41		Bay 2 (stack 7-12)	-26.81936	27.84820	27		1.2	339	125 606	30.85	Continuous
I42			-26.81936	27.84820	27		1.2	356	135 581	33.3	Continuous
I43			-26.81936	27.84820	27		1.2	339	122 145	30	Continuous
I44			-26.81936	27.84820	27		1.2	342	131 713	32.35	Continuous
I45			-26.81936	27.84820	27		1.2	345	140 060	34.4	Continuous
I46			-26.81936	27.84820	27		1.2	331	118 277	29.05	Continuous
I47		Bay 3 (stack 13-18)	-26.81918	27.84860	27		1.2	335	114 409	28.1	Continuous
I48			-26.81918	27.84860	27		1.2	351	137 820	33.85	Continuous
I49			-26.81918	27.84860	27		1.2	343	127 642	31.35	Continuous
I50			-26.81918	27.84860	27		1.2	342	134 156	32.95	Continuous
I51			-26.81918	27.84860	27		1.2	353	132 935	32.65	Continuous

Point Source number	Industry name	Source name	Latitude (decimal degrees)	Longitude (decimal degrees)	Height of Release Above Ground (m)	Height Above Nearby Building (m) (a)	Diameter at Stack Tip / Vent Exit (m)	Actual Gas Exit Temperature (°C)	Actual Gas Volumetric Flow (m³/hr)	Actual Gas Exit Velocity (m/s)	Continuous or batch
I52			-26.81918	27.84860	27		1.2	346	100 810	24.76	Continuous
I53	NAP Bunsen Street	NAP Bunsen Street	-26.82524	27.86023	75		1.5	215	39 634	6.23	Continuous
Point sources applying for postponement											
I32	Section 6900	Heavy Ends B incinerator (B6990)	-26.82549	27.84035	40		1.5	650	63617	10	Continuous
I33		High sulfur pitch incinerator (B6930)	-26.82537	27.84022	40		1.5	180	139958	22	Continuous
I34		Spent caustic incinerator (B6993)	-26.82553	27.84043	40		1.2	83	50894	12.5	Continuous
Notes: (a) "Height above nearby building" is given as the minimum difference between the release height and the height of nearby buildings, where the point source is located equidistant from more than one building. Building height differences only included for sources affected by building downwash effects. (b) Height of release lower than nearby building.											

4.2 Point Source Maximum Emission Rates during Normal Operating Conditions

In cases where periodic compliance measurements are conducted, these are measured in accordance with the methods prescribed in Schedule A of the MES, and aligned with what is prescribed in the Atmospheric Emission Licence (AEL). These reflect the average of measurements conducted over a 3-hour period during normal operating conditions.

Table 4-2: Point source emission rates during normal operating conditions (units: g/s)

Point Source number	Industry name	Source name	SO ₂	NO _x as NO ₂	PM	CO	HF	Sum of heavy metals	Hg	Cd+Tl	TOCs	HCl	NH ₃	Dioxins/Furans
<i>Baseline point sources</i>														
I1	Solvents	AAA: ST6010	7.42E-02	1.40E-01	1.96E-01									
I2		Butanol ST1040	4.82E-02	6.75E-02	3.22E-01									
I3	ATR Phenosolvan	Fired Heater ATR A Train	7.67E-01	4.97E+00	6.74E-01									
I4		Fired Heater ATR B Train	1.05E+00	5.44E+00	6.71E-01									
I5	Prillan Plant	J 4062 A Dust scrubber	0.00E+00	0.00E+00	2.14E-01									

Point Source number	Industry name	Source name	SO ₂	NO _x as NO ₂	PM	CO	HF	Sum of heavy metals	Hg	Cd+Tl	TOCs	HCl	NH ₃	Dioxins/Furans
I6		J 4062 B Dust scrubber	0.00E+00	0.00E+00	1.86E-01									
I7		J4063 A	0.00E+00	0.00E+00	7.24E-01									
I8		J4063 B	0.00E+00	0.00E+00	4.92E-01									
I9		J4063 C	0.00E+00	0.00E+00	7.18E-01									
I10	Sasol Polymers - Monomers (excluding flares)	Steam cracker furnaces, B002a,b	1.43E-02	2.57E-02	0.00E+00									
I11		Steam cracker furnaces, B003 and MEA	6.34E-03	1.11E-02	0.00E+00									
I12	Merisol (excluding flares)	Fuel gas furnace	0.00E+00	2.54E-03	0.00E+00									
I13		Phenol Plant	3.04E-02	0.00E+00	0.00E+00									
I14		SOx scrubber on N-base units	6.66E-02	0.00E+00	2.85E-03									
I15	Sasol Wax	Oven B 4701	5.83E-02	3.88E-01	0.00E+00									
I16		Oven B 4702	3.68E-01	4.13E-01	0.00E+00									
I17		Oven B 4801	3.55E-02	3.01E-02	0.00E+00									
I18		Oven B 4802	4.33E-01	3.68E-01	0.00E+00									
I19		Oven L 4234 Catalyst washout	0.00E+00	8.63E-02	0.00E+00									
I20		Cat Prep Salt Plant	0.00E+00	1.90E-03	1.87E-02									
I21		Cat prep SBR	0.00E+00	9.29E-02	8.14E-01									
I22		Cat Prep FBR	0.00E+00	3.20E-02	3.51E-01									
I23	Steam station	SS1 Boiler 4	2.95E+01	5.37E+01	6.10E+00									
I24		SS1 Boiler 5&6	7.66E+01	1.20E+02	1.09E+01									
I25		SS1 Boiler 7&8	8.04E+01	1.24E+02	8.59E+00									
I26		SS2 Boiler 9-15	2.73E+02	4.11E+02	3.10E+01									
I27	Vinyl business - VCM (excluding autoclaves)	VCM incinerator	6.02E-03	4.12E-02	6.06E-02	2.56E-05	0.00E+00	1.42E-03	5.14E-06	2.11E-05	2.78E-03	1.17E-02	0.00E+00	1.67E-05
I28		VCM Cracker	1.68E-02	4.39E-01	0.00E+00									
I29		PVC Dryer stack North (A)	1.38E-01	1.61E-01	3.85E-01									
I30		PVC Dryer stack South (B)	1.12E-01	3.01E-01	6.03E-01									
I31		HCl Burner stacks (3 sources)	0.00E+00	3.36E-02	0.00E+00									

Point Source number	Industry name	Source name	SO ₂	NO _x as NO ₂	PM	CO	HF	Sum of heavy metals	Hg	Cd+Tl	TOCs	HCl	NH ₃	Dioxins/Furans
I35	SGEPP – Engines	Bay 1 (stack 1 - 6)	9.77E-02	2.57E+00	2.38E-01									
I36			3.49E-02	2.65E+00	1.17E-01									
I37			3.65E-02	4.10E+00	1.83E-01									
I38			3.90E-02	3.26E+00	1.64E-01									
I39			3.77E-02	2.43E+00	1.74E-01									
I40			4.15E-02	3.13E+00	9.29E-02									
I41		Bay 2 (stack 7-12)	3.33E-02	2.96E+00	1.10E-01									
I42			3.49E-02	2.97E+00	2.38E-01									
I43			3.61E-02	2.74E+00	1.43E-01									
I44			3.81E-02	2.64E+00	1.02E-01									
I45			4.38E-02	2.88E+00	1.17E-01									
I46			3.61E-02	2.74E+00	5.80E-02									
I47		Bay 3 (stack 13-18)	3.33E-02	2.63E+00	1.32E-01									
I48			4.06E-02	3.04E+00	2.01E-01									
I49			3.61E-02	2.52E+00	1.43E-01									
I50			3.74E-02	3.52E+00	1.53E-01									
I51			4.19E-02	2.85E+00	2.83E-01									
I52			3.46E-02	2.12E+00	1.06E-01									
I53	NAP Bunsen Street	NAP Bunsen Street	0.00E+00	5.96E+00	0.00E+00									
Point sources applying for postponement														
I32	Section 6900	Heavy Ends B incinerator (B6990)	2.00E+00	1.14E+00	1.08E+00	3.55E-02	0.00E+00	1.27E-01	0.00E+00	0.00E+00	3.17E-02	1.07E-02	4.25E-03	1.90E-04
I33		High sulfur pitch incinerator (B6930)	2.86E+01	7.00E+00	7.96E-01	7.16E-02	1.20E-02	1.59E-01	3.17E-04	6.34E-03	1.49E-01	4.77E-02	1.43E-02	3.17E-04
I34		Spent caustic incinerator (B6993)	2.51E+00	3.10E+00	2.66E+00	1.25E+01	0.00E+00	2.85E-03	0.00E+00	0.00E+00	1.27E-01	2.21E-02	4.06E-02	4.12E-04

4.3 Point Source Maximum Emission Rates during Start-up, Maintenance and/or Shut-down

Unplanned downtime events such as upset conditions are undesirable from a production perspective as well as an environmental perspective and Sasol endeavours to minimise unplanned downtime by conducting regular and pro-active maintenance and ensuring control of the process within their designed operating parameters. While unplanned downtime cannot be completely eliminated, it is minimised as far as practicably possible, and rectified with high priority.

The MES prescribes that start-up, shut-down, upset and maintenance events should not exceed 48-hours – and if they do, a Section 30 National Environmental Management Act (NEMA) incident is incurred (as also indicated in the Air Emission Licence (AEL)). SO can confirm that, in the preceding two years, its facility has not exceeded the 48-hour window during start up, maintenance, upset and shutdown conditions, which has ensured that ambient impacts are limited in duration. A 48-hour breach was however communicated to the Department of Environmental Affairs (DEA) based on a misaligned interpretation of the legislation. During their investigations, the EMLs did however confirm that the reported exceedance was not a NEMA Section 30 reportable incident.

Sasol owns and operates accredited ambient air quality monitoring stations in the vicinity of its Sasolburg plant. The real-time ambient air quality monitoring data is closely followed during upset conditions at the plant, to ensure that air quality does not exceed the national ambient air quality standards as a consequence of Sasol's activities.

The SO have an annual phase shut down on both the Sasol One and Midland sites with a total shut-down once every four years for statutory maintenance and inspections. These shut-downs are planned well in advance. Visible emissions are normally associated with cold start-up from the Nitric acid plant and boilers as well as the reformers, which results in the flaring of gas.

The Atmospheric Impact Report (AIR) Regulations require that the maximum emissions during start-up, shut down and upset conditions must be included within the AIR for the processes. This information is unfortunately not available for two practical reasons, explained below.

1. Since Sasol operates predominantly gaseous plants, operating the plant under start-up, shut down and upset condition is a period of high instability and for safety reasons, as few people as possible are allowed on the plant. Therefore ad hoc sampling under these conditions is a safety risk and therefore the sampling cannot be conducted. It should further be emphasised that the aim of the plant personnel is to get the plant back into operation as soon as possible and therefore the support required by sampling teams cannot be provided as the focus is on returning the plant to stable operation.

Another practical limitation is identification of the precise process conditions that will result in a maximum emission concentration. Since these conditions are unstable, large variations in plant conditions occur dynamically and pin pointing the exact combination of conditions at which to take the sample indicative of a maximum concentration is virtually impossible. Additional to the last mentioned, a maximum concentration may hypothetically exist for only a couple of minutes, however the prescribed legislation requires certain sampling techniques to be done over a period of at least an hour and then to be repeated for two times. Doing this under start-up, shut down and upset conditions are almost impossible due to the dynamics of a plant.

2. In the event where online monitoring is available, Sasol can attempt to make concentrations available for start-up, shut down and upset conditions; however, in investigating this Sasol has realised that the maximum concentrations are higher than the calibration range of the instrument, meaning that the online instrument is yielding only its maximum value. Since the actual true maximum concentration is higher than the instrument

maximum, the true actual concentration cannot be provided and therefore an accurate maximum concentration under start-up, shut-down and upset conditions cannot be included.

In mentioning the above, cognisance should be taken that Sasol's ambient air quality monitoring stations monitor ambient air quality over a 24-hour period and any upset, start-up or shut down events will reflect in the ambient air quality measurements and results. Therefore, maximum measured concentrations, although not quantified on site, is included in measured values for ambient air quality.

4.4 Fugitive Emissions

Fugitive emissions on the Sasolburg sites are managed and quantified through two fugitive emissions monitoring programs.

4.4.1 *Fallout dust*

Fallout dust is governed by the National Dust Control Regulations (NDCR) (Government Gazette No. 36974, No. R. 827; 1 November 2013). SO has 12 dustfall monitoring stations measuring the dust fallout on and around the site. The dust fallout buckets are placed in locations where the likely fallout of dust from coal stockpiles, fine ash dams and construction activities will occur, to ensure adequate control of most probable dust sources is in place. The Safety, Health and Environment function at the Sasolburg site is responsible for the measurement and management of dust in accordance with the NDCR and an accredited third party is responsible for replacing and analysing the buckets on a monthly basis.

The results for an annual sampling campaign for fallout dust are included in Appendix C3 (Figure C-1 to Figure C-12). These figures indicate that the fallout dust is predominantly within the lower range considered acceptable for residential areas, despite being an industrial site. Sasol inherently does not operate a process with large quantities of dust or large stock piles of possible fugitive dust emissions, with the exception of some coal stock piles and fine ash dams. The operational fine ash dam is wet and therefore wind-blown dust is limited. Non-operational fine ash dams are vegetated as soon as possible to reduce windblown dust.

The monitoring plan philosophy is that Sasol conduct monitoring and investigate spikes in the monitoring results. In the event that a spike is due to possible long-term effect, the problem will be addressed to ensure low levels of fugitive fallout dust.

4.4.2 *Fugitive VOCs*

The second monitoring program is associated with fugitive VOC emissions. These emissions originate from various basins and ponds, as well as from process equipment such as storage tanks. The on-site monitoring of fugitive process emissions is associated with Leak Detection and Repair. A third party contractor is contracted to conduct leak detection, with the help of a "sniffer" device and an infrared camera, to identify and quantify the leaks associated with various process emissions. The report results are then included in the maintenance plan and the leaking process units are repaired per schedule. This process has been in operation for a period exceeding five years. Subsequent to the changeover from coal to gas in 2004, the presence of harmful VOCs such as benzene, toluene and xylene is limited to vehicle emissions.

4.5 Emergency Incidents

There were no reportable emergency incidents, relating to air quality, in the relevant two year period (2015/2016).

Emergency incidents on the site are handled through standard operating procedures governing the actions that need to take place as well as defining the responsibilities of the parties involved in managing the incident. Part of any environmental incident/emergency response, the environmental respondent will evaluate the incident and then classify it according to an internal ranking as well as against relevant legislative requirements which will then trigger the necessary reporting requirements.

5 IMPACT OF ENTERPRISE ON THE RECEIVING ENVIRONMENT

5.1 Analysis of Emissions' Impact on Human Health

The report includes the results for three emission scenarios per pollutant, in order to establish the delta impacts against air quality limit values. The scenarios are as follows:

- *Baseline Emissions* – modelling conducted based on the current routine inventory and impacts
- *Minimum Emissions Standards* – modelling conducted based on plants theoretically complying with:
 - Existing Plant Standards, and;
 - New Plant Standards
- *Alternative Emission Limits* – the emission reductions as proposed by SO, where applicable and different from the scenarios above.

5.1.1 Study Methodology

5.1.1.1 Study Plan

The study methodology may conveniently be divided into a “preparatory phase” and an “execution phase”. The basic methodology followed in this assessment is provided in Figure 5-1.

The preparatory phase included the following basic steps prior to performing the actual dispersion modelling and analyses:

1. Understand Scope of Work
2. Assign Appropriate Specialists
3. Review of legal requirements (e.g. dispersion modelling guideline)
4. Prepare a Plan of Study for Peer Review
5. Decide on Dispersion Model

The Regulations Regarding Air Dispersion Modelling (Gazette No 37804 published 11 July 2014) was referenced for the dispersion model selection (Appendix B).

Three Levels of Assessment are defined in the Regulations Regarding Air Dispersion Modelling:

- Level 1: where worst-case air quality impacts are assessed using simpler screening models
- Level 2: for assessment of air quality impacts as part of license application or amendment processes, where impacts are the greatest within a few kilometres downwind (less than 50km)
- Level 3: require more sophisticated dispersion models (and corresponding input data, resources and model operator expertise) in situation:
 - where a detailed understanding of air quality impacts, in time and space, is required;
 - where it is important to account for causality effects, calms, non-linear plume trajectories, spatial variations in turbulent mixing, multiple source types & chemical transformations;
 - when conducting permitting and/or environmental assessment process for large industrial developments that have considerable social, economic and environmental consequences;
 - when evaluating air quality management approaches involving multi-source, multi-sector contributions from permitted and non-permitted sources in an airshed; or,
 - when assessing contaminants resulting from non-linear processes (e.g. deposition, ground-level O₃, particulate formation, visibility)

The models recommended for Level 3 assessments are CALPUFF or SCIPUFF. In this study, CALPUFF was selected for the following reasons (as referenced in Figure 5-1 - Model Aspects to Consider and Dispersion Models):

- This Lagrangian Gaussian Puff model is also well suited to simulate low or calm wind speed conditions. Alternative regulatory models such as the US EPA AERMOD model treats all plumes as straight-line trajectories, which under calm wind conditions over-estimates the plume travel distance (Busini *et al.*, 2012; Gulia *et al.* 2015; Lakes Environmental, 2017).
- CALPUFF is able to perform chemical transformations. In this study the conversion of NO to NO₂ and the secondary formation of particulate matter was a concern.

The execution phase (i.e. dispersion modelling and analyses) firstly involves gathering specific information in relation to the emission source(s) and site(s) to be assessed. This includes:

- Source information: Emission rate, exit temperature, volume flow, exit velocity, etc.;
- Site information: Site building layout, terrain information, land use data;
- Meteorological data: Wind speed, wind direction, temperature, cloud cover, mixing height;
- Receptor information: Locations using discrete receptors and/or gridded receptors.

The model uses this specific input data to run various algorithms to estimate the dispersion of pollutants between the source and receptor. The model output is in the form of a predicted time-averaged concentration at the receptor. These predicted concentrations are compared with the relevant ambient air quality standard or guideline. Post-processing can be carried out to produce percentile concentrations or contour plots that can be prepared for reporting purposes.

The following steps were followed for the execution phase of the assessment:

- Decide on meteorological data input (Figure 5-1 - CALMET). A summary of the model control options for CALMET is provided in Appendix D. Refer to Section 5.1.4.6.
- Prepare all meteorological model input files (Figure 5-1 - CALMET)
 - Surface meteorological files
 - WRF meteorological files
 - Topography
 - Land Use
- Select control options in meteorological model (Figure 5-1 - CALMET)
 - Dispersion coefficients
 - Vertical levels
 - Receptor grid
- *Feedback to Project Team and revise where necessary*
- Review emissions inventory and ambient measurements
- *Feedback to Project Team and revise where necessary*
- Decide on dispersion model controls and module options (Figure 5-1 - CALPUFF). A summary of the model control options for CALPUFF is provided in Appendix E. Refer to Section 5.1.4.6
- Decide on dispersion module options (Figure 5-1 - CALPUFF).
 - Sulfate and nitrate formation module (MESOPUFF or RiVAD)
 - NO₂ formation (MESOPUFF or RiVAD)
 - Model resolution
- *Feedback to Project Team and revise where necessary*
- Decide on modelling domain and receptor locations (Figure 5-1 – CALPUFF and Simulations)

- *Feedback to Project Team and revise where necessary*
- Prepare all dispersion model input files (Figure 5-1 - CALPUFF)
 - Control options
 - Measured ambient O₃ and NH₃ for chemical transformation module
 - Meteorology
 - Source data
 - Receptor grid and discrete receptors
- Review all modelling input data files and fix where necessary
- Simulate source groups per pollutant and calculate air concentration levels for regular and discrete grid locations for the following scenarios (Figure 5-1 – Simulations):
 - Baseline (current) air emissions
 - Change Baseline sources to reflect theoretical compliance with “Existing Plant” standards
 - Change Baseline sources to reflect theoretical compliance with “New Plant” standards
 - Change Baseline sources to reflect “Alternative Emission Limits”, where applicable
- Compare against National Ambient Air Quality Standards (NAAQS)
- Preparation of draft AIR
- *Present AIR to Project Team*
- Preparation of final AIR.

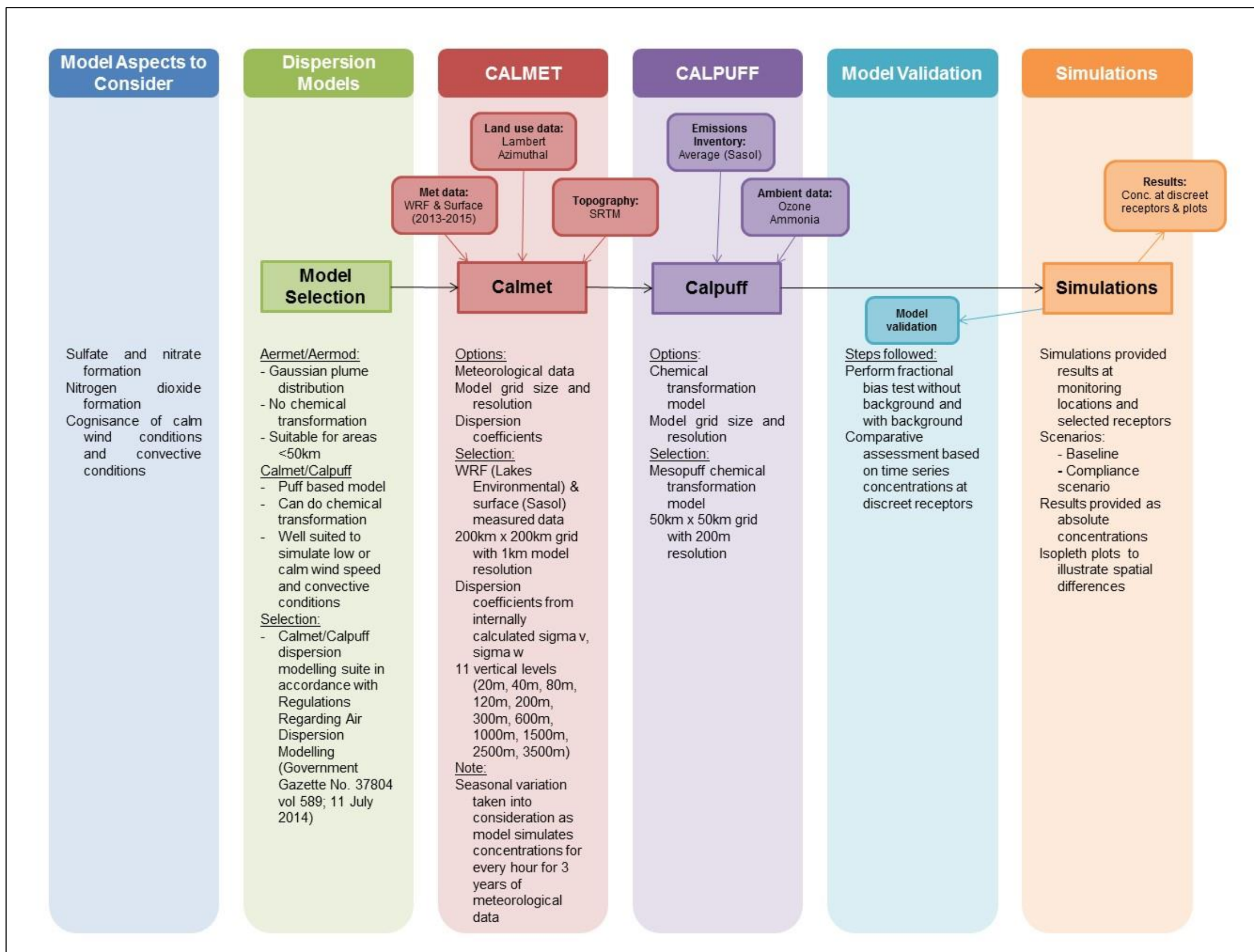


Figure 5-1: The basic study methodology followed for the assessment

In order to assess the impact of the postponements for which SO is applying, four emissions scenarios were modelled, with the results throughout the AIR presented as illustrated in Figure 5-2.

1. **Current baseline emissions**, reflective of the impacts of present operations, which are modelled as averages of measurements taken from periodic emission monitoring. This scenario is represented by the first column in the presentation of all AIR graphs (shown in blue in Figure 5-2). Baseline emissions were derived from 3rd parties and accredited (ISO/IEC17025) laboratories. Emissions measurements follow the requirements prescribed in Schedule A of GN 893. The reason baseline emissions were modelled as averages of measured point source emissions was to obtain a picture of long-term average impacts of SO emissions on ambient air concentrations, which could be reasonably compared with monitored ambient concentrations, as a means of assessing the representativeness of the dispersion model's predictions. Modelling baseline emissions at a ceiling level, which is seldom reflective of actual emissions, would over-predict ambient impacts, and therefore not allow for reasonable assessment of the model's representativeness.

The following three scenarios are modelled to reflect the administrative basis of the MES, being ceiling emission levels. These scenarios are therefore theoretical cases where the point source is constantly emitting at the highest expected emission level possible under normal operating conditions, for the given scenario (i.e. the 100th percentile emission concentration).

2. **Compliance with the 2015 existing plant standards**. This is modelled as a ceiling emissions limit (i.e. maximum emission concentration) aligned with the prescribed standard, and reflects a scenario where abatement equipment is introduced to theoretically reduce emissions to conform to the standards. This scenario is represented by the second column in the presentation of all AIR graphs (shown in red in Figure 5-2).
3. **Compliance with the 2020 new plant standards**. This is modelled as a ceiling emissions limit (i.e. maximum emission concentration) aligned with the prescribed standard, and reflects a scenario where abatement equipment is introduced to theoretically reduce emissions to conform to the standards. This scenario is then represented by the third column in the presentation of all AIR graphs (shown in green in Figure 5-2).
4. **A worst-case scenario of operating constantly at the requested alternative emissions limits**, which have been specified as ceiling emissions limits (i.e. maximum emission concentrations). This scenario is represented by the fourth column in the presentation of all AIR graphs (shown in purple in Figure 5-2). It is re-emphasised that SO will not physically increase its current baseline emissions (expressed as an average). SO seeks alternative emissions limits which are aligned with the manner in which the MES are stated and which accommodate the natural variability inherent in emissions under different operating conditions, and hence must request a ceiling emissions limit rather than an average emissions limit. The alternative emission limit is hence simply a different way of expressing current baseline emissions (in cases where further abatement is not possible), or may even reflect a reduction in average baseline emissions (in cases where further abatement is possible, but not to a level which achieves compliance with the MES ceiling emissions limits).

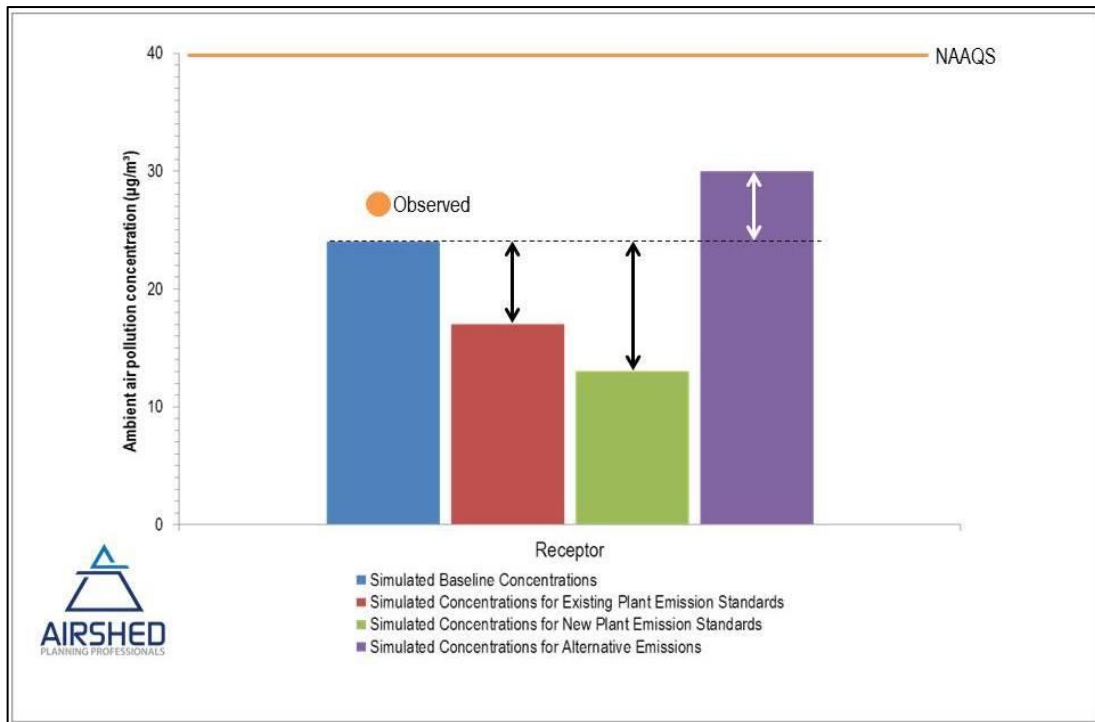


Figure 5-2: Schematic displaying how the dispersion modelling scenarios are presented, for each monitoring station receptor in the modelling domain

In Figure 5-2, the black arrows above the red and green bars reflect the predicted delta (change) in ambient impacts of SO₂'s baseline emissions versus the given compliance scenario. At a practical level, the white arrow on the purple bar represents the theoretical delta increase in short-term ambient impacts, where 100th percentile emissions occur, compared with the predicted impact of average current baseline emissions. The orange dot in Figure 5-2 represents physically measured ambient air quality, reflective of the total impact of all sources in the vicinity, as the 99th percentile recorded value over the averaging period. On a given day, there is a 99% chance that the actual measured ambient air quality would be lower than this value, but this value is reflected for the purpose of aligning with modelling requirements. The orange line represents the applicable NAAQS.

5.1.1.3 CALPUFF/CALMET Modelling Suite

As discussed in the previous section, the CALPUFF model was selected for use in the current investigation to predict maximum short-term (1 and 24-hour) and annual average ground-level concentrations at various receptor locations within the computational domain. CALPUFF is a multi-layer, multi-species non-steady-state puff dispersion model that can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal (Scire *et al.*, 2000a). It can accommodate arbitrarily varying point source, area source, volume source, and line source emissions. The CALPUFF code includes algorithms for near-source effects such as building downwash, transitional plume rise, partial plume penetration, sub grid scale terrain interactions as well as longer range effects such as pollutant removal due to wet scavenging and dry deposition, chemical transformation, vertical wind shear, overwater transport and coastal interaction effects.

The model is intended for use on scales from tens of metres to hundreds of kilometres from a source (US EPA 1998). The CALPUFF model allows the user to select from a number of calculation options, including a choice of dispersion coefficient and chemical transformation formulations. The different dispersion coefficient approaches accommodated in the CALPUFF model include:

- stability-based empirical relationships such as the Pasquill-Gifford or McElroy-Pooler dispersion coefficients;
- turbulence-based dispersion coefficients (based on measured standard deviations of the vertical and crosswind horizontal components of the wind); and
- similarity theory to estimate the turbulent quantities using the micrometeorological variables calculated by CALMET

The most desirable approach is to use turbulence-based dispersion coefficients using measured turbulent velocity variances or intensity components, if such data are readily available and they are of good quality. However, since reliable turbulent measurements are generally not available, the next best recommendation is to use the similarity approach.

CALPUFF includes parameterized chemistry modules for the formation of secondary sulfate and nitrate from the oxidation of the emitted primary pollutants, SO₂ and NO_x. The conversion processes are assumed to be linearly dependent (first-order) on the relevant primary species concentrations. Two options are included, namely the MESOPUFF II and RIVAD/ARM3 chemistry options. In both options, a fairly simple stoichiometric thermodynamic model is used to estimate the partitioning of total inorganic nitrate between gas-phase nitric acid and particle-phase ammonium nitrate. Ammonia and O₃ concentrations are required as background values to the model.

CALPUFF uses dry deposition velocities to calculate the dry deposition of gaseous and particulate pollutants to the surface. These dry deposition velocities can either be user-specified or calculated internally in CALPUFF. A resistance-based model is used for the latter option. For gaseous pollutants, the resistances that are considered are the atmospheric resistance, the deposition layer resistance, and the canopy resistance. For particles, a gravitational settling term is included and the canopy resistance is assumed to be negligible. CALPUFF uses the scavenging coefficient approach to parameterize wet deposition of gases and particles. The scavenging coefficient depends on pollutant characteristics (e.g., solubility and reactivity), as well as the precipitation rate and type of precipitation. The model provides default values for the scavenging coefficient for various species and two types of precipitation (liquid and frozen). These values may be overridden by the user.

CALPUFF also has the capability to model the effects of vertical wind shear by explicitly allowing different puffs to be independently advected by their local average wind speed and direction, as well as by optionally allowing well-mixed puffs to split into two or more puffs when across-puff shear becomes important. Another refinement is an option to use a probability density function (pdf) model to simulate vertical dispersion during convective conditions.

The CALPUFF modelling system consists of a number of software components, as summarised in Table 5-1, however only CALMET and CALPUFF contain the simulation engines to calculate the three-dimensional atmospheric boundary layer conditions and the dispersion and removal mechanisms of pollutants released into this boundary layer. The other components are mainly used to assist with the preparation of input and output data. Table 5-1 also includes the development versions of each of the codes used in this investigation.

Table 5-1: Summary description of CALPUFF/CALMET model suite with versions used in the investigation

Module	Version	Description
CALMET	v6.334	Three-dimensional, diagnostic meteorological model
CALPUFF	v6.42	Non-steady-state Gaussian puff dispersion model with chemical removal, wet and dry deposition, complex terrain algorithms, building downwash, plume fumigation and other effects.
CALPOST	V6.292	A post-processing program for the output fields of meteorological data, concentrations and deposition fluxes.
CALSUM	v1.4 ⁽¹⁾	Sums and scales concentrations or wet/dry fluxes from two or more source groups from

Module	Version	Description
		different CALPUFF runs
PRTMET	v 4.495 ⁽¹⁾	Lists selected meteorological data from CALMET and creates plot files
POSTUTIL	v1.641 ⁽¹⁾	Processes CALPUFF concentration and wet/dry flux files. Creates new species as weighted combinations of modelled species; merges species from different runs into a single output file; sums and scales results from different runs; repartitions nitric acid/nitrate based on total available sulfate and ammonia.
TERREL	v3.69 ⁽¹⁾	Combines and grids terrain data
CTGPROC	v3.5 ⁽¹⁾	Processes and grids land use data
MAKEGEO	v3.2 ⁽¹⁾	Merges land use and terrain data to produce the geophysical data file for CALMET

Note ⁽¹⁾: These modules indicate version number as listed on http://www.src.com/calpuff/download/mod6_codes.htm (for CALPro Plus v6) [version number not given in graphical interface or 'About' information].

A summary of the main CALMET and CALPUFF control options are given in Appendices D and E, respectively.

5.1.2 Legal Requirements

5.1.2.1 Atmospheric Impact Report

In the event where an application for postponement is being made, Section 21 of NEM: Air Quality Act (AQA), Regulations 11 and 12 state:

1. An application for postponement may be made to the National Air Quality Officer
2. The application contemplated in Regulation 11 must include, amongst others, an Atmospheric Impact Report.

The format of the Atmospheric Impact Report is stipulated in the Regulations Prescribing the Format of the AIR, Government Gazette No. 36904, Notice Number 747 of 2013 (11 October 2013) (Appendix B; Table B-1).

Sasol appointed Airshed to compile this AIR to meet the requirements of Regulation 12 (Postponement of compliance time frames) of the Listed Activities and Associated MES (Government Gazette No. 37054, 22 November 2013) (Appendix B; Table B-1).

5.1.2.2 National Ambient Air Quality Standards

Modelled concentrations will be assessed against NAAQS (Table 5-2), where they are prescribed by South African legislation. Where no NAAQS exists for a relevant non-criteria pollutant, health screening effect levels based on international guidelines are used. These are discussed with the results of dispersion modelling in Section 1.1.1.1.

Table 5-2: National Ambient Air Quality Standards

Pollutant	Averaging Period	Concentration ($\mu\text{g}/\text{m}^3$)	Frequency of Exceedance	Compliance Date
Benzene (C_6H_6)	1 year	5	0	1 January 2015
Carbon Monoxide (CO)	1 hour	30000	88	Immediate
	8 hour ^(a)	10000	11	Immediate
Lead (Pb)	1 year	0.5	0	Immediate
Nitrogen Dioxide (NO_2)	1 hour	200	88	Immediate
	1 year	40	0	Immediate
Ozone (O_3)	8 hour ^(b)	120	11	Immediate
Inhalable particulate matter less than $2.5 \mu\text{m}$ in diameter ($\text{PM}_{2.5}$)	24 hour	40	4	Immediate until 31 December 2029
	24 hour	25	4	1 January 2030
	1 year	20	0	Immediate until 31 December 2029
	1 year	15	0	1 January 2030
Inhalable particulate matter less than $10 \mu\text{m}$ in diameter (PM_{10})	24 hour	75	4	Immediate
	1 year	40	0	Immediate
Sulfur Dioxide (SO_2)	10 minutes	500	526	Immediate
	1 hour	350	88	Immediate
	24 hour	125	4	Immediate
	1 year	50	0	Immediate

Notes:

- (a) Calculated on 1 hour averages.
- (b) Running average.

5.1.2.3 National Dust Control Regulations

South Africa's Draft National Dust Control Regulations were published on 27 May 2011 with the dust fallout standards passed and subsequently published on 1 November 2013 (Government Gazette No. 36974). These are called the National Dust Control Regulations (NDCR). The purpose of the regulations is to prescribe general measures for the control of dust in all areas including residential and light commercial areas. Acceptable dustfall rates according to the regulations are summarised in Table 5-3.

Table 5-3: Acceptable dustfall rates

Restriction areas	Dustfall rate (D) in $\text{mg}/\text{m}^2\text{-day}$ over a 30 day average	Permitted frequency of exceedance
Residential areas	$D < 600$	Two within a year, not sequential months.
Non-residential areas	$600 < D < 1\,200$	Two within a year, not sequential months.

The regulations also specify that the method to be used for measuring dustfall and the guideline for locating sampling points shall be ASTM D1739 (1970), or equivalent method approved by any internationally recognized body. It is important to note that dustfall is assessed for nuisance impact and not inhalation health impact.

5.1.3 Regulations Regarding Air Dispersion Modelling

Air dispersion modelling provides a cost-effective means for assessing the impact of air emission sources, the major focus of which is to determine compliance with the relevant ambient air quality standards. Regulations regarding Air Dispersion Modelling were promulgated in Government Gazette No. 37804 vol. 589; 11 July 2014, and recommend a suite of dispersion models to be applied for regulatory practices as well as guidance on modelling input requirements, protocols and procedures to be followed. The Regulations Regarding Air Dispersion Modelling are applicable:

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

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

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

Dispersion modelling can typically be used in the:

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

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

- Stack height increases;

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

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

New generation dispersion models, including models such as AERMOD and CALPUFF¹, simulate the dispersion process using planetary boundary layer (PBL) scaling theory. PBL depth and the dispersion of pollutants within this layer are influenced by specific surface characteristics such as surface roughness, albedo and the availability of surface moisture:

- Roughness length (z_0) is a measure of the aerodynamic roughness of a surface and is related to the height, shape and density of the surface as well as the wind speed.
- Albedo is a measure of the reflectivity of the Earth's surface. This parameter provides a measure of the amount of incident solar radiation that is absorbed by the Earth/atmosphere system. It is an important parameter since absorbed solar radiation is one of the driving forces for local, regional, and global atmospheric dynamics.
- The Bowen ratio provides measures of the availability of surface moisture injected into the atmosphere and is defined as the ratio of the vertical flux of sensible heat to latent heat, where sensible heat is the transfer of heat from the surface to the atmosphere via convection and latent heat is the transfer of heat required to evaporate liquid water from the surface to the atmosphere.

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

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

Chapter 5 provides general guidance on geophysical data, model domain and coordinates system required in dispersion modelling, whereas Chapter 6 elaborates more on these parameters as well as the inclusion of background air concentration data. The chapter also provides guidance on the treatment of NO₂ formation from NO_x emissions, chemical transformation of sulfur dioxide into sulfates and deposition processes.

Chapter 7 of the Regulations outline how the plan of study and modelling assessment reports are to be presented to authorities. A comparison of how this study met the requirements of the Regulations is provided in Appendix B.

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

5.1.4 Atmospheric Dispersion Processes

CALPUFF initiates the simulation of point source plumes with a calculation of buoyant plume rise as discussed below in Section 5.1.4.1. Transport winds are extracted from the meteorological data file at the location of the stack and at the effective plume height (stack height plus plume rise). For near-field effects, the height of the plume in transition to the final plume height is taken into account. The puff release rate is calculated internally, based on the transport speed and the distance to the closest receptor.

As the puff is transported downwind, it grows due to dispersion and wind shear, and the trajectory is determined by advection winds at the puff location and height at each time step. The pollutant mass within each puff is initially a function of the emission rate from the original source. The pollutant mass is also subject to chemical transformation, washout by rain and dry deposition, when these options are selected, as is the case in this application. Chemical transformation and removal are calculated based on a one-hour time step.

Both wet and dry deposition fluxes are calculated by CALPUFF, based on a full resistance model for dry deposition and the use of precipitation rate-dependent scavenging coefficients for wet deposition. Pollutant mass is removed from the puff due to deposition at each time step. For the present modelling analyses, most options were set at “default” values, including the MESOPUFF II transformation scheme² and the treatment of terrain.

5.1.4.1 Plume Buoyancy

Gases leaving a stack mix with ambient air and undergo three phases namely the initial phase, the transition phase and the diffusion phase (Figure 5-3). The initial phase is greatly determined by the physical properties of the emitted gases. These gases may have momentum as they enter the atmosphere and are often heated and therefore warmer than the ambient air. Warmer gases are less dense than the ambient air and are therefore buoyant. A combination of the gases' momentum and buoyancy causes the gases to rise (vertical jet section, in Figure 5-3). In the Bent-Over Jet Section, entrainment of the cross flow is rapid because, by this time, appreciable growth of vortices has taken place. The self-generated turbulence causes mixing and determines the growth of plume in the thermal section. This is referred to as plume rise and allows air pollutants emitted in this gas stream to be lifted higher in the atmosphere. Since the plume is higher in the atmosphere and at a further distance from the ground, the plume will disperse more before it reaches ground level. With greater volumetric flow and increased exit gas temperatures, the plume centreline would be higher than if either the volumetric flow or the exit gas temperature is reduced. The subsequent ground level concentrations would therefore be lower.

² A sensitivity study was carried out with the RIVAD II transformation scheme to examine the performance of the different approaches to calculating the SO₂ to SO₄ and NO_x to NO₃ transformation rates. The concentrations from the RIVAD II and the MESOPUFF II transformation schemes showed no real bias with the secondary particulate formation varying by -41% to 31% for the two schemes.

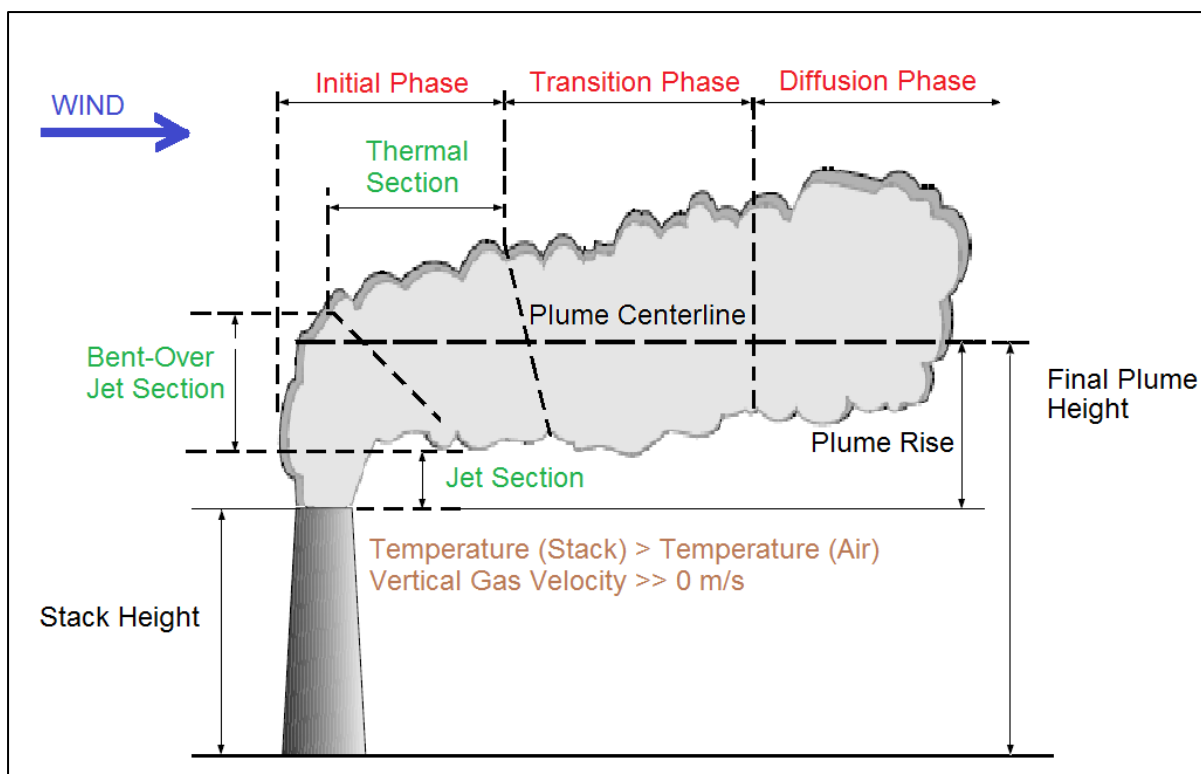


Figure 5-3: Plume buoyancy

This is particularly important in understanding some of the dispersion model results in Section 5.1.8. As an example, consider the emissions from a boiler. With the introduction of retrofitted emission controls (e.g. wet scrubber or bag filters), the exit gas temperature and perhaps the volumetric flow would be lower than the original values. Thus it is quite possible that the resultant decrease in plume momentum and buoyancy may actually result in higher ground level concentrations despite the reduction in point source emission concentrations, due to the lower plume centreline.

5.1.4.2 Urban & Rural Conditions

Land use information is important to air dispersion modelling, firstly to ensure that the appropriate dispersion coefficients and wind profiles (specified as surface roughness) are used, and secondly, that the most appropriate chemical transformation models are employed. Urban conditions result in different dispersion conditions than in rural areas, as well as changing the vertical wind profiles. Urban conditions are also generally associated with increased levels of VOCs, thereby influencing chemical equilibria between the photochemical reactions of NO_x , CO and O_3 .

It can be appreciated that the definition of urban and rural conditions for the dispersion coefficients and wind profiles, on the one hand, and chemical reactions on the other, may not be the same. Nonetheless, it was decided to use the US Environmental Protection Agency's (US EPA's) guideline on air dispersion models (US EPA 2005), to classify the surrounding land-use as rural or urban based on the Auer method, which is strictly recommended for selecting dispersion coefficients.

The classification scheme is based on the activities within a 3 km radius of the emitting stack. Areas typically defined as rural include residences with grass lawns and trees, large estates, metropolitan parks and golf courses, agricultural areas, undeveloped land and water surfaces. An area is defined as urban if it has less than 35% vegetation coverage or the area falls into one of the use types in Table 5-4.

Table 5-4: Definition of vegetation cover for different developments (US EPA 2005)

Urban Land-Use		
Type	Development Type	Vegetation Cover
I1	Heavy industrial	Less than 5%
I2	Light/moderate industrial	Less than 10%
C1	Commercial	Less than 15%
R2	Dense/multi-family	Less than 30%
R3	Multi-family, two storey	Less than 35%

According to this classification scheme, the study area is classified as urban.

5.1.4.3 Nitrogen Dioxide Formation

Of the several species of nitrogen oxides, only NO₂ is specified in the NAAQS. Since most sources emit uncertain ratios of these species and these ratios change further in the atmosphere due to chemical reactions, a method for determining the amount of NO₂ in the plume must be selected.

Estimation of this conversion normally follows a tiered approach, as discussed in the Regulations Regarding Air Dispersion Modelling (Government Gazette No. 37804, published 11 July 2014), which presents a scheme for annual averages:

Tier 1: Total Conversion Method

Use any of the appropriate models recommended to estimate the maximum annual average NO₂ concentrations by assuming a total conversion of NO to NO₂. If the maximum NO_x concentrations are less than the NAAQS for NO₂, then no further refinement of the conversion factor is required. If the maximum NO_x concentrations are greater than the NAAQS for NO₂, or if a more "realistic" estimate of NO₂ is desired, proceed to the second tier level.

Tier 2: Ambient Ratio Method (ARM) - Multiply NO_x by a national ratio of NO₂/NO_x = 0.80

Assume a wide area quasi-equilibrium state and multiply the Tier 1 empirical estimate NO_x by a ratio of NO₂/NO_x = 0.80. The ratio is recommended for South Africa as the conservative ratio based on a review of ambient air quality monitoring data from the country. If representative ambient NO and NO₂ monitoring data is available (for at least one year of monitoring), and the data is considered to represent a quasi-equilibrium condition where further significant changes of the NO/NO₂ ratio is not expected, then the NO/NO₂ ratio based on the monitoring data can be applied to derive NO₂ as an alternative to the national ratio of 0.80.

In the Total Conversion Method, the emission rate of all NO_x species is used in the dispersion model to predict ground-level concentrations of total NO_x. These levels of NO_x are assumed to exist as 100% NO₂, and are directly compared to the NAAQS for NO₂. If the NAAQS are met, the Tier 2 methods are not necessary.

Although not provided in the Regulations (Section 5.1.3), the conversion of NO to NO₂ may also be based on the amount of ozone available within the volume of the plume. The NO₂/NO_x conversion ratio is therefore coupled with the dispersion of the plume. This is known as the Ozone Limiting Method (OLM). Use of onsite ozone data is always preferred for the OLM method.

Ideally, the NO₂ formation should be dealt with in the dispersion model. CALPUFF has one such a module, known as the RIVAD / ARM3 chemical formulations. The RIVAD / ARM3 chemical formulations option in the CALPUFF model can be used to calculate NO₂ concentrations directly in rural (non-urban) areas (Morris et al., 1988). The RIVAD / ARM3 option

incorporates the effect of chemical and photochemical reactions on the formation of nitrates and other deposition chemicals. However, since the study area could be classified as urban (Section 5.1.4.2), the RIVAD / ARM3 chemical formulations should not be used.

Whilst the MESOPUFF II chemical transformation scheme, which is also included in the CALPUFF model accommodates NO_x reactions, these are only considering the formation of nitrates and not the NO / NO_2 reactions.

Given all of the above limitations, it was decided to employ the Ambient Ratio Method (ARM), i.e. the second version of the DEA Tier 2 option. The ARM ambient ratio method is based upon the premise that the NO_2/NO_x ratio in a plume changes as it is transported but attains an equilibrium value some distance away from the source (Scire and Borissova, 2011). In their study, Scire and Borissova analysed hourly monitored NO_2 and NO_x data for 2006 at 325 monitoring sites throughout USA, which amounted to approximately 2.8 million data points for each species. These observations were grouped into a number of concentration ranges (bins), and the binned data were used to compute bin maximums and bin average curves. Short-term (1-hr) NO_2/NO_x ratios were subsequently developed based on bin-maximum data. Similarly, long-term (annual average) NO_2/NO_x ratios were based on bin-averaged data. The method was tested using the NO_2/NO_x ratios applied to the observed NO_x at selected stations to predict NO_2 , and then compared to observed NO_2 concentrations at that station. The comparison of NO_2 derived from observed NO_x using these empirical curves was shown to be a conservative estimate of observed NO_2 , whilst at the same time arriving at a more realistic approximation than if simply assuming a 100% conversion rate. More details of the adopted conversion factors are given in Appendix F.

5.1.4.4 *Particulate Formation*

CALPUFF includes two chemical transformation schemes for the calculation of sulfate and nitrate formation from SO₂ and NO_x emissions. These are the MESOPUFF II and the RIVAD / ARM3 chemical formulations. Whilst the former scheme is not specifically restricted to urban or rural conditions; the latter was developed for use in rural conditions. Since the study area could be classified as urban (Section 5.1.5), the RIVAD / ARM3 chemical formulations should not be used. The chemical transformation scheme chosen for this analysis was therefore the MESOPUFF II scheme. As described in the CALPUFF User Guide it is a “pseudo first-order chemical reaction mechanism” and involves five pollutant species namely SO₂, sulfates (SO₄), NO_x, nitric acid (HNO₃) and particulate nitrate. CALPUFF calculates the rate of transformation of SO₂ to SO₄, and the rate of transformation of NO_x to NO₃, based on environmental conditions including the ozone concentration, atmospheric stability, solar radiation, relative humidity, and the plume NO_x concentration. The daytime reaction formulation depends on solar radiation and the transformation increases non-linearly with the solar radiation (see the SO₂ to SO₄ transformation rate equation (equation 2-253 in the CALPUFF User Guide). At night, the transformation rate defaults to a constant value of 0.2% per hour. Calculations based on these formulas show that the transformation rate can reach about 3 per cent per hour at noon on a cloudless day with 100 ppb of ozone.

With the MESOPUFF-II mechanism, NO_x transformation rates depend on the concentration levels of NO_x and O₃ (equations 2-254 and 2-255 in the CALPUFF User Guide) and both organic nitrates (RNO₃) and HNO₃ are formed. According to the scheme, the formation of RNO₃ is irreversible and is not subject to wet or dry deposition. The formation of HNO₃, however, is reversible and is a function of temperature and relative humidity. The formation of particulate nitrate is further determined through the reaction of HNO₃ and NH₃. Background NH₃ concentrations are therefore required as input to calculate the equilibrium between HNO₃ and particulate nitrate. At night, the NO_x transformation rate defaults to a constant value of 2.0% per hour. Hourly average ozone and ammonia concentrations were included as input in the CALPUFF model to facilitate these sulfate and nitrate formation calculations.

The limitation of the CALPUFF model is that each puff is treated in isolation, i.e. any interaction between puffs from the same or different points of emission is not accounted for in these transformation schemes. CALPUFF first assumes that ammonia reacts preferentially with sulfate, and that there is always sufficient ammonia to react with the entire sulfate present within a single puff. The CALPUFF model performs a calculation to determine how much NH₃ remains after the particulate sulfate has been formed and the balance would then be available for reaction with NO₃ within the puff. The formation of particulate nitrate is subsequently limited by the amount of available NH₃. Although this may be regarded a limitation, in this application the particulate formation is considered as a group and not necessarily per species.

5.1.4.5 *Ozone Formation*

Similar to sulphate, nitrate and nitrogen dioxide, O₃ can also be formed through chemical reactions between pollutants released into the atmosphere. As a secondary pollutant, O₃ is formed in the lower part of the atmosphere, from complex photochemical reactions following emissions of precursor gases such as NO_x and VOCs (Seinfeld and Pandis, 1998). O₃ is produced during the oxidation of CO and hydrocarbons by hydroxyls (OH) in the presence of NO_x and sunlight (Seinfeld and Pandis, 1998). The rate of ozone production can therefore be limited by CO, VOCs or NO_x. In densely populated regions with high emissions of NO_x and hydrocarbons, rapid O₃ production can take place and result in a surface air pollution problem. In these urban areas O₃ formation is often VOC-limited. O₃ is generally NO_x-limited in rural areas and downwind suburban areas.

O₃ concentration levels have the potential to become particularly high in areas where considerable O₃ precursor emissions combine with stagnant wind conditions during the summer, when high insolation and temperatures occur (Seinfeld and Pandis, 1998). The effects of sunlight on O₃ formation depend on its intensity and its spectral distribution.

The main sectors that emit ozone precursors are road transport, power and heat generation plants, household (heating), industry, and petrol storage and distribution. In many urban areas, O₃ nonattainment is not caused by emissions from the local area alone. Due to atmospheric transport, contributions of precursors from the surrounding region can also be important. The transport of O₃ is determined by meteorological and chemical processes which typically extend over spatial scales of several hundred kilometres. Thus, in an attempt to study O₃ concentrations in a local area, it is necessary to include regional emissions and transport. This requires a significantly larger study domain with the inclusion of a significantly more comprehensive emissions inventory of NO_x and VOCs sources (e.g. vehicle emissions in Gauteng). Such a collaborative study was not within the scope of this report.

5.1.4.6 Model Input

5.1.4.6.1 Meteorological Input Data

The option of Partial Observations was selected for the CALMET wind field model which used both simulated and observed meteorological data (refer to Appendix D for all CALMET control options). For simulated data, the Weather Research and Forecasting mesoscale model (known as WRF) was used.

The WRF Model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. It features two dynamical cores, a data assimilation system, and a software architecture facilitating parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometres. WRF can generate atmospheric simulations using real data (observations, analyses) or idealized conditions. WRF offers operational forecasting a flexible and computationally-efficient platform, while providing recent advances in physics, numeric, and data assimilation contributed by developers across the very broad research community.

WRF data for the period 2013 to 2015 on a 4 km horizontal resolution for a 200 km by 200 km was used. An evaluation of the WRF data is provided in Table 5-5 with the benchmark for the WRF data provided in Table 5-4. This evaluation was undertaken for a point extracted at OR Tambo (see Figure 5-8). OR Tambo was selected for the evaluation as it is expected that the data quality at this weather station is of high standard. From the evaluation, the daily average WRF results for the period 2013 to 2015 were within the benchmarks for model evaluation, with the exception of the gross error for the wind direction (WRF providing value of 35 degrees where benchmark is at ≤30 degrees) and index of agreement for humidity (WRF providing value of 0.55 where benchmark is at ≥0.6). A comparison of wind roses from measured meteorological data at OR Tambo (Figure 5-4) to CALMET data (extracted at OR Tambo) (Figure 5-5) is provided below. The measured wind direction at OR Tambo has a higher frequency of winds from the north than the WRF data. The gross error for wind direction could influence the CALPUFF simulated pollutant concentrations by up to 35 degrees. This is limited by the inclusion of measured wind speed and direction at surface stations near SO.

Table 5-5: Benchmarks for WRF Model Evaluation

	Wind Speed	Wind Direction	Temperature	Humidity
IOA	≥ 0.6		≥ 0.8	≥ 0.6
RMSE	≤ 2 m/s			
Mean Bias	≤ ± 0.5 m/s	≤ ± 10 deg	≤ ± 0.5 K	≤ ± 1 g/kg
Gross Error		≤ 30 deg	≤ 2 K	≤ 2 g/kg

Table 5-6: Daily evaluation results for the WRF simulations for the 2013-2015 extracted at OR Tambo

	Wind Speed	Wind Direction	Temperature	Humidity
IOA	0.61		0.91	0.55
RMSE	1.54			
Mean Bias	-0.09	-1.48	-0.46	-0.14
Gross Error		34.97	1.60	1.01

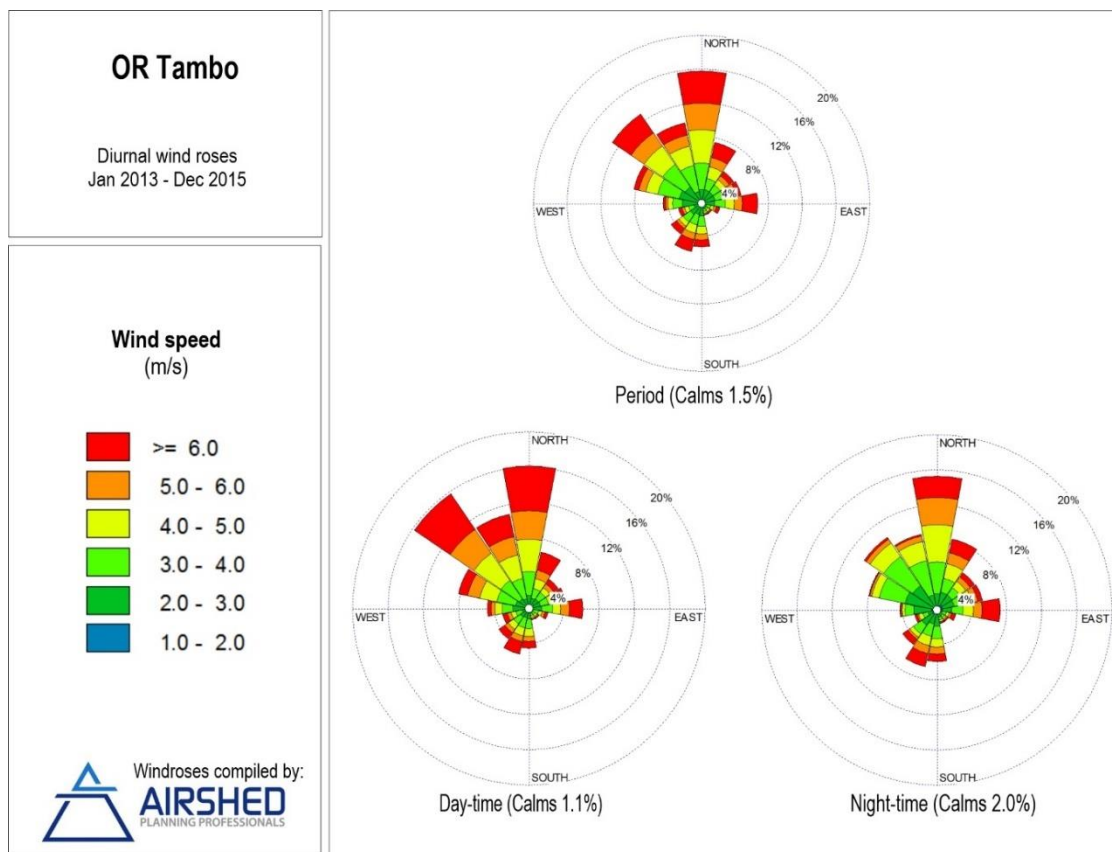


Figure 5-4: Period, day- and night-time wind rose for OR Tambo for the period 2013 - 2015

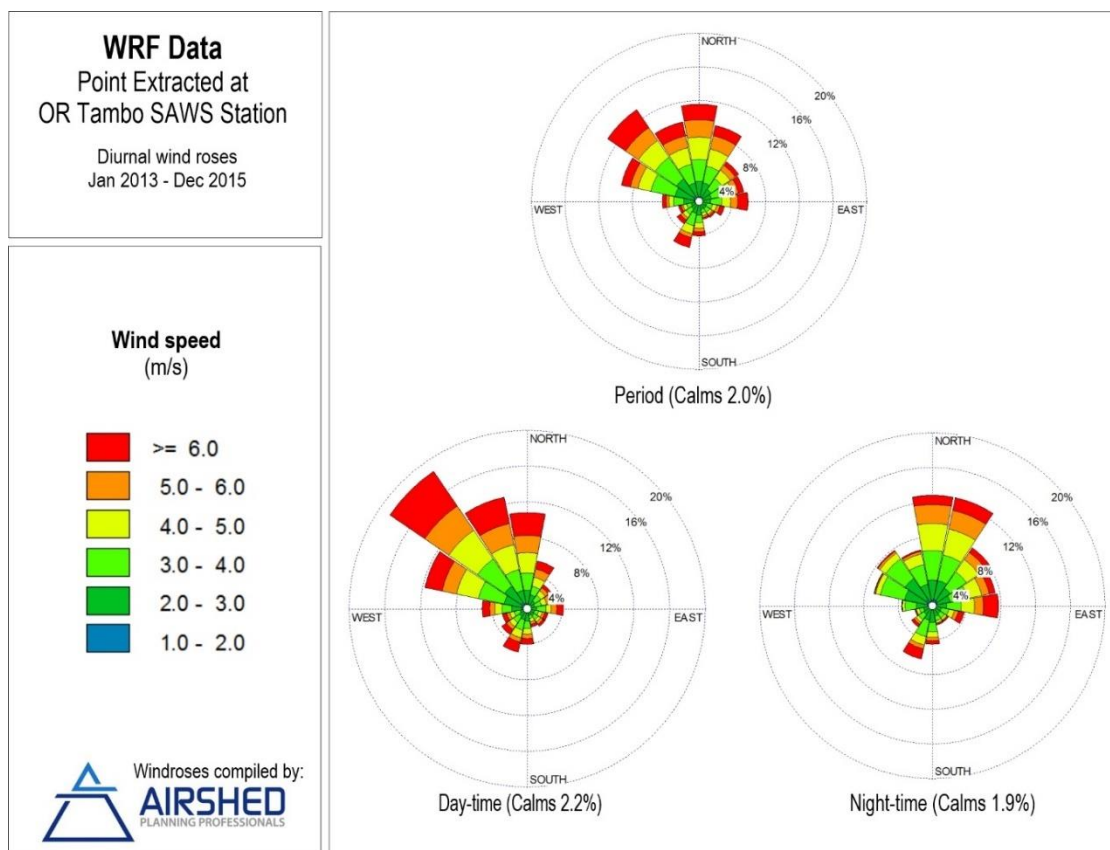


Figure 5-5: Period, day- and night-time wind rose for WRF data as extracted at OR Tambo for the period 2013 - 2015

WRF data was supplemented with surface field observations from four monitoring stations operated by Sasol in the Sasolburg area and three monitoring stations operated by Sasol in the Secunda area. Meteorological parameters provided for the Sasol monitoring stations in the Sasolburg area are provided in Table 5-7.

Table 5-7: Meteorological parameters provided for the Sasol monitoring stations in the Sasolburg area

Monitoring Station	Latitude	Longitude	Closest Residential Area	Meteorology						
				WD	WS	Temp	RH	Press	SR	Rain
Sasol 1 Fence Line*	-26.834722	27.848611	Sasolburg	✓	✓	✓	✓	✓	✓	✓
Eco Park	-26.777619	27.837317	Vaalpark	✓	✓	✓	✓	✓	✓	✓
AJ Jacobs	-26.822778	27.826111	Sasolburg	✓	✓	✓				
Leitrim	-26.850278	27.874167	Sasolburg	✓	✓	✓		✓		

* Sasol 1 Fence Line used only as a meteorological station and for measured ammonia (NH₃) used to estimate secondary particulate formation in CALPUFF but not for ambient concentration comparison, due to potential bias to industry as the station is located on-site.

WD: Wind direction
WS: Wind speed
Temp: Temperature
RH: Relative humidity
Press: Surface pressure
SR: Solar radiation

Figure 5-6 and Figure 5-7 provides examples of the CALMET layer 1 (up to 20 m above surface) wind vector plots from the CALMET data for 15 May 2013 at 05:00 and 2 February 2014 at 05:00 respectively. The spatial variations in the wind field over parts of the domain are due to terrain effects which are to be expected during this part of the diurnal cycle.

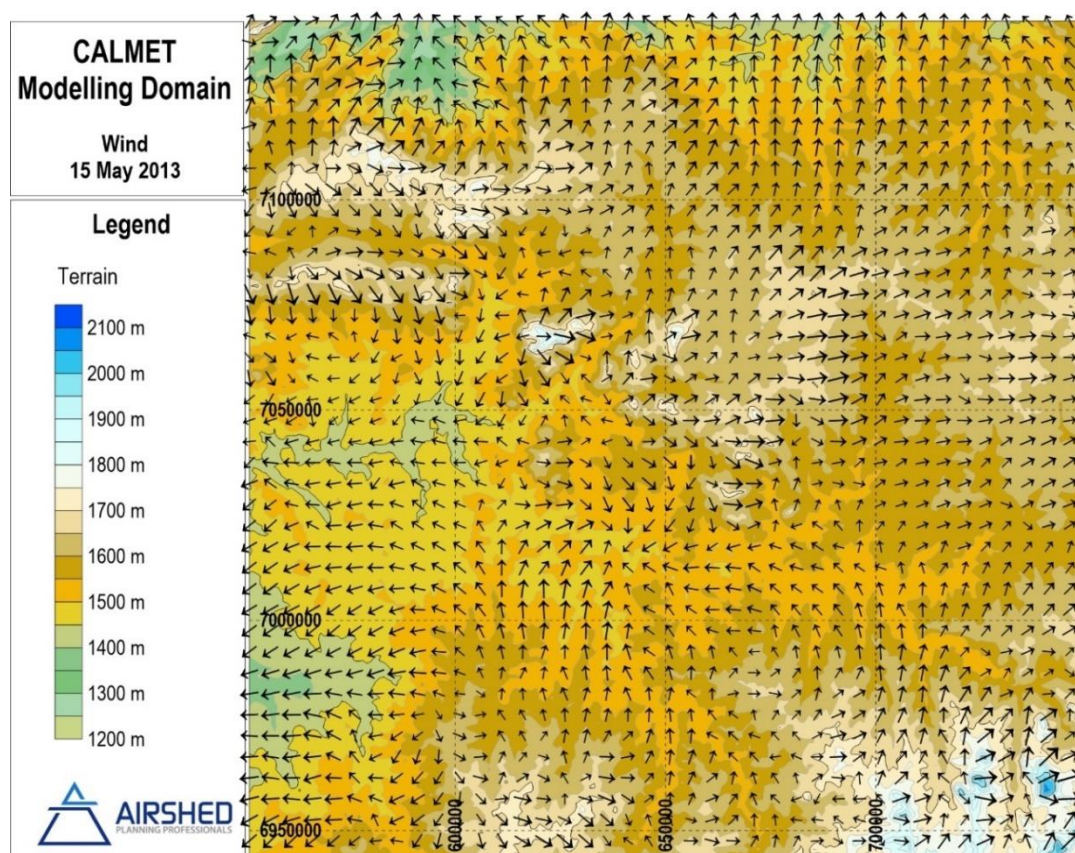


Figure 5-6: CALMET Layer 1 wind vector plot for 15 May 2013 at 05:00

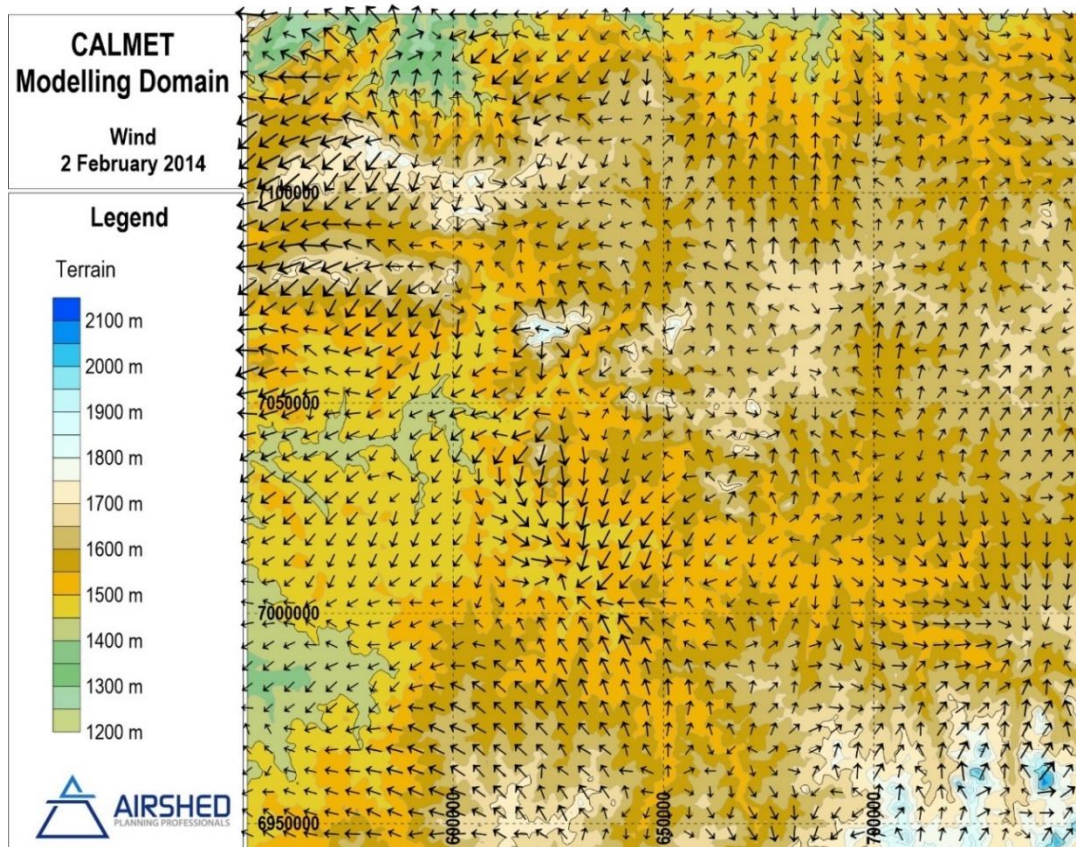


Figure 5-7: CALMET Layer 1 wind vector plot for 2 February 2014 at 05:00

5.1.4.6.2 Land Use and Topographical Data

Readily available terrain and land cover data for use in CALMET was obtained from the Atmospheric Studies Group (ASG) via the United States Geological Survey (USGS) web site at ASG. Use was made of Shuttle Radar Topography Mission (SRTM) (90 m, 3 arc-sec) data and Lambert Azimuthal land use data for Africa.

Figure 5-8 provides the terrain contours and landuse categories over the entire CALMET domain and the location of the CALPUFF computational domain.

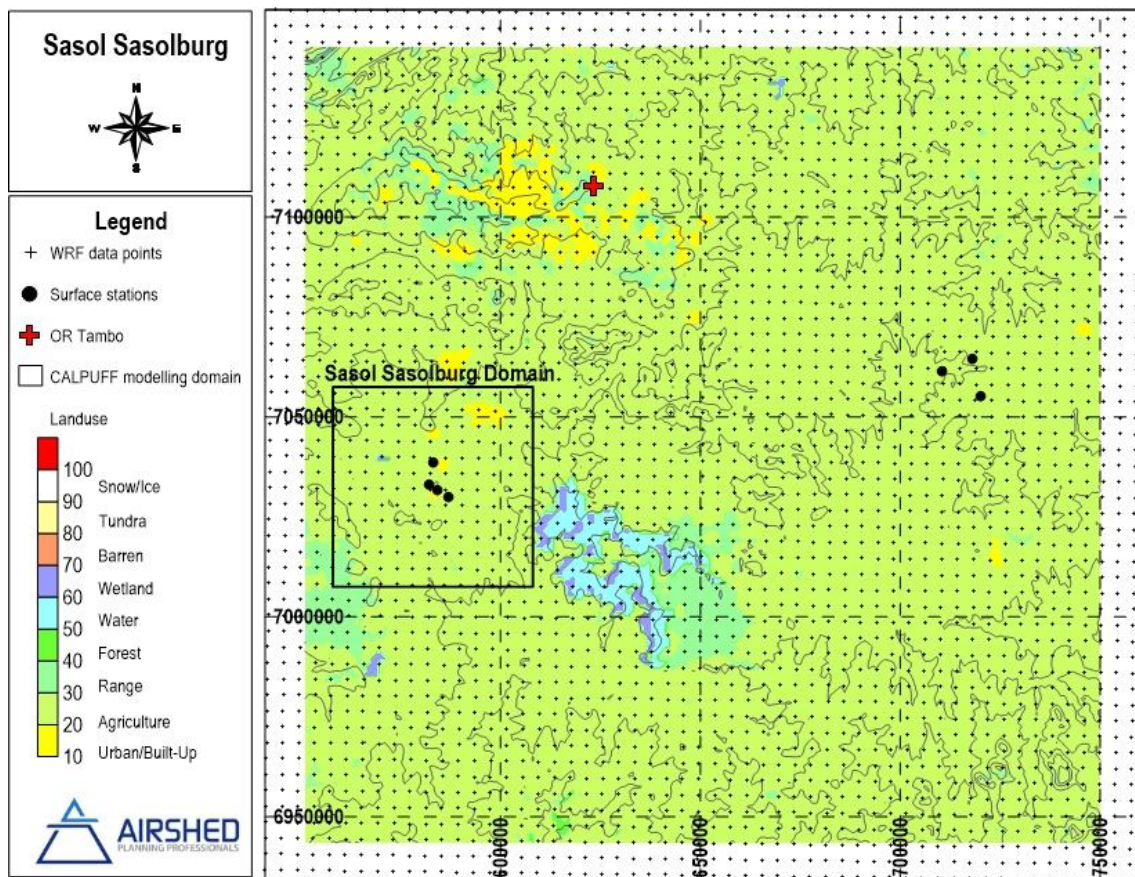


Figure 5-8: Land use categories, terrain contours, meteorological WRF grid points and surface station locations displayed on 200 x 200 km CALMET domain (1 km resolution)

5.1.4.6.3 Dispersion Coefficients

The option of dispersion coefficients from internally calculated sigma v, sigma w using micrometeorological variables (u^* , w^* , L , etc.) was selected (refer to Appendix E for all CALPUFF control options).

5.1.4.6.4 Grid Resolution and Model Domain

The CALMET modelling domain included an area of 200 km by 200 km with a grid resolution of 1 km. The vertical profile included 11 vertical levels up to a height of 3 500 m. The CALPUFF model domain selected for the sources at the Sasol Sasolburg facility included an area of 50 km by 50 km with a grid resolution of 200 m. This area was selected based on the area of impact around Sasolburg simulated during an assessment undertaken for the Vaal Triangle Airshed Priority Area.

5.1.4.6.5 Building downwash

The impact of building downwash on ground-level pollutant concentrations was evaluated using "ScreenView" - a Tier 1 screening model which includes the same building downwash scheme as CALPUFF. For the most conservative simulation of downwind concentrations "ScreenView" was used with a full meteorological set. The SO site was selected for evaluation due to the relatively short distances between sources and receptors. The screening exercise assessed the individual impact of three sources selected based on location; stack height; proximity to nearby buildings (excluding complex pipework

structures); and, proximity to receptors. The baseline emission parameters (temperature, release height, exit velocities, etc.) were used in combination with three theoretical building heights (10, 15, and 20 m). A single emission rate (1 m/s) was used to simulated the ground-level concentrations at automated distances between 1 m and 5 000 m from the sources, at 100 m intervals.

The screening assessment indicated that building downwash did not affect downwind concentration as a result of the boilers, due to height of release (75 m for Steam Station 1). Sources with lower release heights (15 m and 20 m) were found to increase ground-level concentrations downwind of the source where the scale of increase was dependent on the height of the near-by building. The distance after which simulate ground-level concentrations matched levels for comparative simulations where building downwash was not included was a minimum of 1 800 m.

Due to the close proximity between sources, buildings and receptors at the SO facility, building downwash was accounted for in the dispersion modelling, specifically buildings and sources along the western boundary of the facility, which is within 100 m of a residential area (Table 5-8). The AERMOD Building Profile Input Program (BPIP) module was used to generate a building downwash input file for CALPUFF where building dimensions were provided by Sasol.

Table 5-8: Parameters of buildings on the SO facility included in the dispersion modelling

Building ID	Latitude	Longitude	Height (m)	X length (m)	Y length (m)	Angle from North
1	-26.83214	27.84326	10.0	15.0	24.0	332°
2	-26.83169	27.84446	10.1	30.5	50.5	332°
3	-26.83192	27.84290	8.5	30.0	30.0	332°
4	-26.83164	27.84270	37.0	11.2	24.0	332°
5A	-26.83199	27.84266	6.0	18.0	19.0	332°
5B	-26.83206	27.84254	6.0	12.0	30.0	332°
5C	-26.83182	27.84256	9.0	5.0	14.0	332°
6A	-26.83197	27.84236	8.0	9.0	14.0	332°
6B	-26.83170	27.84233	6.0	7.0	7.0	332°
6C	-26.83172	27.84251	6.0	9.0	10.0	332°
7	-26.83188	27.84188	12.0	12.0	3.5	332°
8A	-26.83207	27.84156	7.0	6.0	11.0	332°
8B	-26.83197	27.84149	4.0	6.0	30.0	332°
9	-26.83156	27.84206	2.0	5.0	12.0	332°
11	-26.83135	27.84253	37.0	40.0	40.0	332°
13	-26.83249	27.84264	5.0	11.0	35.0	332°
16	-26.82605	27.84036	13.0	20.0	32.6	63°
17	-26.82843	27.84057	13.6	32.0	55.0	332°
19	-26.82878	27.84025	13.6	40.0	90.0	332°
20	-26.82874	27.84082	13.0	22.0	25.0	332°
21	-26.82951	27.84067	9.0	16.0	22.0	332°
22	-26.82994	27.84130	10.0	16.8	42.2	22.5°
23	-26.82524	27.83835	10.0	19.9	43.8	332°
24	-26.82574	27.83844	26.6	18.0	20.0	332°
25	-26.82623	27.83830	10.0	17.5	79.2	63°

5.1.5 Atmospheric Dispersion Potential

Meteorological mechanisms govern the dispersion, transformation, and eventual removal of pollutants from the atmosphere. The analysis of hourly average meteorological data is necessary to facilitate a comprehensive understanding of the dispersion potential of the site. The horizontal dispersion of pollution is largely a function of the wind field. The wind speed determines both the distance of downward transport and the rate of dilution of pollutants. A summary of the measured meteorological data is given in Appendix G.

Sasol currently operate four meteorological stations in the Sasolburg area (viz. Sasol 1 Fence Line, Eco Park, AJ Jacobs and Leirim). For this assessment, data from the Sasol operated meteorological stations was provided for the period 2013 to 2015. Parameters useful in describing the dispersion and dilution potential of the site (i.e. wind speed, wind direction, temperature and atmospheric stability) are subsequently discussed.

5.1.5.1 *Surface Wind Field*

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

The period wind field and diurnal variability (2013 to 2015) for the four Sasol operated meteorological stations in the Sasolburg area is provided in Figure 5-9 to Figure 5-12.

The predominant flow field at Sasol 1 Fence Line is from the easterly and westerly sectors with the highest frequency of winds from the east-southeast (~10%). During day-time conditions winds from the west increase while winds from the east-southeast are more frequent during night-time conditions. A high frequency of strong winds (>6m/s) are measured at this monitoring station (Figure 5-9).

The predominant flow field at Eco Park is from the east-southeast (~10%). During day-time conditions winds from the north-western sector increases while winds from the east-southeast are more frequent during night-time conditions (Figure 5-10).

The predominant wind direction at AJ Jacobs is from the north-northeast (~8% frequency of occurrence) (Figure 5-11). Very little wind is measured from the south-eastern sector. During day-time conditions winds from the western sector increase while winds from the north-northeast are more frequent during night-time conditions. A higher frequency of low-speed winds (1-2 m/s) was measured at this monitoring station.

The predominant wind direction at Leirim is from the north-northeast (~10% frequency of occurrence). During day-time conditions winds from the western sector increase while winds from the north and north-northeast are more frequent during night-time conditions (Figure 5-12).

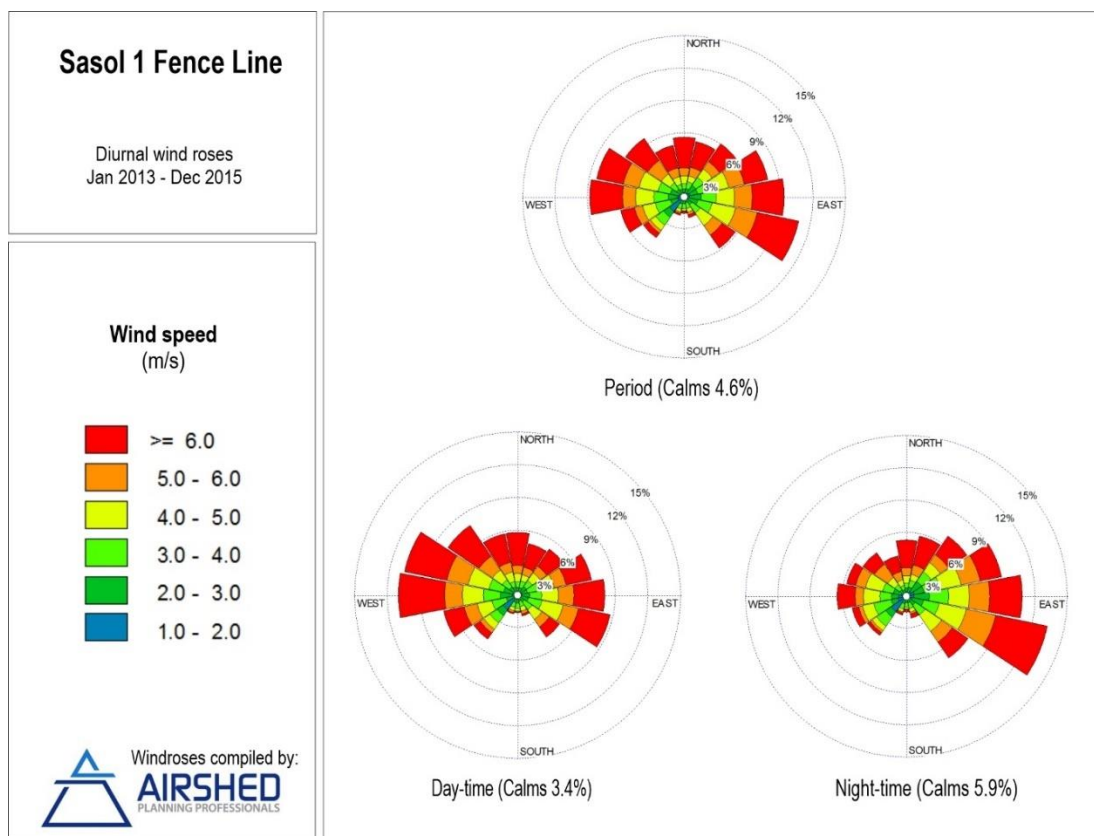


Figure 5-9: Period, day- and night-time wind rose for Sasol 1 Fence Line for the period 2013 - 2015

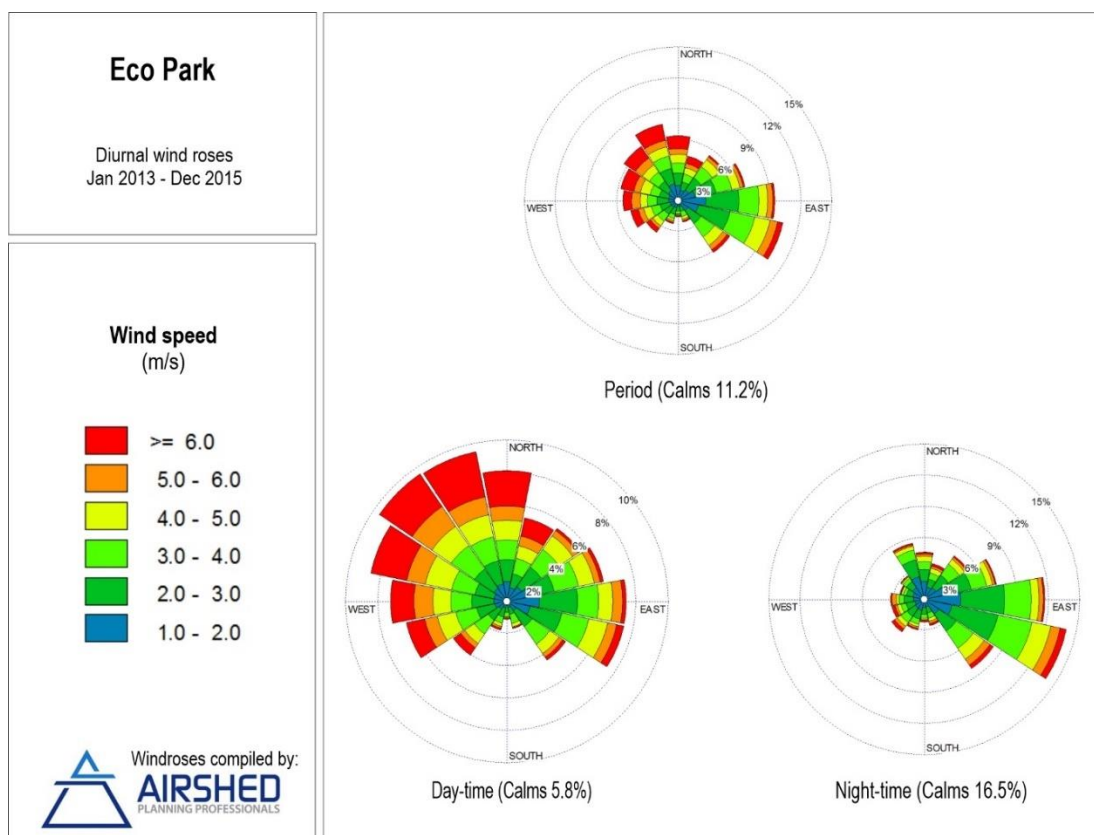


Figure 5-10: Period, day- and night-time wind rose for Eco Park for the period 2013 - 2015

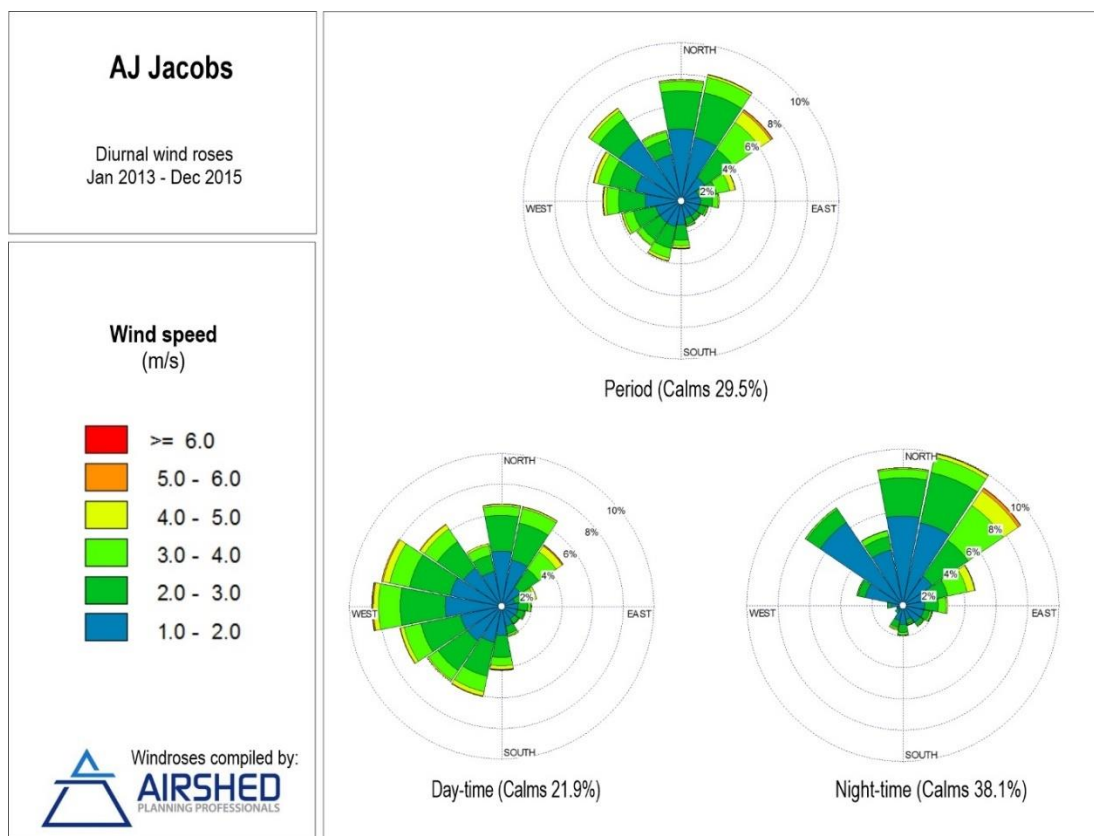


Figure 5-11: Period, day- and night-time wind rose for AJ Jacobs for the period 2013 - 2015

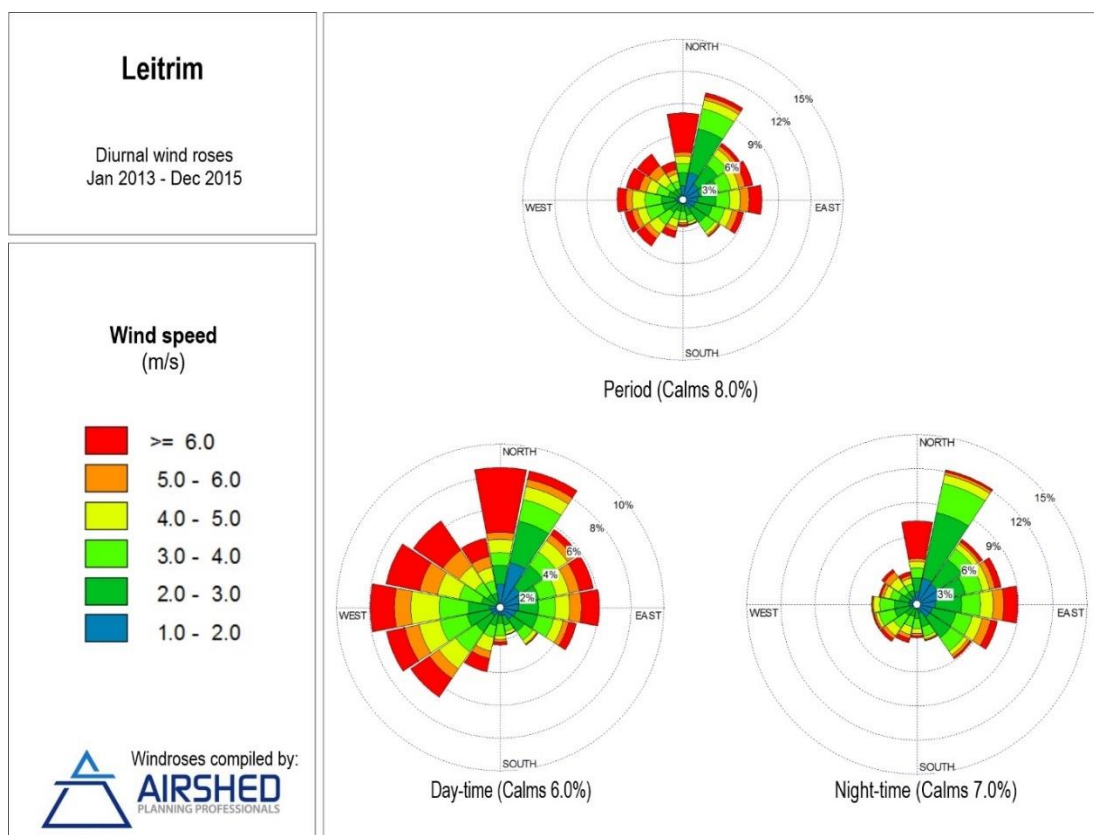


Figure 5-12: Period, day- and night-time wind rose for Leitrim for the period 2013 - 2015

5.1.5.2 Temperature

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

The average monthly temperature trends are presented in Figure 5-13, Figure 5-14 and Figure 5-15 for Sasol 1 Fence Line, Eco Park and Leitrim respectively. The majority (98.4%) of the temperature data provided for AJ Jacobs for the period 2013-2015 ranged between 19°C and 28°C. Due to the relatively small variation of temperature values recorded at AJ Jacobs the data appears to be inaccurate and were not included in the CALMET simulations. Monthly mean and hourly maximum and minimum temperatures are given in Table 5-7. Average temperatures ranged between 6.9 °C and 22.6 °C. The highest temperatures occurred in January/February and the lowest in June. During the day, temperatures increase to reach maximum at around 15:00 in the afternoon. Ambient air temperature decreases to reach a minimum at around 07:00 i.e. just before sunrise.

Table 5-9: Monthly temperature summary (2013 - 2015)

Hourly Minimum, Hourly Maximum and Monthly Average Temperatures (°C) (2013 - 2015)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sasol 1 Fence Line												
Minimum	13.8	13.4	12.2	7.4	4.3	-0.7	1.0	2.7	7.4	9.4	10.8	13.3
Maximum	25.0	26.0	23.8	20.6	20.8	15.2	16.0	18.6	22.2	24.2	23.4	23.8
Average	19.4	19.7	17.7	14.0	12.0	6.9	8.4	10.8	14.7	16.9	17.3	18.4
Eco Park												
Minimum	17.2	16.3	15.0	10.3	6.6	3.0	4.0	6.3	11.1	13.4	14.4	17.4
Maximum	27.8	28.0	25.4	23.2	23.0	19.3	19.2	22.1	26.0	27.5	26.6	27.5
Average	22.4	22.0	19.9	16.4	14.5	10.6	11.2	14.1	18.4	20.5	20.7	22.4
Leitrim												
Minimum	16.9	15.5	14.6	9.6	6.3	3.7	4.4	5.4	10.6	13.2	13.9	17.1
Maximum	28.7	28.6	25.9	23.8	24.1	19.3	20.3	23.3	26.1	28.4	28.2	28.3
Average	22.6	21.7	19.7	16.3	14.6	11.0	11.7	14.1	17.9	20.8	21.4	22.5

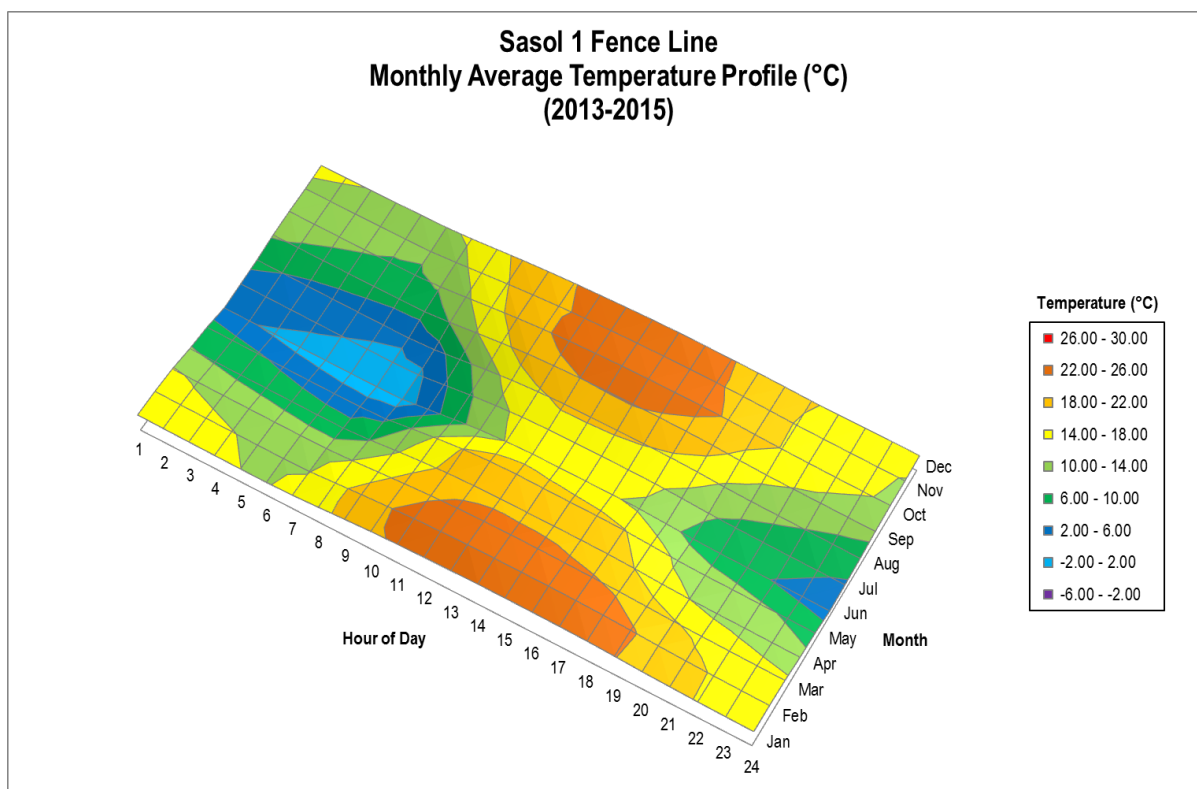


Figure 5-13: Monthly average temperature profile for Sasol 1 Fence Line (2013 – 2015)

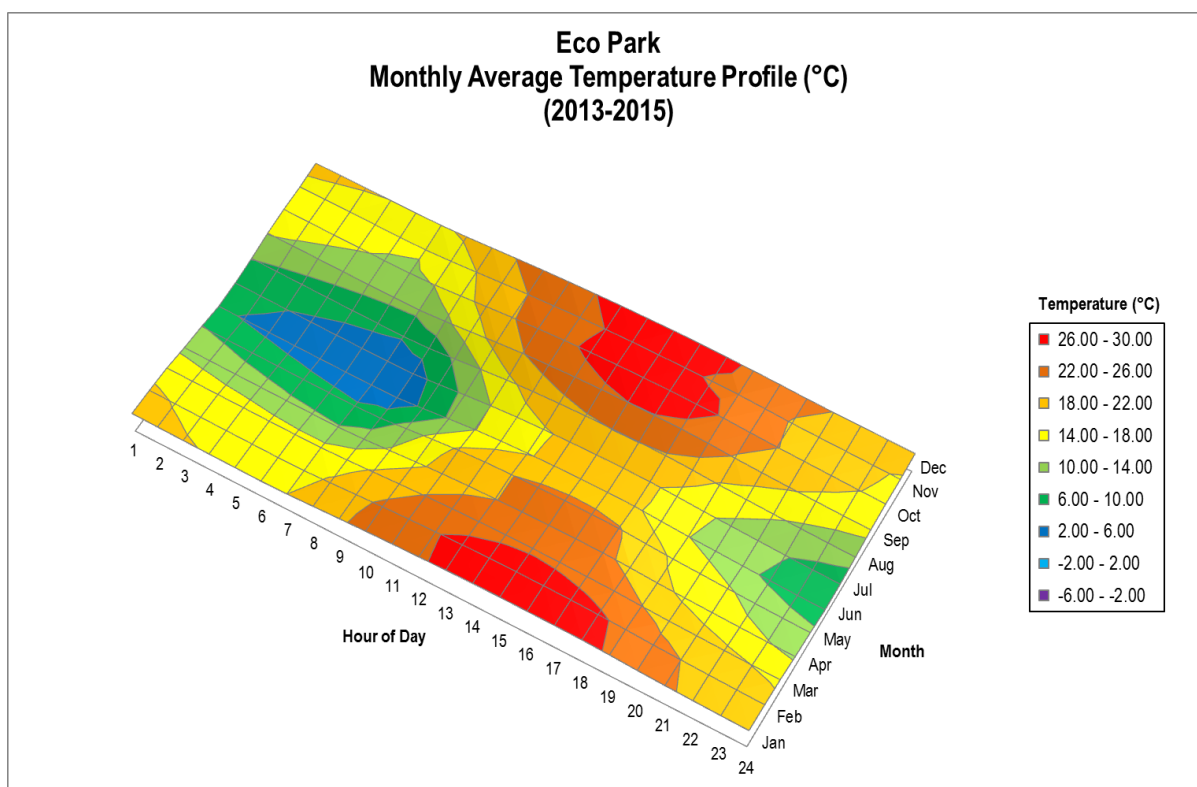


Figure 5-14: Monthly average temperature profile for Eco Park (2013 – 2015)

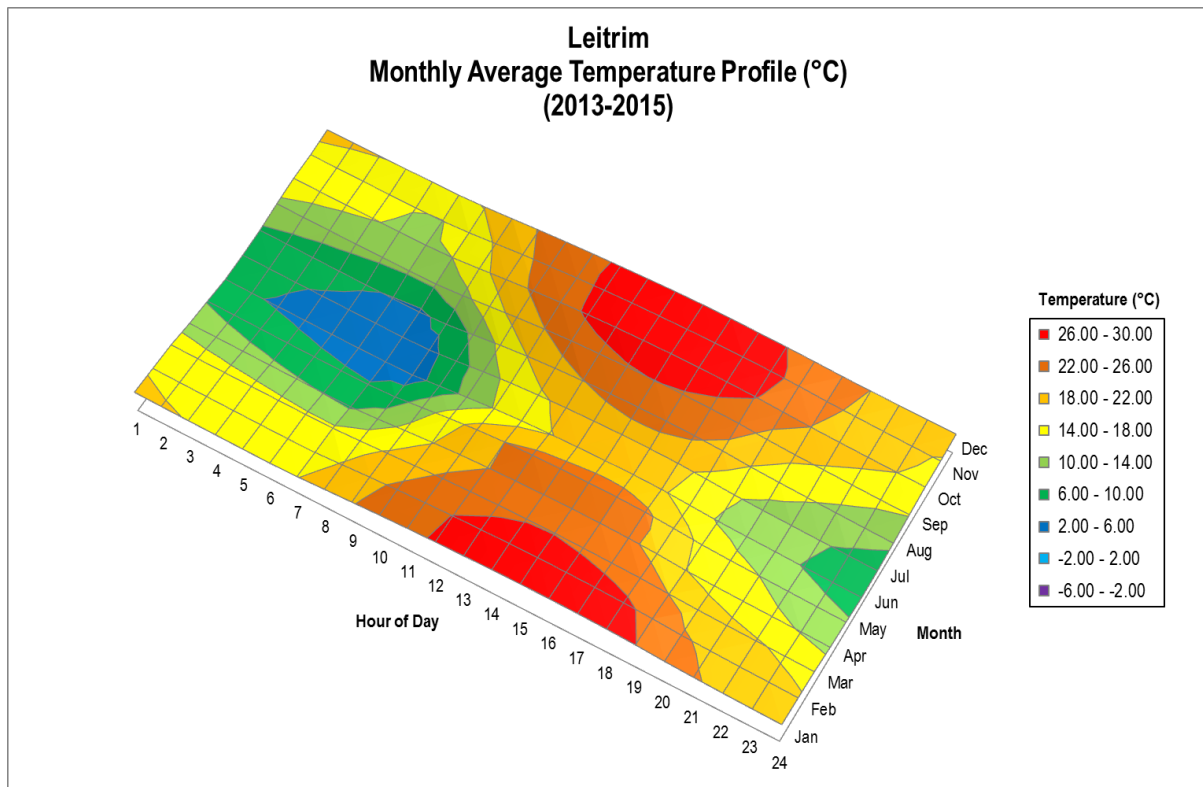


Figure 5-15: Monthly average temperature profile for Leitrim (2013 – 2015)

5.1.5.3 Atmospheric Stability

The atmospheric boundary layer properties are described by two parameters; the boundary layer depth and the Monin-Obukhov length.

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 (Tiwary and Colls, 2010), and described by the inverse Monin-Obukhov length and the boundary layer depth is provided in Figure 5-16. 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, unstable conditions can result in very high concentrations of poorly diluted emissions close to the stack. This is called looping (Figure 5-16 (c)) and occurs mostly during daytime hours. Neutral conditions disperse the plume fairly equally in both the vertical and horizontal planes and the plume shape is referred to as coning (Figure 5-16 (b)). Stable conditions prevent the plume from mixing vertically, although it can still spread horizontally and is called fanning (Figure 5-16 (a)) (Tiwary & Colls, 2010).

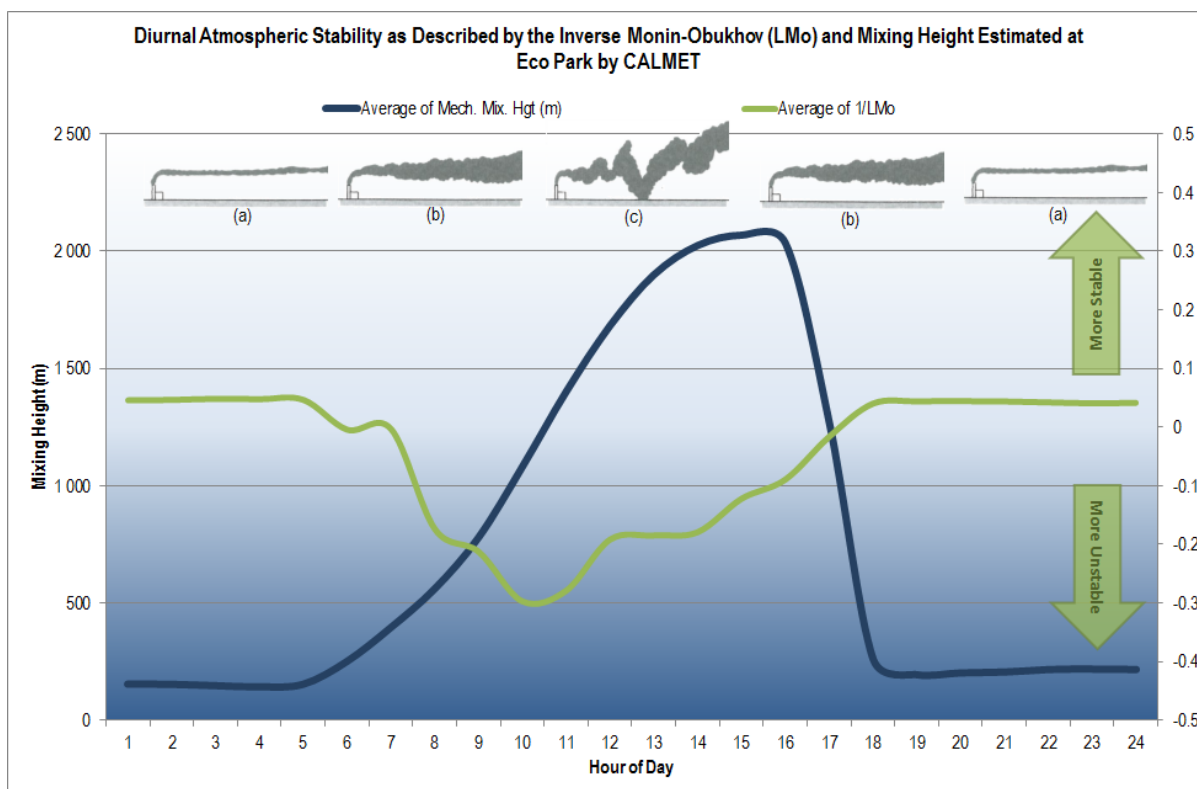


Figure 5-16: Diurnal atmospheric stability (extracted from CALMET at the Eco Park monitoring point)

5.1.5.4 Air Quality Monitoring data

A summary of ambient data measured at Leitrim, AJ Jacobs and Eco Park for the period 2013 – 2015 is provided in Table 5-9, Table 5-10 and Table 5-11 respectively. A summary of ambient air quality data recorded at the DEA stations - Three Rivers, Sharpeville, and Zamdela - is provided in Table 5-14, Table 5-15, and Table 5-16. Time series of the measured ambient air quality data is provided in Appendix G.

Table 5-10: Summary of the ambient NH₃ measurements at Fence Line for the period 2010-2012 (units: µg/m³)

Period	Hourly				Annual Average
	Max	99 th Percentile	90 th Percentile	50 th Percentile	
NH ₃					
2010	231.34	65.19	6.59	0.59	4.74
2011	270.11	82.68	15.98	1.10	6.60
2012	236.77	88.22	23.29	5.18	10.11
Average	246.07	78.69	15.28	2.29	7.15
NOTE: * Ammonia is no longer monitored at the Sasol monitoring stations and therefore data for the most recent available period was used.					

Table 5-11: Summary of the ambient measurements at Leitrim for the period 2013-2015 (units: µg/m³)

Period	Availability	Hourly				Annual Average	No of recorded hourly exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
NO ₂							
2013	69%	150.8	74.7	46.0	16.5	21.0	
2014	26%	293.3	165.4	46.5	7.9	18.7	13
2015	76%	283.2	86.2	52.7	18.2	23.7	1
Average			108.8	48.4	14.2	21.8	

SO ₂							
2013	62%	445.4	165.6	57.9	10.1	22.8	2
2014	47%	758.5	187.3	106.8	54.2	60.8	4
2015	44%	845.3	206.6	91.2	32.3	43.0	11
Average			186.5	85.3	32.2	40.3	
Period	Availability	Daily				Annual Average	No of recorded daily exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
SO ₂							
2013	62%	110.0	88.6	43.8	19.9	23.8	
2014	47%	173.1	138.7	88.6	58.7	60.0	3
2015	44%	131.8	120.4	84.5	35.0	41.0	1
Average			115.9	72.3	37.9	41.6	
PM ₁₀							
2013	76%	184.5	156.5	106.2	45.4	56.3	17
2014	77%	186.6	163.8	91.8	39.3	49.8	12
2015	80%	192.1	153.9	106.3	39.8	50.5	16
Average			158.0	101.4	41.5	52.2	
PM _{2.5}							
2013	0%						
2014	0%						
2015	65%	117.0	75.2	50.0	19.3	24.2	5
Average			75.2	50.0	19.3	24.2	
O ₃							
2013	77%	111.6	86.6	72.8	50.9	52.2	
2014	28%	47.8	40.4	27.7	17.9	19.2	
2015	0%						
Average			63.5	50.3	34.4	43.4	

Table 5-12: Summary of the ambient measurements at AJ Jacobs for the period 2013-2015 (units: µg/m³)

Period	Availability	Hourly				Annual Average	No of recorded hourly exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
NO ₂							
2013	96%	95.4	54.4	30.8	9.0	13.1	
2014	99%	135.3	86.8	52.8	20.8	25.2	
2015	86%	127.4	79.1	46.0	14.9	20.6	
Average			73.5	43.2	14.9	19.7	
SO ₂							
2013	96%	785.3	303.0	95.9	20.1	42.1	47
2014	99%	534.0	292.5	103.2	28.4	46.0	34
2015	98%	603.6	284.1	111.1	46.3	56.2	34
Average			293.2	103.4	31.6	48.2	
Period	Availability	Daily				Annual Average	No of recorded daily exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
SO ₂							
2013	96%	259.6	181.0	90.8	29.7	42.6	18
2014	99%	171.9	151.2	93.7	37.1	46.0	19
2015	98%	224.6	152.9	104.5	52.5	56.5	14
Average			161.7	96.4	39.8	48.4	
PM ₁₀							
2013	92%	168.4	128.7	91.5	45.5	51.9	8
2014	98%	141.3	118.4	80.2	38.2	44.8	4
2015	96%	124.6	119.9	81.1	39.5	46.4	3
Average			122.4	84.3	41.1	47.7	
PM _{2.5}							
2013	0%						

Period	Availability	Hourly				Annual Average	No of recorded hourly exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
2014	85%	70.7	54.5	30.3	17.0	18.9	2
2015	93%	51.0	48.2	30.9	16.1	18.3	
Average			51.3	30.6	16.5	18.6	

Table 5-13: Summary of the ambient measurements at Eco Park for the period 2013-2015 (units: µg/m³)

Period	Availability	Hourly				Annual Average	No of recorded hourly exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
NO ₂							
2013	95%	141.3	82.2	49.6	15.4	21.2	
2014	97%	164.1	84.6	50.4	16.9	22.6	
2015	84%	150.5	85.2	54.1	17.0	23.2	
Average			84.0	51.3	16.5	22.3	
SO ₂							
2013	95%	388.8	167.9	58.1	14.0	26.0	2
2014	96%	782.6	211.4	64.2	19.7	31.4	20
2015	96%	1142.4	221.1	88.8	41.7	49.3	5
Average			200.1	70.4	25.2	35.5	
Period	Availability	Daily				Annual Average	No of recorded daily exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
SO ₂							
2013	95%	116.5	86.2	52.8	19.5	25.5	
2014	96%	137.5	119.0	55.2	26.9	31.3	3
2015	96%	119.2	111.7	81.6	47.5	49.3	
Average			105.6	63.2	31.3	35.4	
PM ₁₀							
2013	98%	131.7	106.4	71.5	28.4	34.9	2
2014	97%	112.9	105.3	61.3	23.5	29.7	
2015	93%	150.4	126.1	83.0	27.5	37.2	5
Average			112.6	71.9	26.5	34.0	
PM _{2.5}							
2013	31%	88.5	84.6	56.2	0.0	19.0	10
2014	91%	139.9	61.3	31.5	14.2	17.5	3
2015	95%	61.7	50.5	34.8	14.0	17.2	
Average			65.5	40.9	9.4	17.9	
O ₃							
2013	96%	109.8	100.2	82.7	55.6	57.6	0
2014	99%	108.7	95.9	78.4	53.2	54.1	0
2015	98%	121.5	107.0	79.5	56.4	58.3	1
Average			101.0	80.2	55.1	56.7	

Table 5-14: Summary of the ambient measurements at Three Rivers for the period 2013-2015 (units: µg/m³)

Period	Availability	Hourly				Annual Average	No of recorded hourly exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
NO ₂							
2013	90%	129.0	110.2	40.8	11.0	21.4	
2014	82%	136.0	107.9	42.4	12.8	22.5	
2015	80%	179.0	163.6	57.6	16.4	31.5	
Average			127.2	46.9	13.4	25.0	
SO ₂							
2013	91%	709.0	106.3	23.7	1.8	13.2	7
2014	86%	550.0	100.5	27.3	3.0	17.6	11
2015	53%	592.0	183.7	35.4	3.8	14.5	5
Average			130.2	28.8	2.9	15.1	
Benzene							
2013	71%	30.5	15.2	3.4	0.3	1.4	
2014	37%	20.5	11.9	5.6	1.4	2.3	
2015	37%	17.3	6.6	3.3	0.1	1.0	
Average			11.2	4.1	0.6	1.5	
Period	Availability	Daily				Annual Average	No of recorded daily exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
SO ₂							
2013	91%	65.2	27.9	9.7	3.6	13.2	
2014	86%	54.1	27.3	13.1	5.0	17.6	
2015	53%	40.1	21.1	10.1	4.1	14.5	
Average			25.4	11.0	4.3	15.1	
PM ₁₀							
2013	91%	179.1	139.7	93.1	52.6	56.5	10
2014	85%	122.8	114.7	79.1	48.1	50.2	1
2015	82%	144.2	119.3	84.3	46.2	51.4	3
Average			124.6	85.5	49.0	52.8	
PM _{2.5}							
2013	90%	81.0	59.2	38.7	22.6	24.4	2
2014	83%	73.2	59.6	41.6	23.3	25.4	1
2015	87%	76.6	69.7	45.7	25.6	27.7	5
Average			62.8	42.0	23.8	25.8	
O ₃							
2013	91%	47.4	41.0	33.1	20.0	21.6	
2014	78%	55.0	47.7	31.8	20.6	21.7	
2015	80%	63.9	52.6	42.5	25.9	25.7	
Average			47.1	35.8	22.2	23.0	

Table 5-15: Summary of the ambient measurements at Sharpeville for the period 2013-2015 (units: $\mu\text{g}/\text{m}^3$)

Period	Availability	Hourly				Annual Average	No of recorded hourly exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
NO ₂							
2013	83%	239.5	182.4	69.8	15.2	31.4	16
2014	97%	212.1	139.8	56.7	15.8	28.4	1
2015	86%	344.0	185.0	88.2	21.9	43.9	15
Average			169.1	71.6	17.6	34.3	
SO ₂							
2013	95%	866.3	153.4	42.9	5.2	17.9	7
2014	96%	1206.1	138.1	37.4	5.7	23.2	8
2015	87%	950.4	160.3	45.3	7.0	19.1	16
Average			150.6	41.9	6.0	20.1	
Benzene							
2013	83%	31.9	12.4	5.7	1.7	2.6	
2014	82%	25.4	5.9	1.9	0.5	0.9	
2015	32%	25.9	12.2	3.1	0.5	1.3	
Average			10.2	3.6	0.9	1.7	
Period	Availability	Daily				Annual Average	No of recorded daily exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
SO ₂							
2013	95%	40.8	33.1	14.2	4.9	17.9	
2014	96%	42.6	35.7	19.1	6.7	23.2	
2015	87%	51.5	34.4	16.6	5.8	19.1	
Average			34.4	16.6	5.8	20.1	
PM ₁₀							
2013	90%	386.0	187.8	121.2	55.3	66.3	35
2014	95%	200.0	173.8	109.3	57.0	64.8	25
2015	86%	178.0	153.6	110.3	53.8	62.8	22
Average			171.7	113.6	55.4	64.7	
PM _{2.5}							
2013	90%	125.1	97.7	64.5	29.6	35.2	34
2014	94%	159.9	112.5	62.8	32.6	38.3	34
2015	82%	138.4	97.9	60.6	31.8	36.5	27
Average			102.7	62.6	31.3	36.7	
O ₃							
2013	74%	148.0	53.9	45.6	34.0	35.4	2
2014	97%	55.4	39.3	21.5	51.6	23.7	
2015	87%	63.9	53.6	41.8	26.1	25.7	
Average			49.0	36.3	37.2	27.7	

Table 5-16: Summary of the ambient measurements at Zamdela for the period 2013-2015 (units: $\mu\text{g}/\text{m}^3$)

Period	Availability	Hourly				Annual Average	No of recorded hourly exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
NO ₂							
2013	64%	203.7	115.8	63.6	22.9	29.7	1
2014	82%	223.8	83.2	50.4	20.0	24.0	3
2015	87%	168.1	100.4	62.4	24.6	30.1	
Average			99.8	58.8	22.5	27.9	
SO ₂							
2013	83%	634.4	178.2	54.3	9.3	22.0	10
2014	85%	484.7	202.5	56.9	10.9	24.2	9
2015	87%	322.9	172.7	52.4	9.2	21.4	5
Average			184.5	54.5	9.8	22.5	
Benzene							
2013	80%	31.5	12.5	3.2	0.7	1.4	
2014	82%	31.5	24.2	10.1	2.2	4.0	
2015	63%	16.3	11.4	4.0	0.9	1.7	
Average			16.0	5.8	1.3	2.4	
Period	Availability	Daily				Annual Average	No of recorded daily exceedances
		Max	99 th Percentile	90 th Percentile	50 th Percentile		
SO ₂							
2013	83%	34.1	29.5	16.1	6.7	22.0	
2014	85%	37.6	34.6	19.5	7.0	24.2	
2015	87%	40.1	26.1	16.6	6.8	21.4	
Average			30.1	17.4	6.8	22.5	
PM ₁₀							
2013	68%	496.9	152.6	98.9	55.3	59.8	15
2014	85%	278.7	168.5	115.8	47.9	57.8	25
2015	57%	111.5	125.2	88.7	40.3	46.0	3
Average			148.7	101.1	47.8	55.2	
PM _{2.5}							
2013	77%	100.9	70.4	49.6	27.3	29.3	5
2014	87%	110.5	86.0	55.0	25.1	29.7	16
2015	80%	93.6	73.2	54.2	26.0	30.0	11
Average			76.6	52.9	26.2	29.7	
O ₃							
2013	71%	40.4	60.6	37.2	19.0	23.6	
2014	85%	54.4	39.3	21.2	72.3	28.1	
2015	86%	47.9	65.0	38.5	19.0	24.8	
Average			55.0	32.3	36.8	25.6	

The following graphs summarise the observed concentrations of SO₂, NO₂ and PM₁₀ at the six monitoring sites (Leitrim, AJ Jacobs, Eco Park, Three Rivers, Sharpeville, and Zamdela) monitoring stations for the years 2013, 2014 and 2015. The NAAQS have been included in the graphs for:

- SO₂ hourly (88 hourly exceedances of 350 $\mu\text{g}/\text{m}^3$) and daily average (4 daily exceedances of 125 $\mu\text{g}/\text{m}^3$)
- NO₂ hourly average (88 hourly exceedances of 200 $\mu\text{g}/\text{m}^3$); and,
- PM₁₀ daily average (4 daily exceedances of 75 $\mu\text{g}/\text{m}^3$; 2015 standards).

The hourly 99th percentiles for SO₂ were below the limit value of 350 $\mu\text{g}/\text{m}^3$ at all stations for all three years (Figure 5-17 to Figure 5-22). The daily 99th percentiles for SO₂ were exceeded at Leitrim in 2014 (Figure 5-23) and at AJ Jacobs for 2013, 2014 and 2015 (Figure 5-24) but were below the limit value (125 $\mu\text{g}/\text{m}^3$) at Eco Park, Three Rivers, Sharpeville and Zamdela stations for all three years (Figure 5-25 to Figure 5-28).

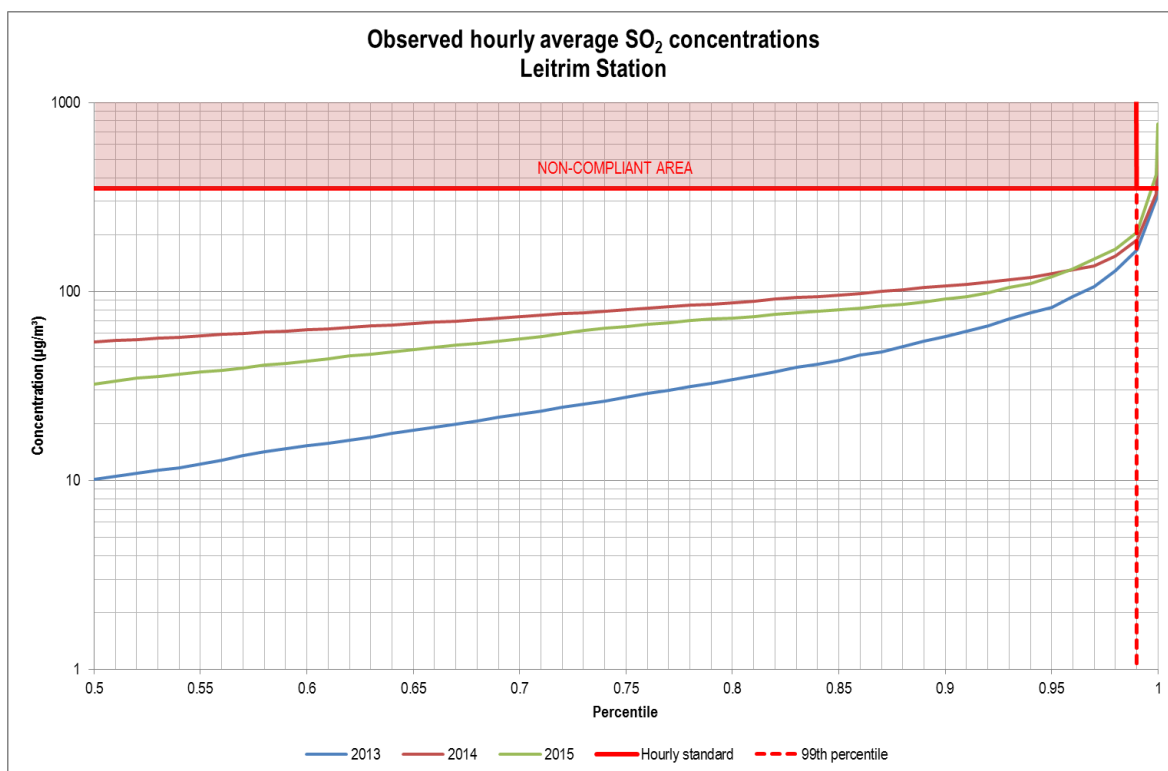


Figure 5-17: Observed hourly average SO₂ concentrations at Leitrim

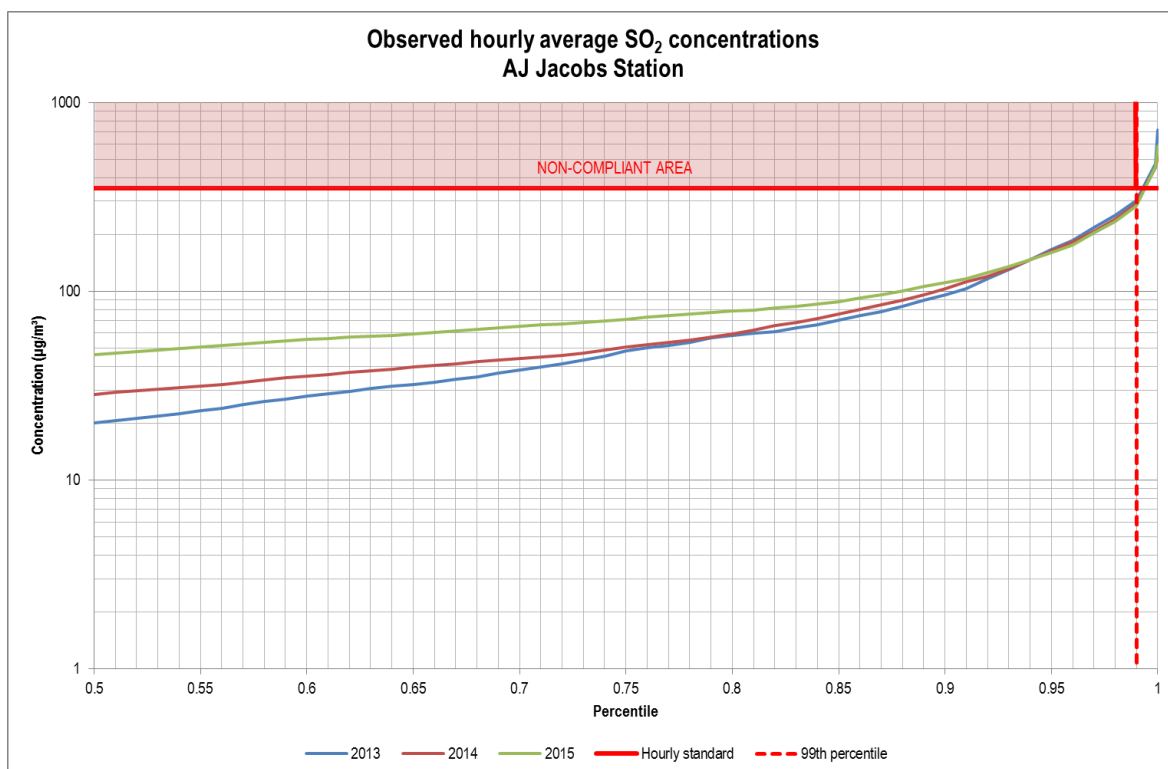


Figure 5-18: Observed hourly average SO₂ concentrations at AJ Jacobs

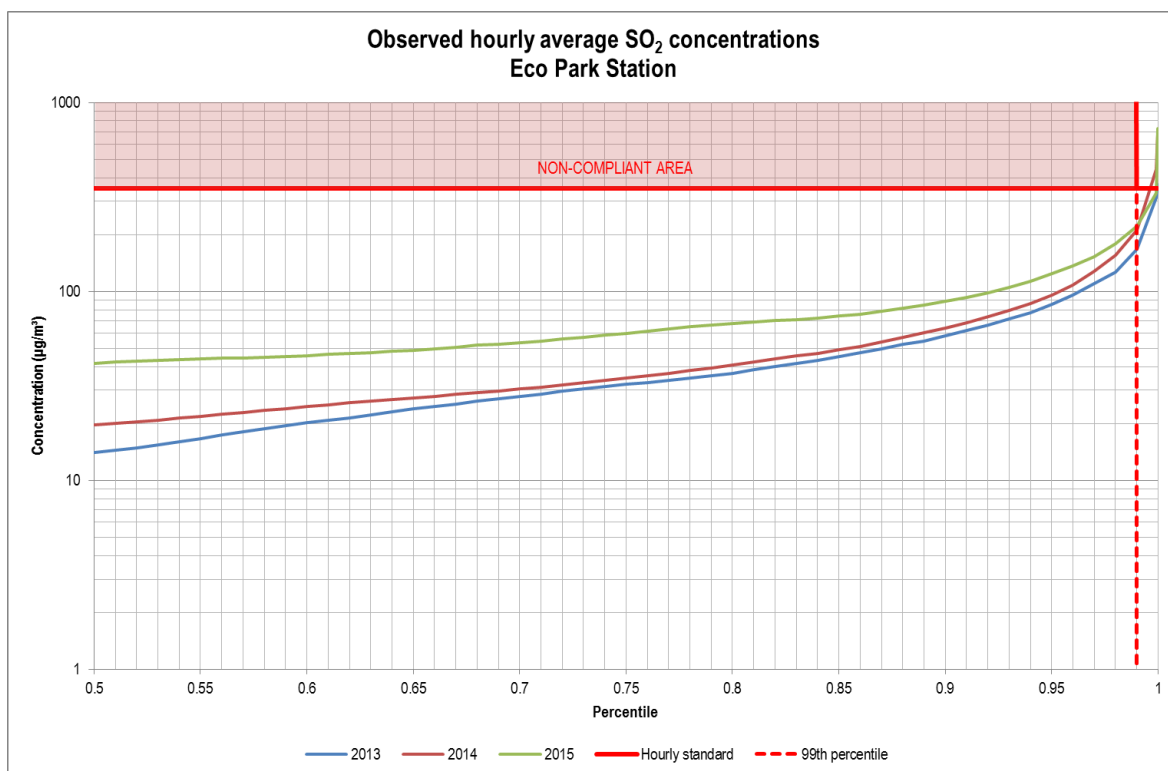


Figure 5-19: Observed hourly average SO₂ concentrations at Eco Park

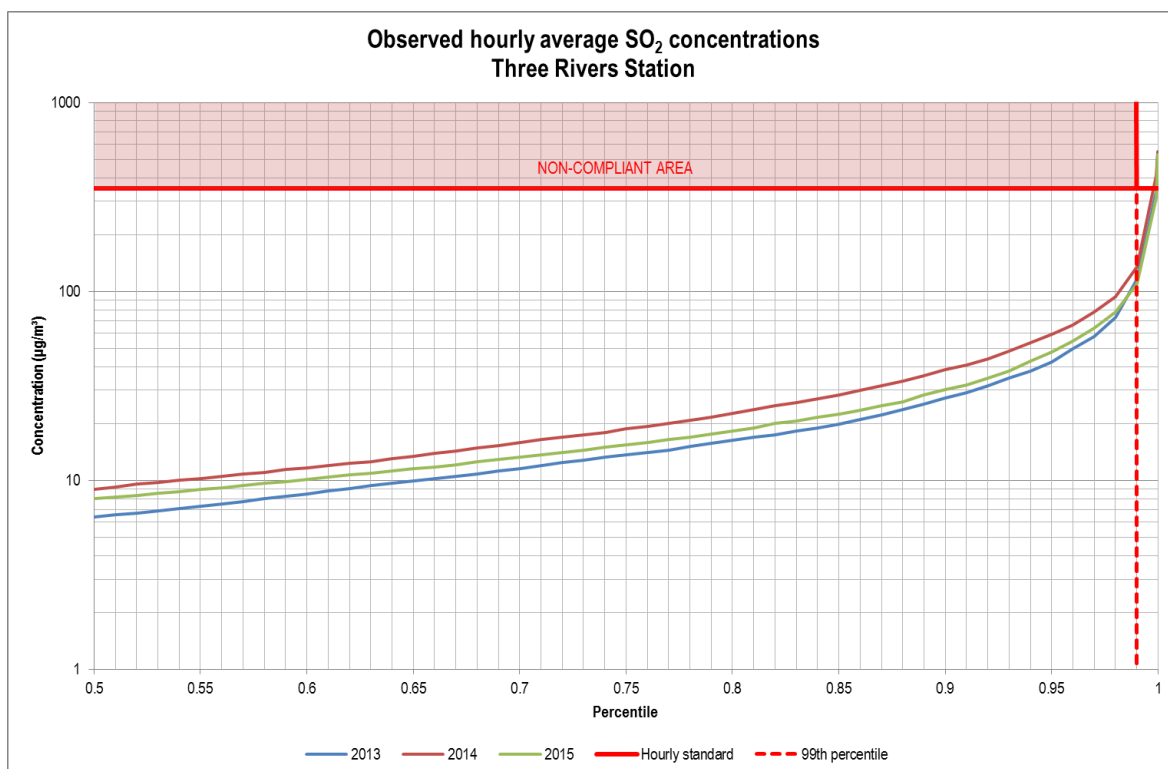


Figure 5-20: Observed hourly average SO₂ concentrations at Three Rivers

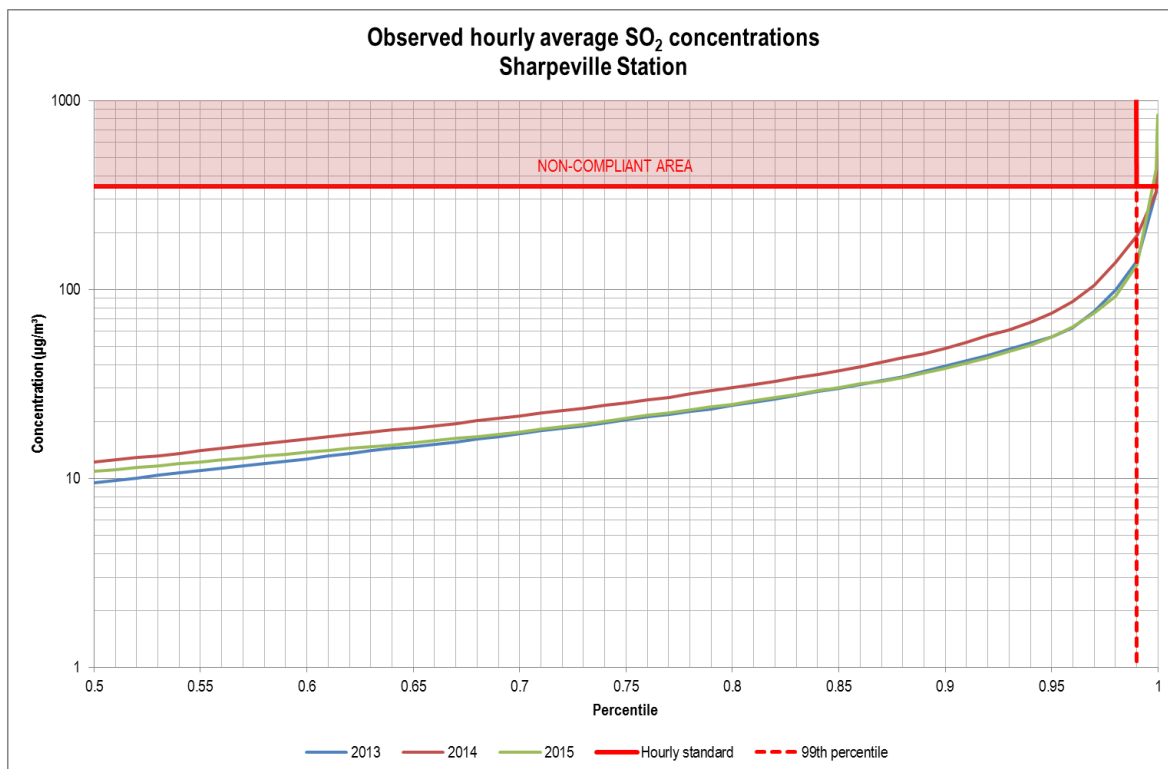


Figure 5-21: Observed hourly average SO₂ concentrations at Sharpeville

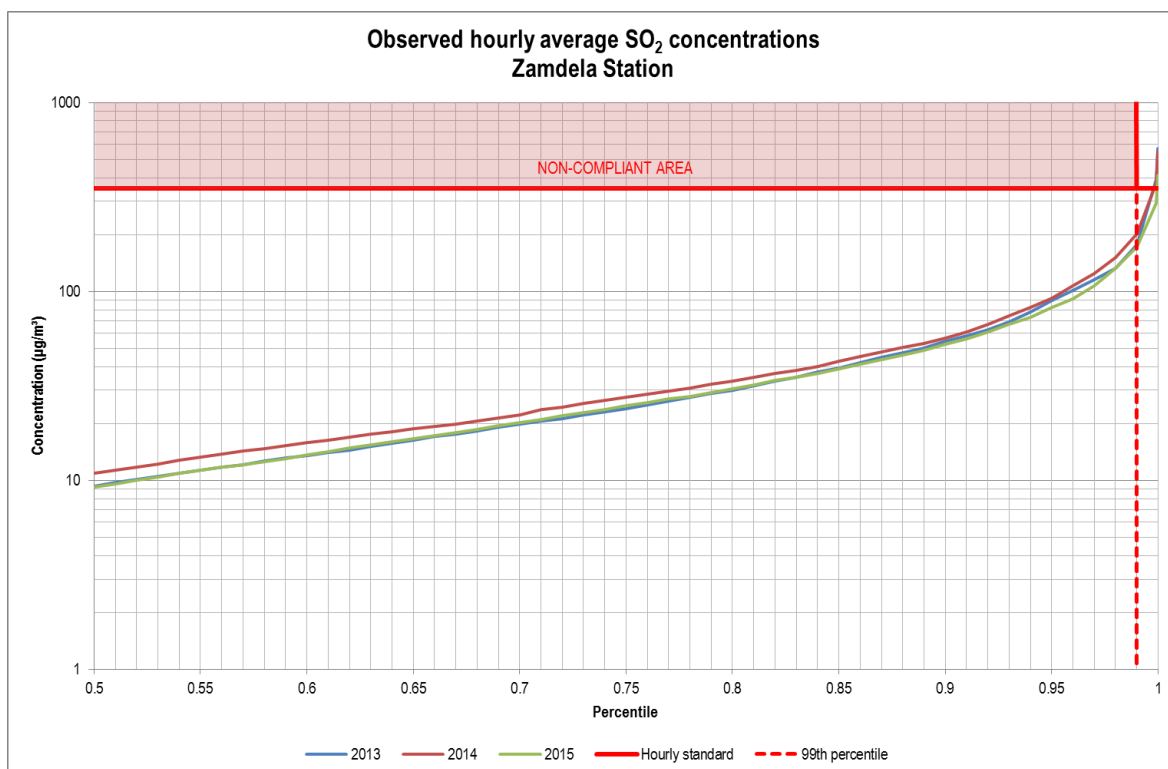


Figure 5-22: Observed hourly average SO₂ concentrations at Zamdela

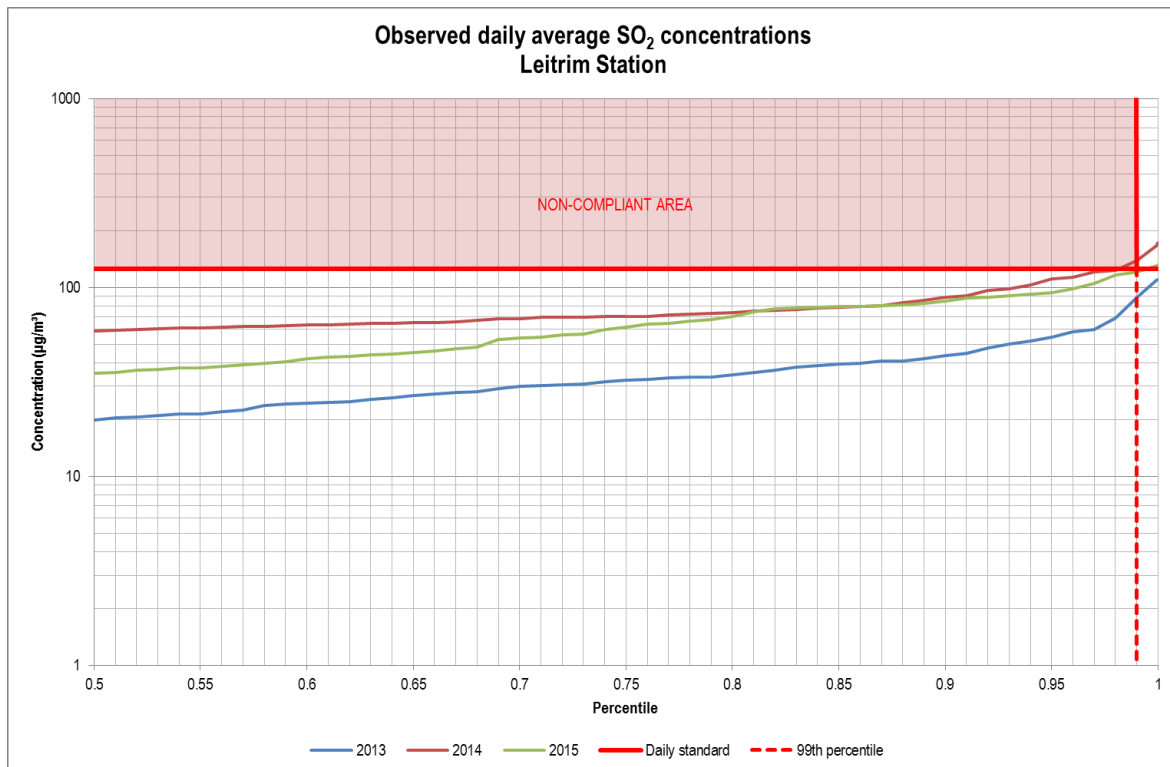


Figure 5-23: Observed daily average SO₂ concentrations at Leitrim

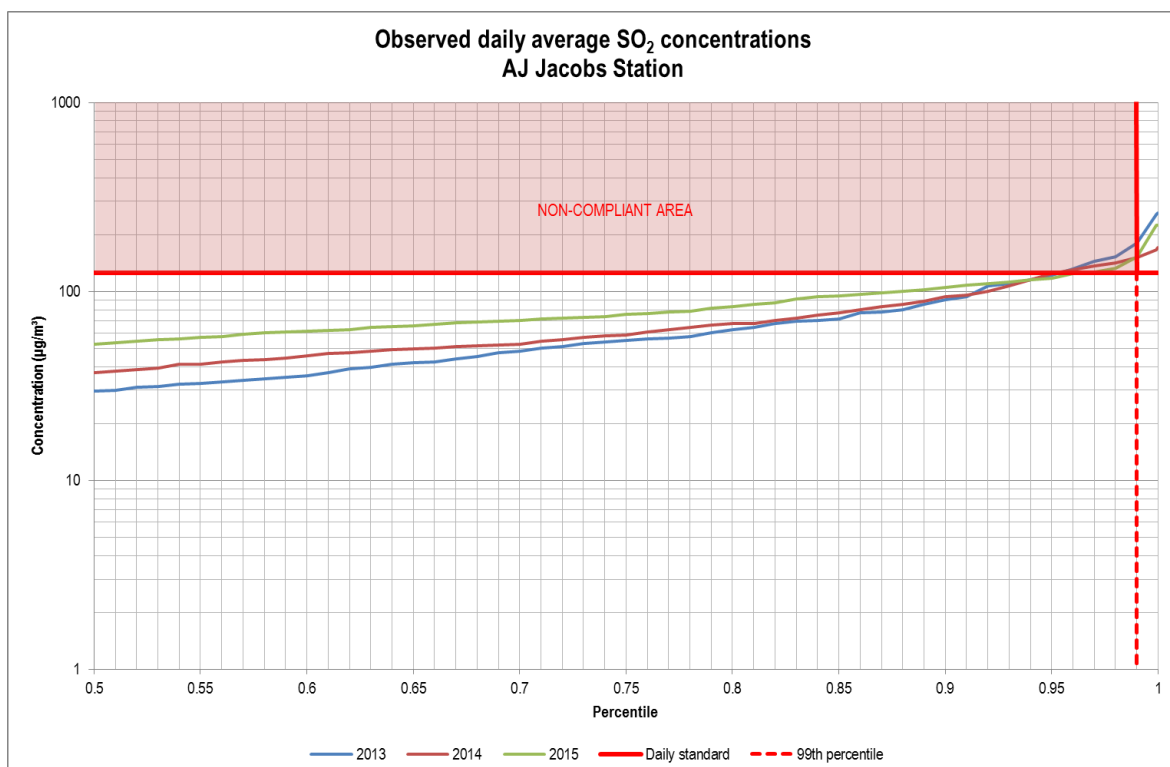


Figure 5-24: Observed daily average SO₂ concentrations at AJ Jacobs

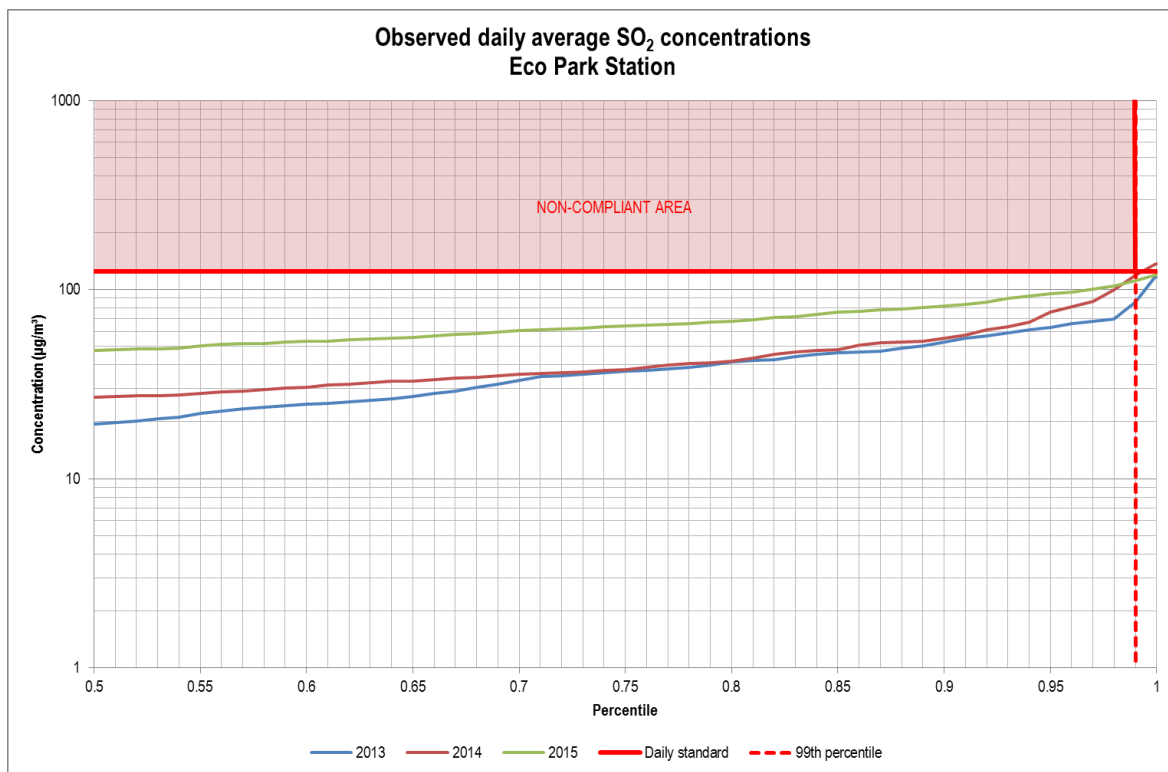


Figure 5-25: Observed daily average SO₂ concentrations at Eco Park

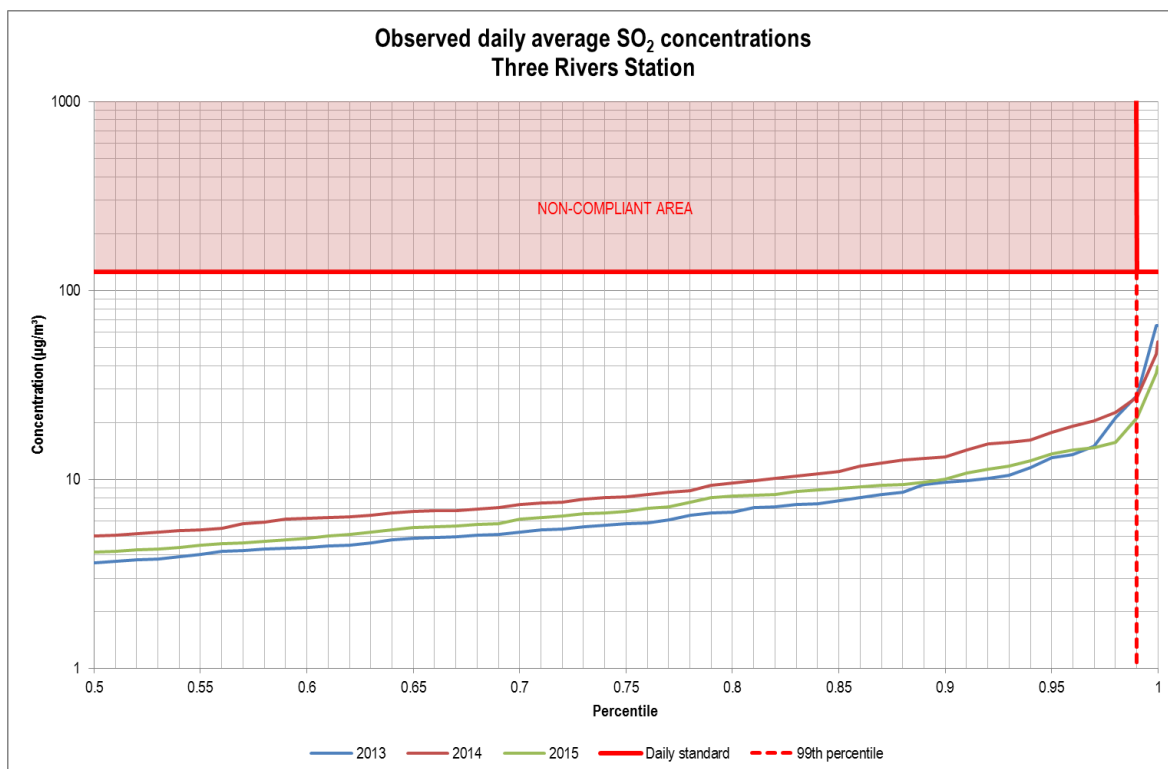


Figure 5-26: Observed daily average SO₂ concentrations at Three Rivers

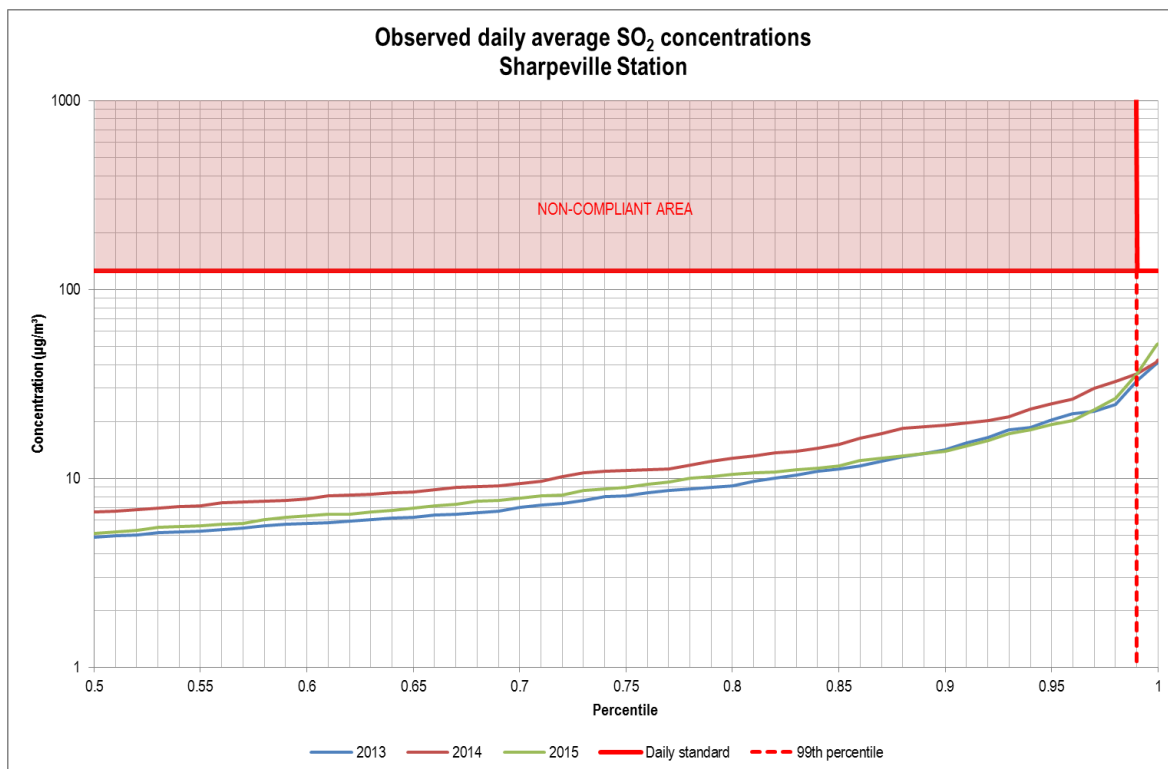


Figure 5-27: Observed daily average SO₂ concentrations at Sharpeville

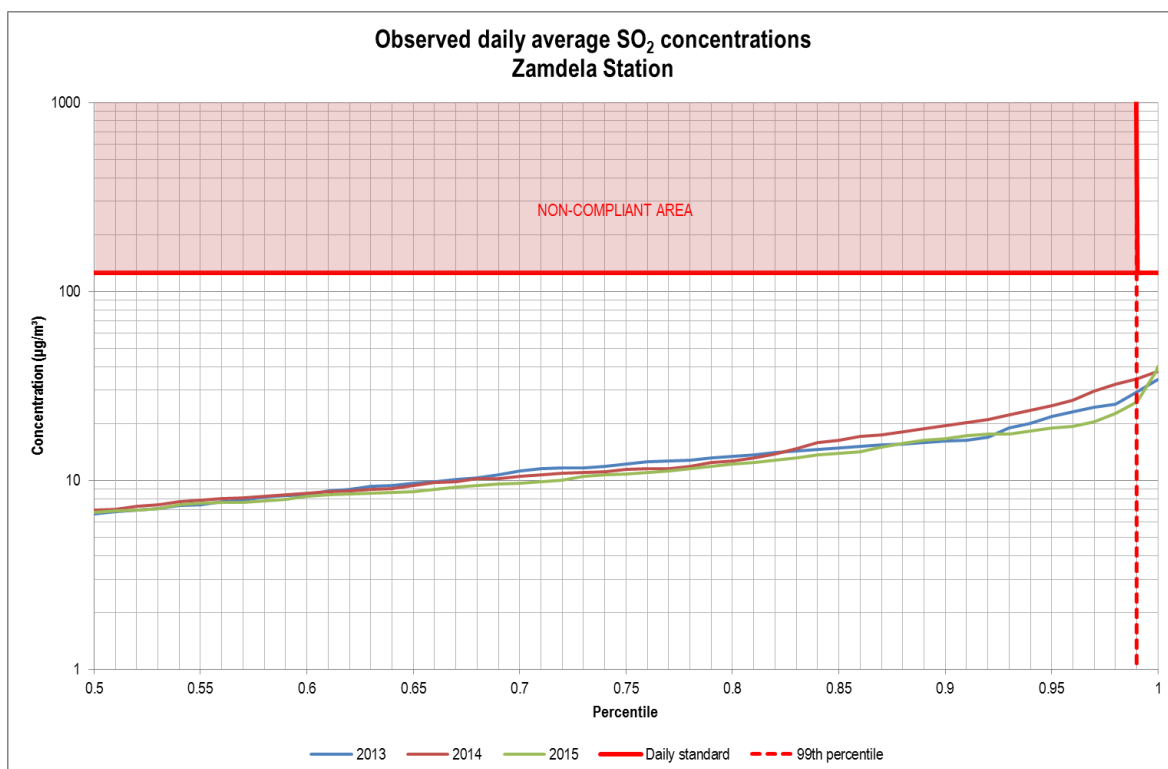


Figure 5-28: Observed daily average SO₂ concentrations at Zamdela

The hourly 99th percentiles for NO₂ were below the limit value (200 µg/m³) at all stations and for all three years (Figure 5-29 to Figure 5-34).

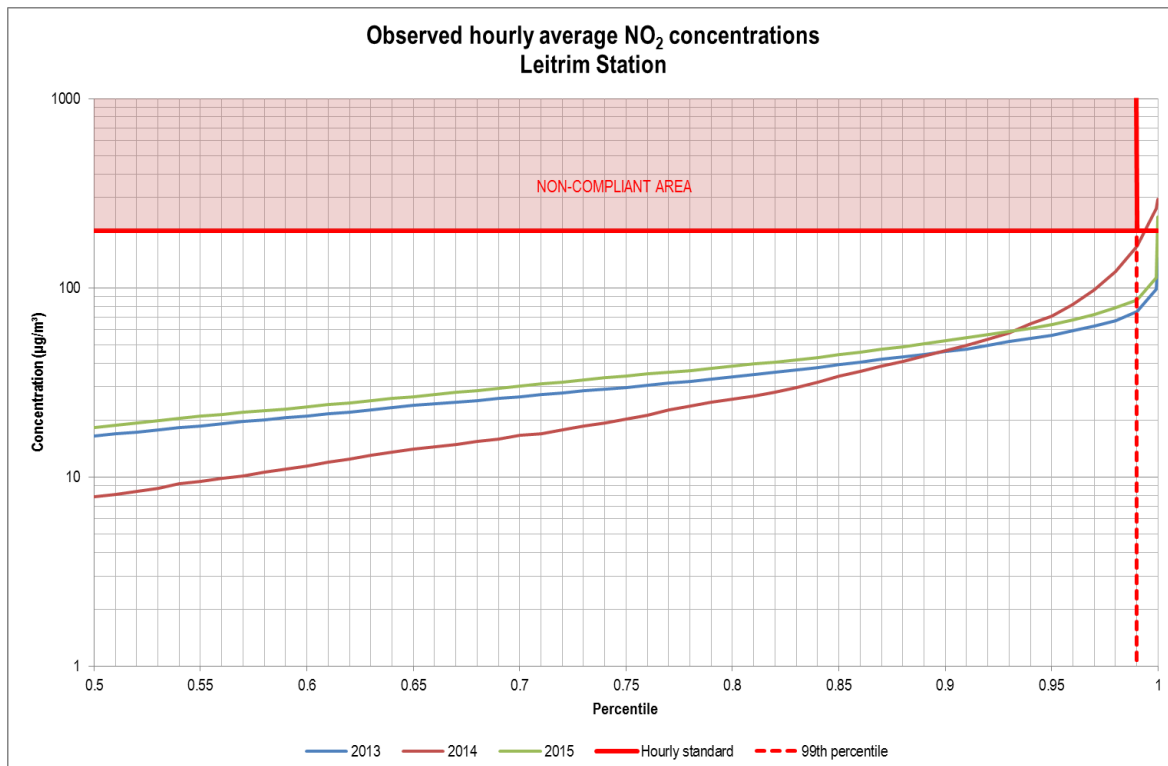


Figure 5-29: Observed hourly average NO₂ concentrations at Leitrim

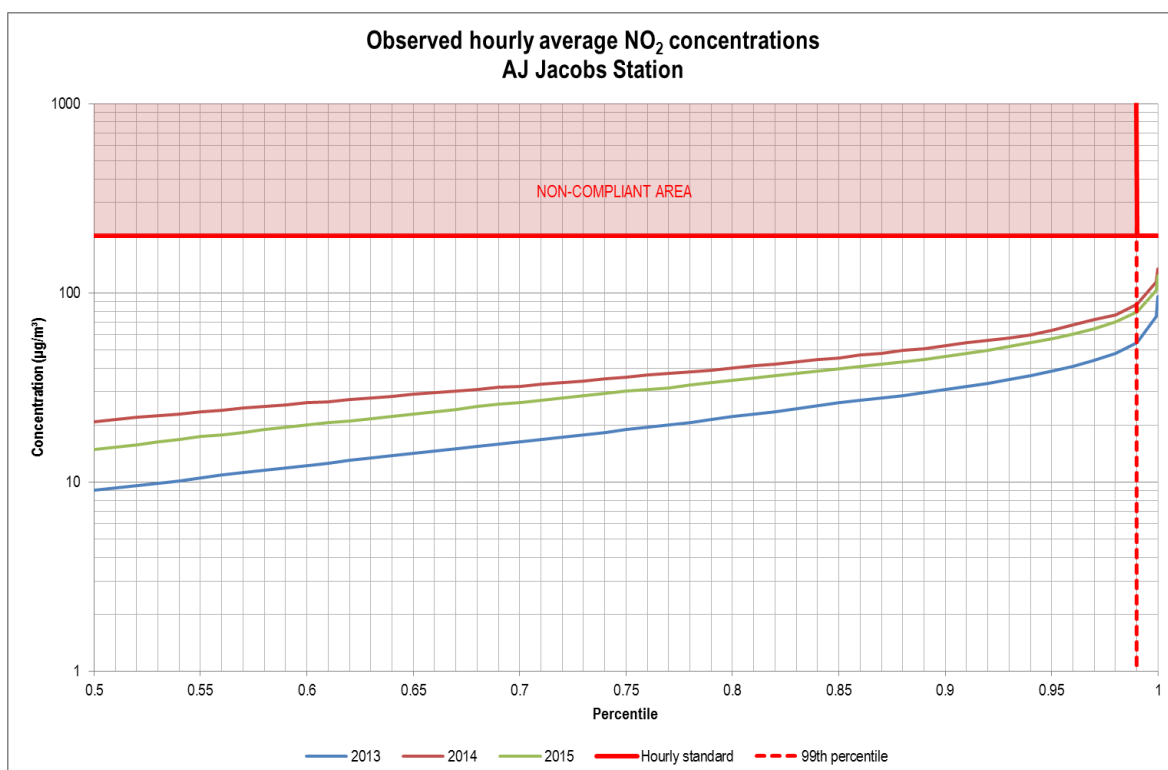


Figure 5-30: Observed hourly average NO₂ concentrations at AJ Jacobs

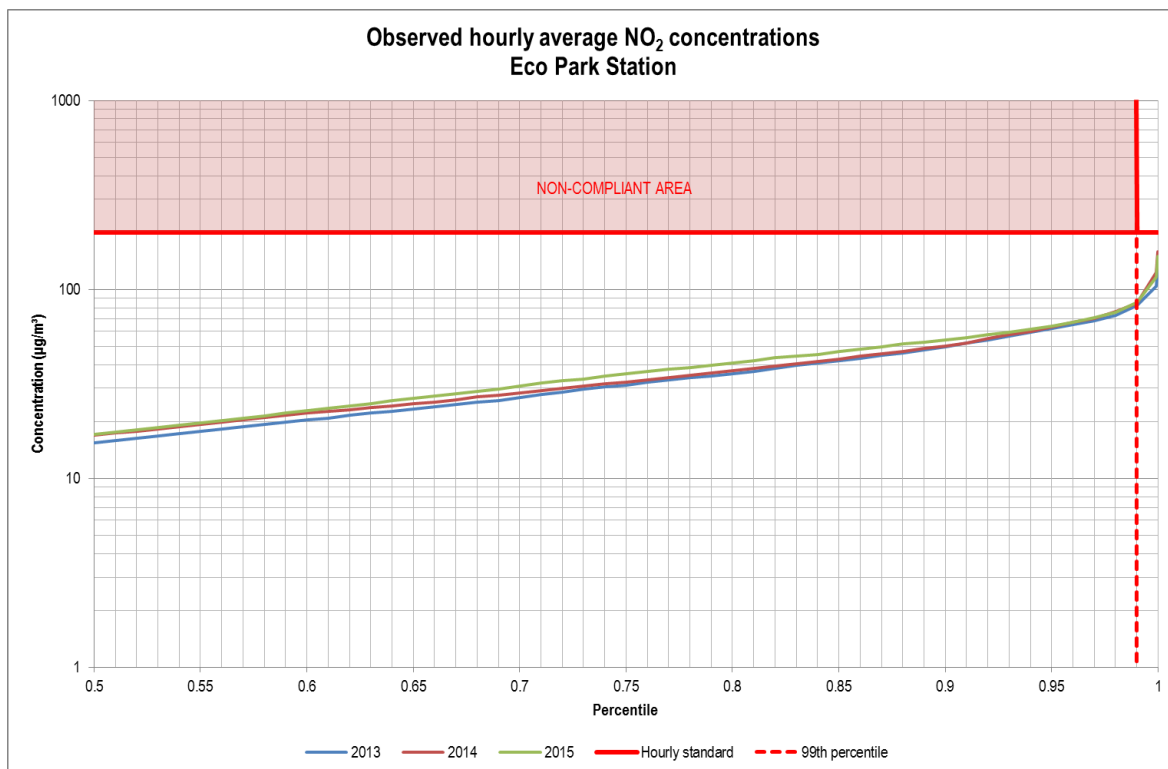


Figure 5-31: Observed hourly average NO₂ concentrations at Eco Park

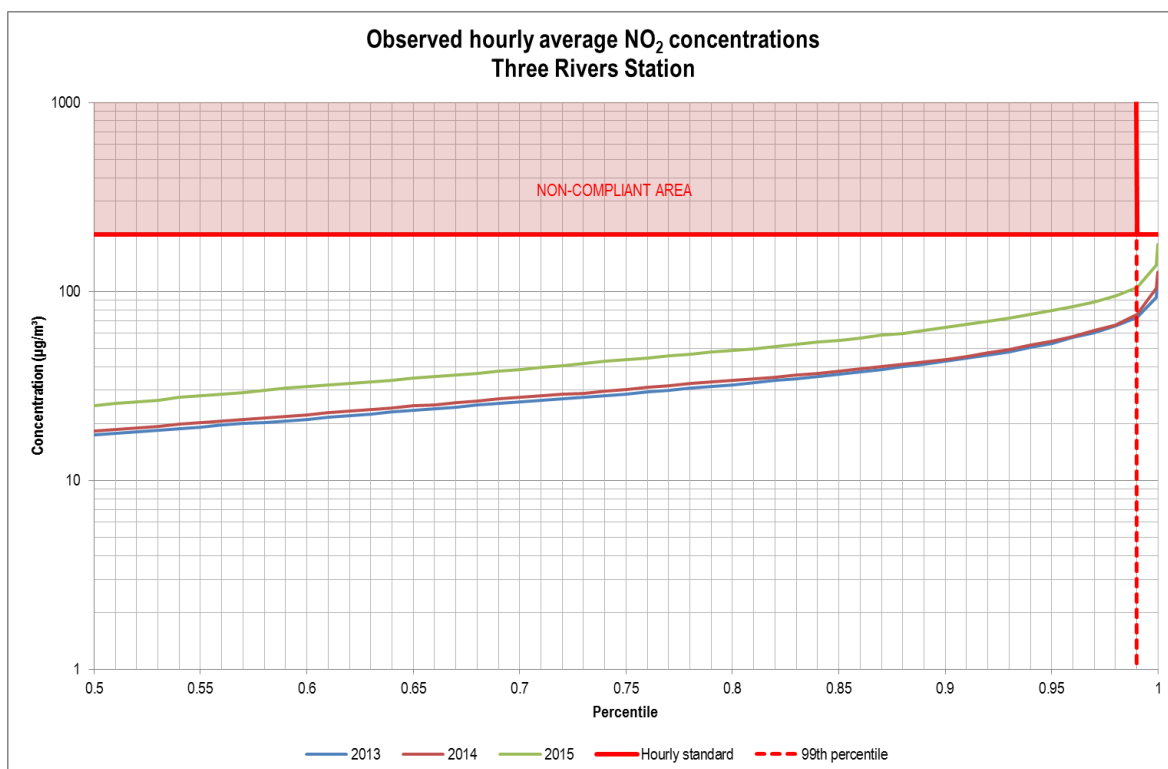


Figure 5-32: Observed hourly average NO₂ concentrations at Three Rivers

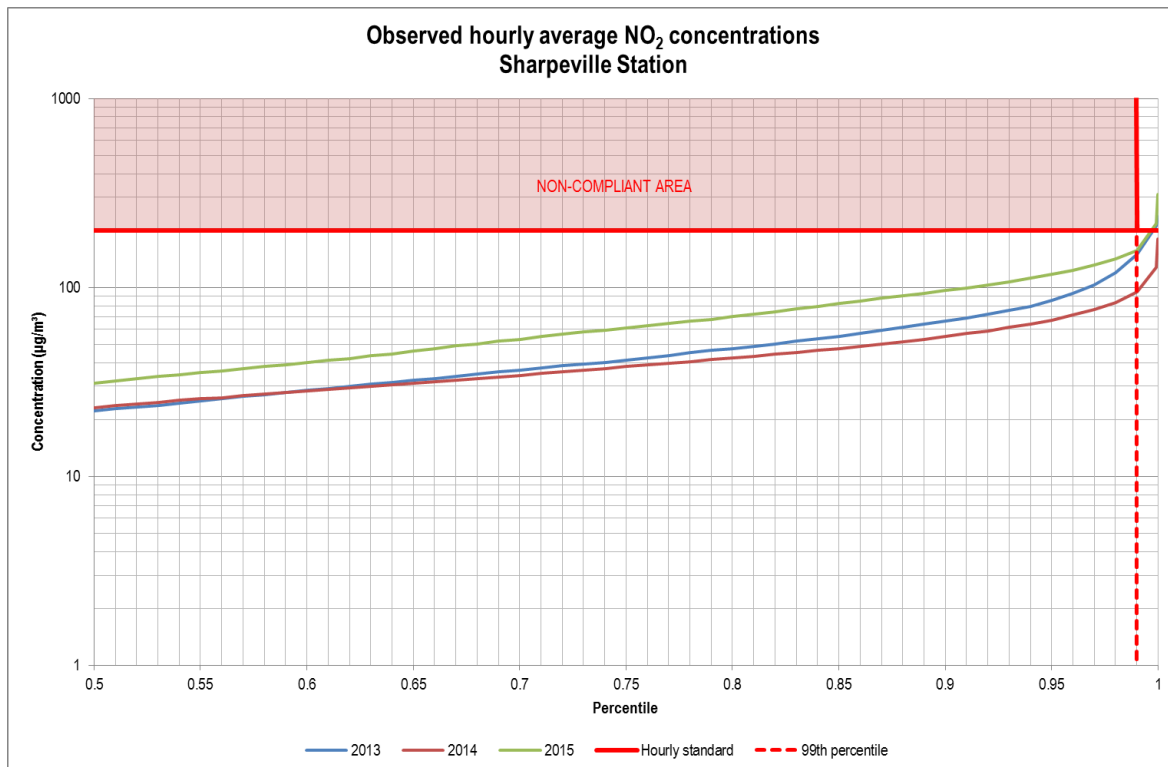


Figure 5-33: Observed hourly average NO₂ concentrations at Sharpeville

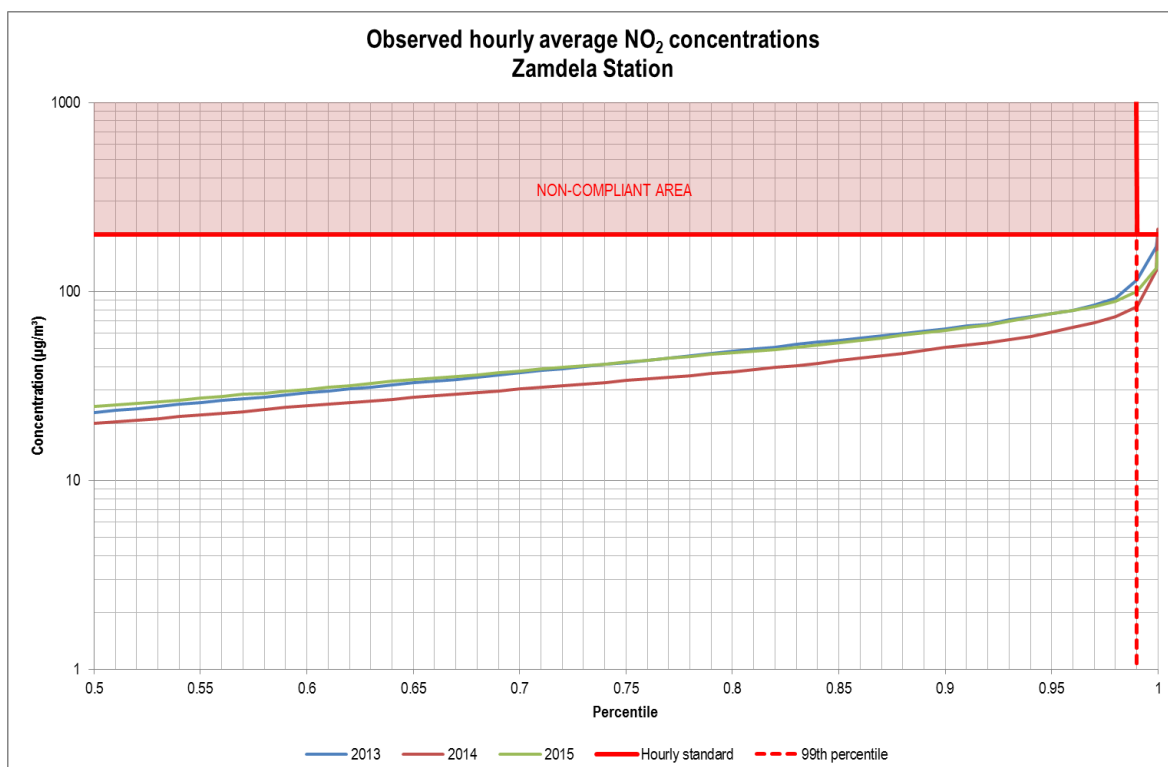


Figure 5-34: Observed hourly average NO₂ concentrations at Zamdela

The daily 99th percentiles for PM₁₀ exceed the limit value (75 µg/m³; 2015 standard) at all stations and for all three years (Figure 5-35 to Figure 5-40) where non-compliance varied between 15% and 55% of the three years assessed.

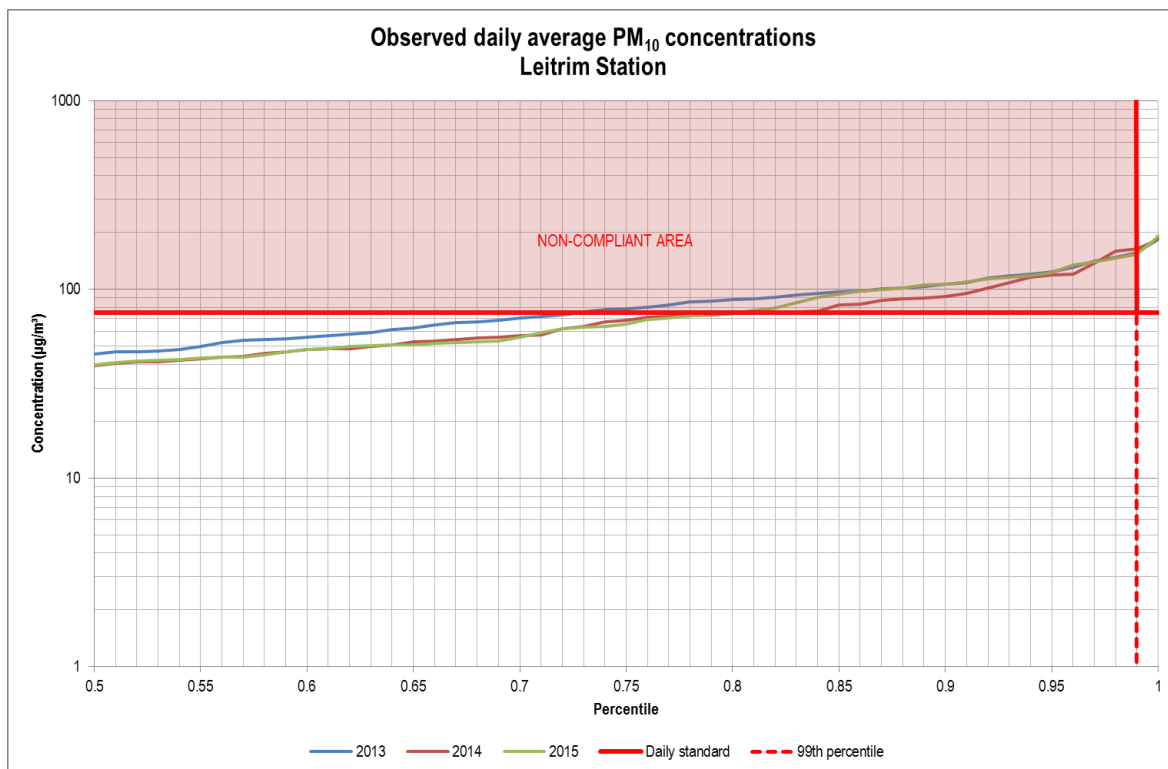


Figure 5-35: Observed daily average PM₁₀ concentrations at Leitrim

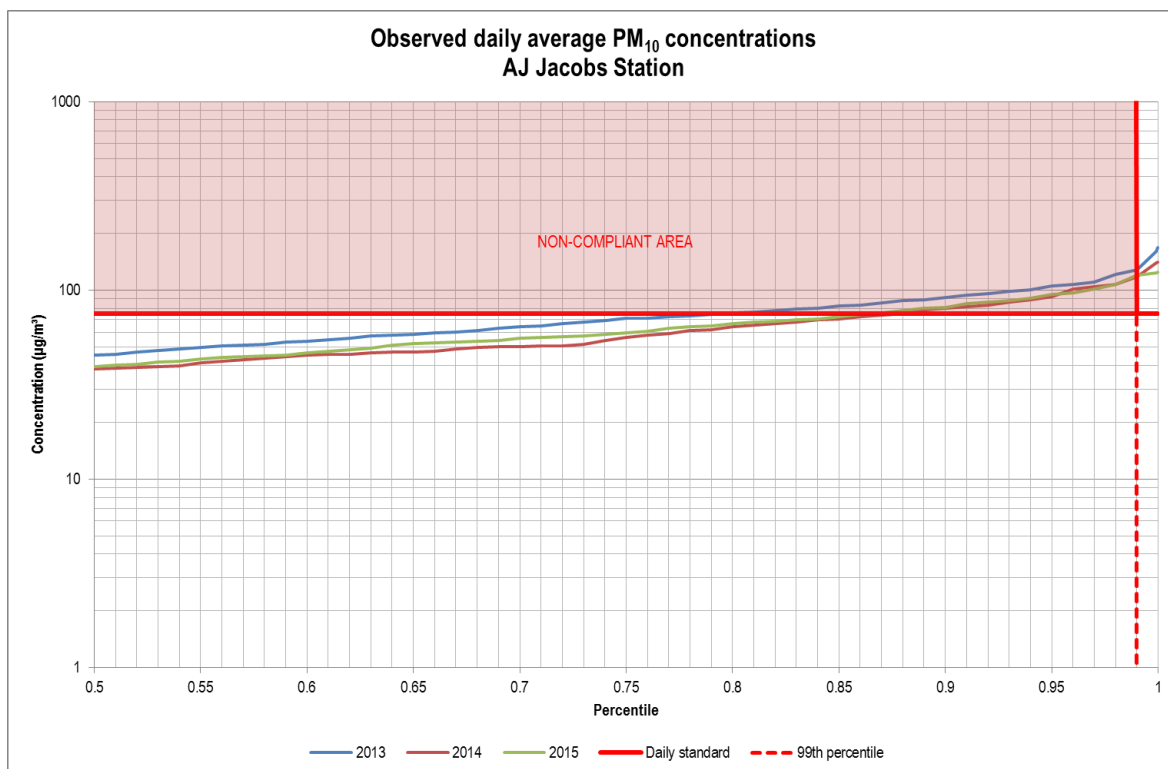


Figure 5-36: Observed daily average PM₁₀ concentrations at AJ Jacobs

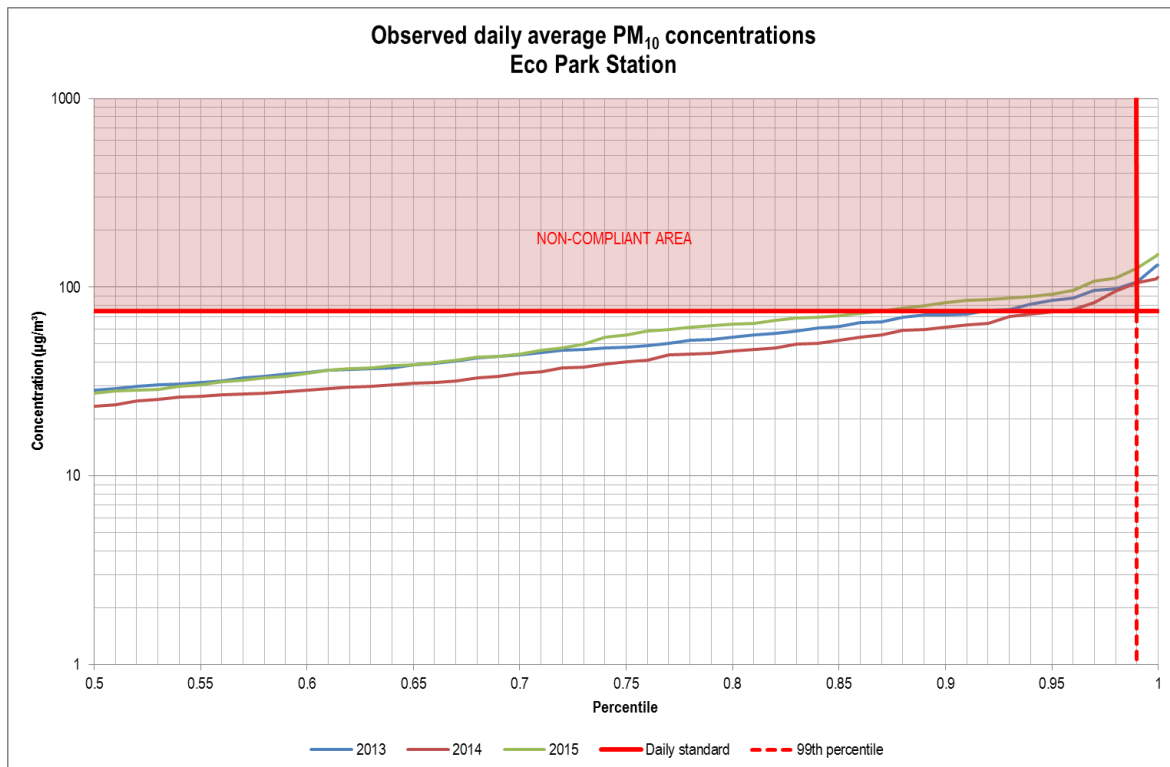


Figure 5-37: Observed daily average PM₁₀ concentrations at Eco Park

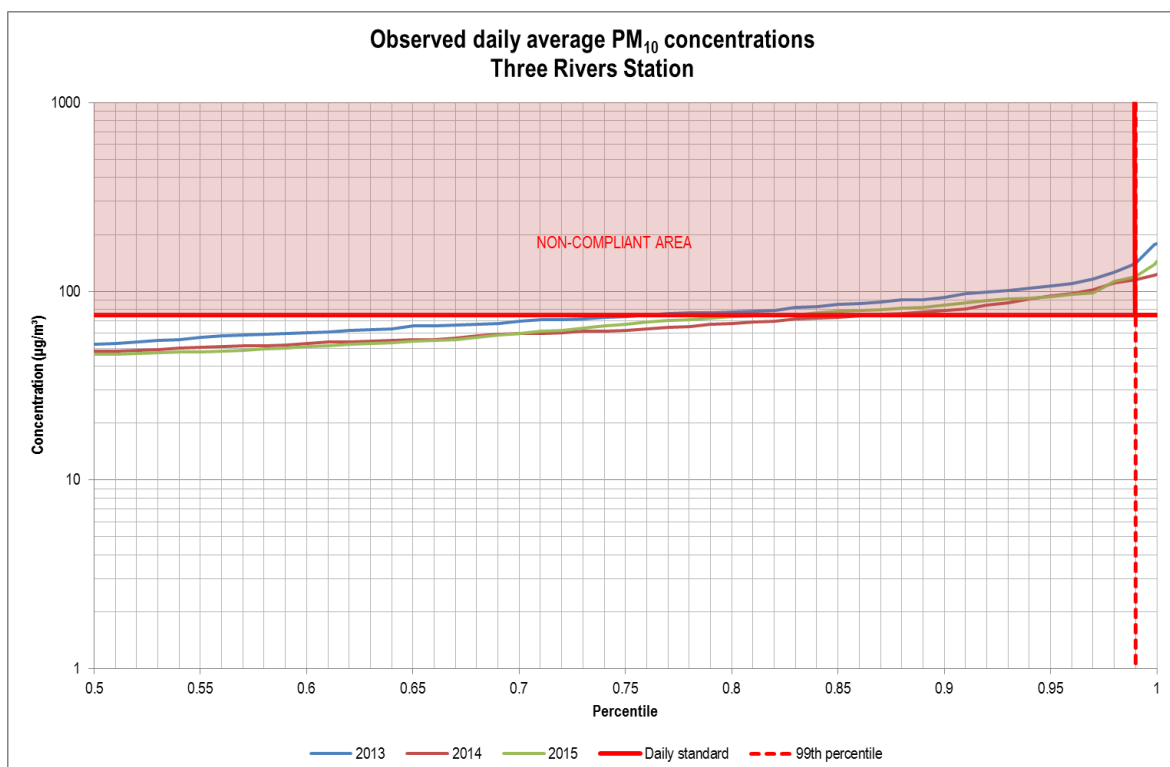


Figure 5-38: Observed daily average PM₁₀ concentrations at Three Rivers

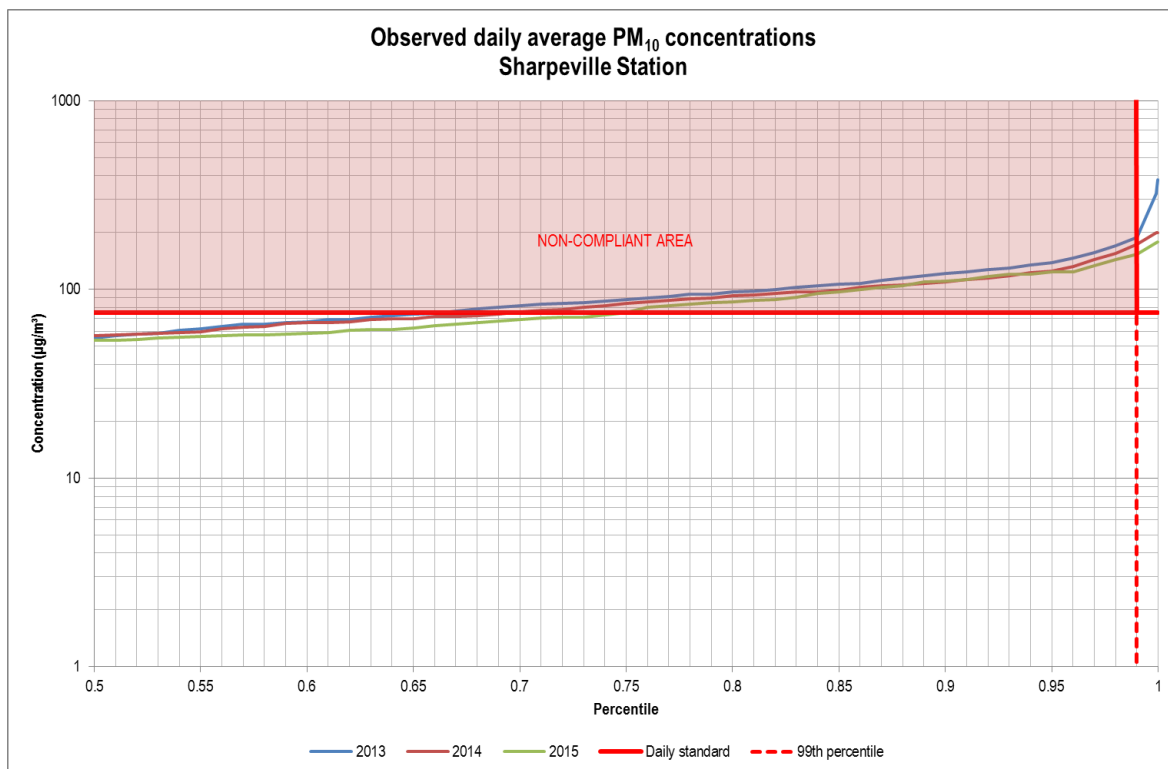


Figure 5-39: Observed daily average PM₁₀ concentrations at Sharpeville

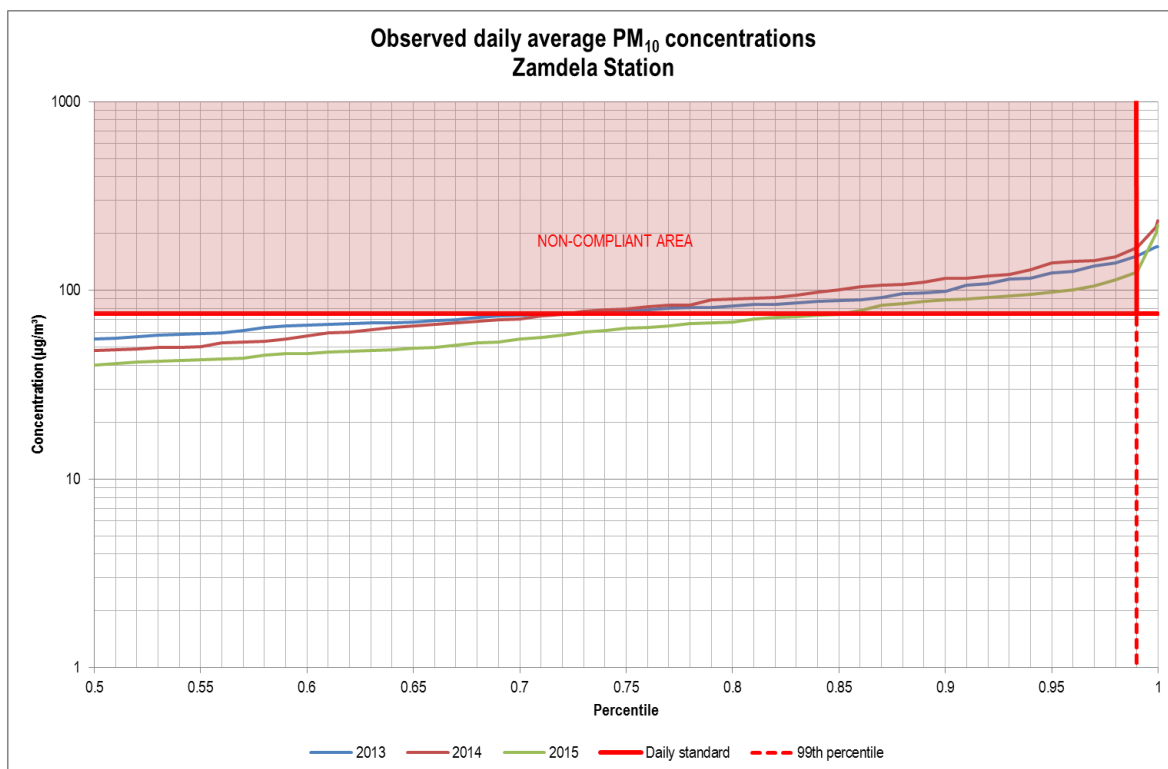


Figure 5-40: Observed daily average PM₁₀ concentrations at Zamdela

Time variation plots (mean with 95% confidence interval) of ambient SO₂, NO₂, and particulate matter (PM₁₀ and PM_{2.5}) concentrations measured the six monitoring stations show the variation of these pollutants over a daily, weekly and annual cycles (Figure 5-41 to Figure 5-52). The daily SO₂ show a typically industrial signature with increased SO₂ concentrations as just before midday due to the break-up of an elevated inversion layer, in addition to the development of daytime convective conditions causing the plume to be brought down to ground level relatively close to the point of release from tall stacks. Increased NO₂ concentrations during peak traffic times (07:00 to 08:00 and 16:00 to 18:00) illustrate the contribution of vehicle emissions to the ambient NO₂ concentrations. The winter (June, July and August) elevation of SO₂ and NO₂ shows the contribution of residential fuel burning to the ambient SO₂ and NO₂ concentrations. The large confidence interval band for AJ Jacobs was a result of the 257 hours (1%) with zero values for NO₂.

Monthly variation of particulate matter shows elevated concentrations during winter months due to the larger contribution from domestic fuel burning, dust from uncovered soil and the lack of the settling influence of rainfall (Figure 5-47 and Figure 5-52).

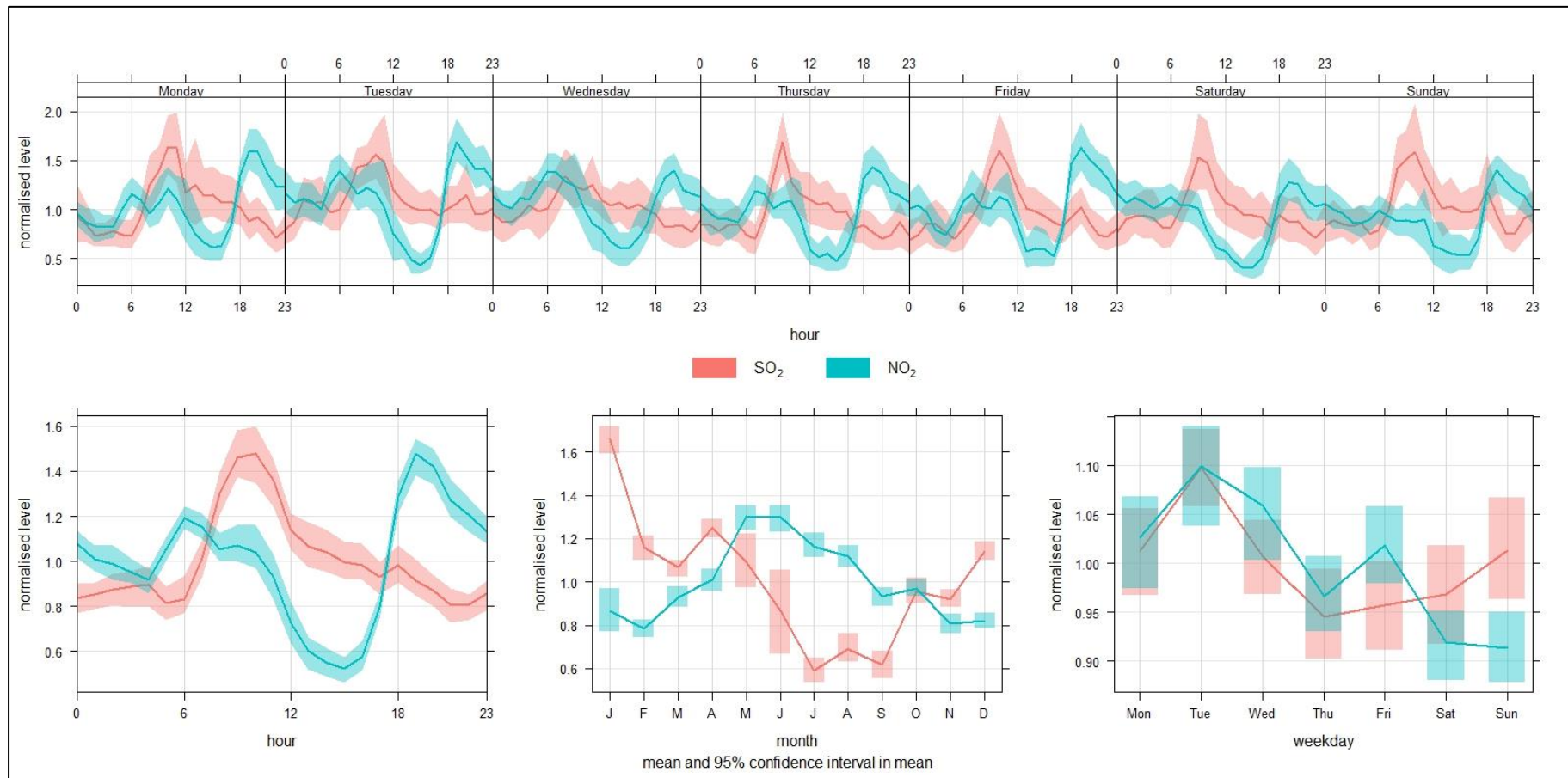


Figure 5-41: Time variation plot of observed SO₂ and NO₂ concentrations at Leitrim (shaded area indicates 95th percentile confidence interval)

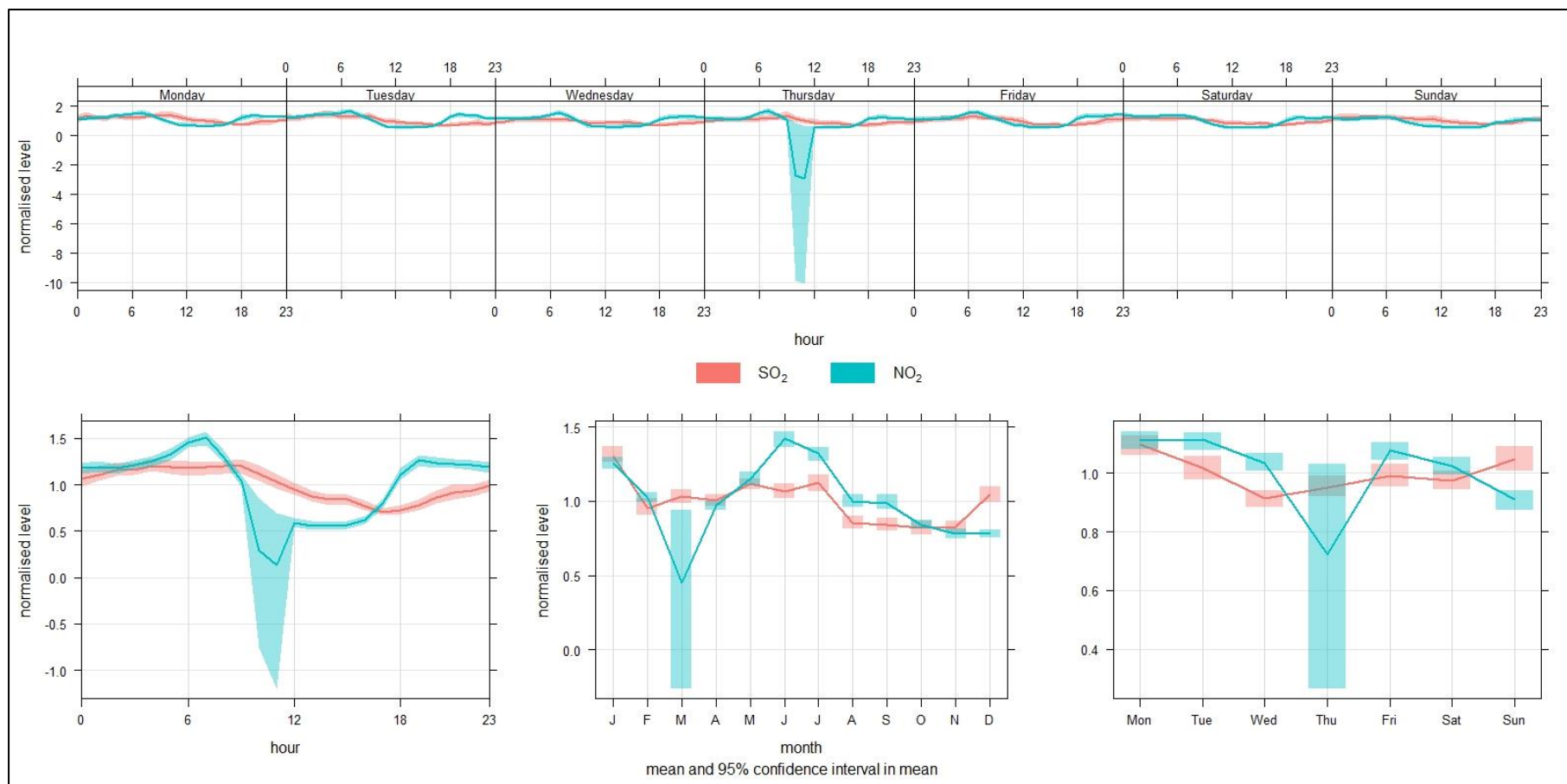


Figure 5-42: Time variation plot of observed SO₂ and NO₂ concentrations at AJ Jacobs (shaded area indicates 95th percentile confidence interval)

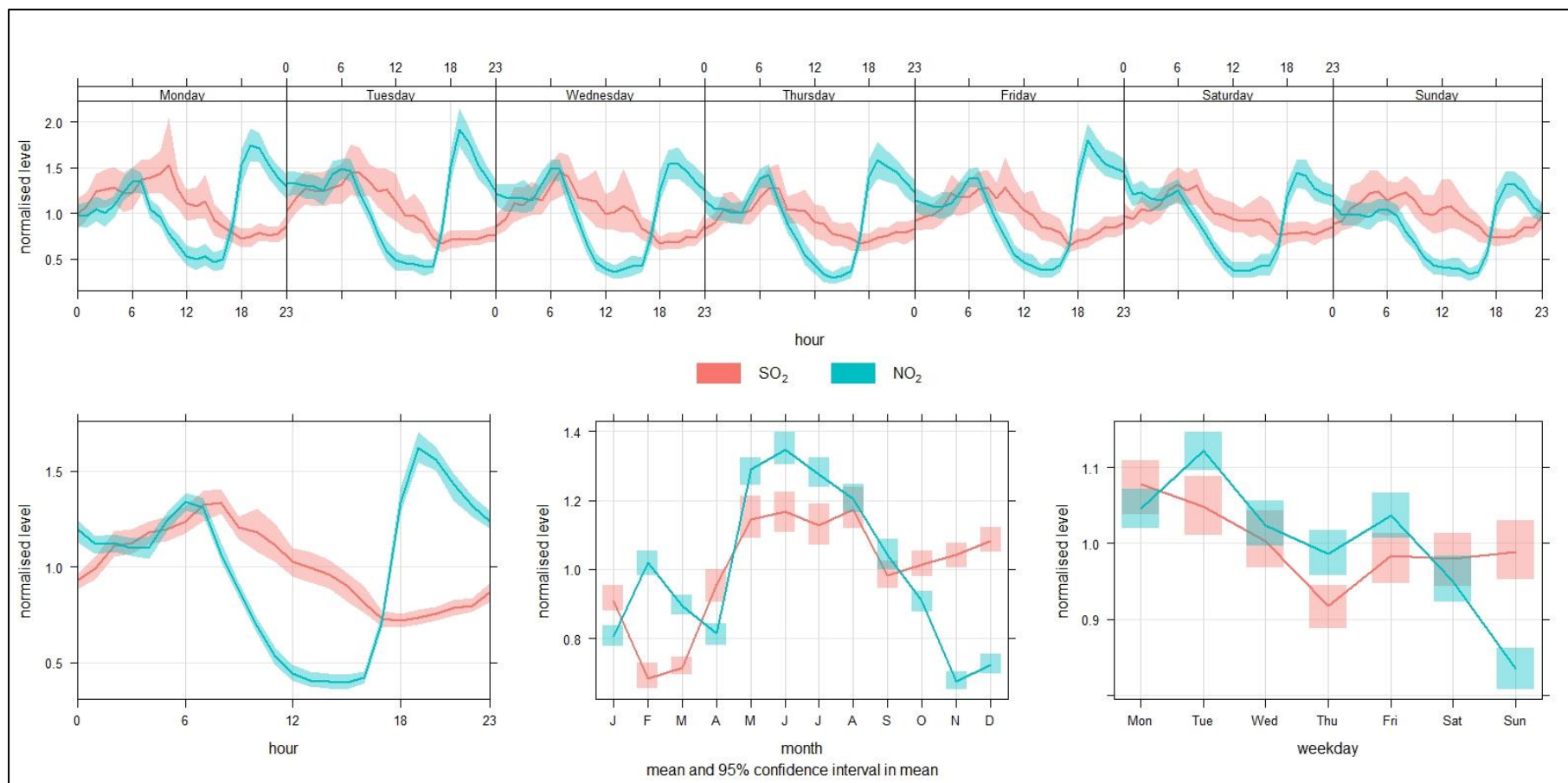


Figure 5-43: Time variation plot of observed SO₂ and NO₂ concentrations at Eco Park (shaded area indicates 95th percentile confidence interval)

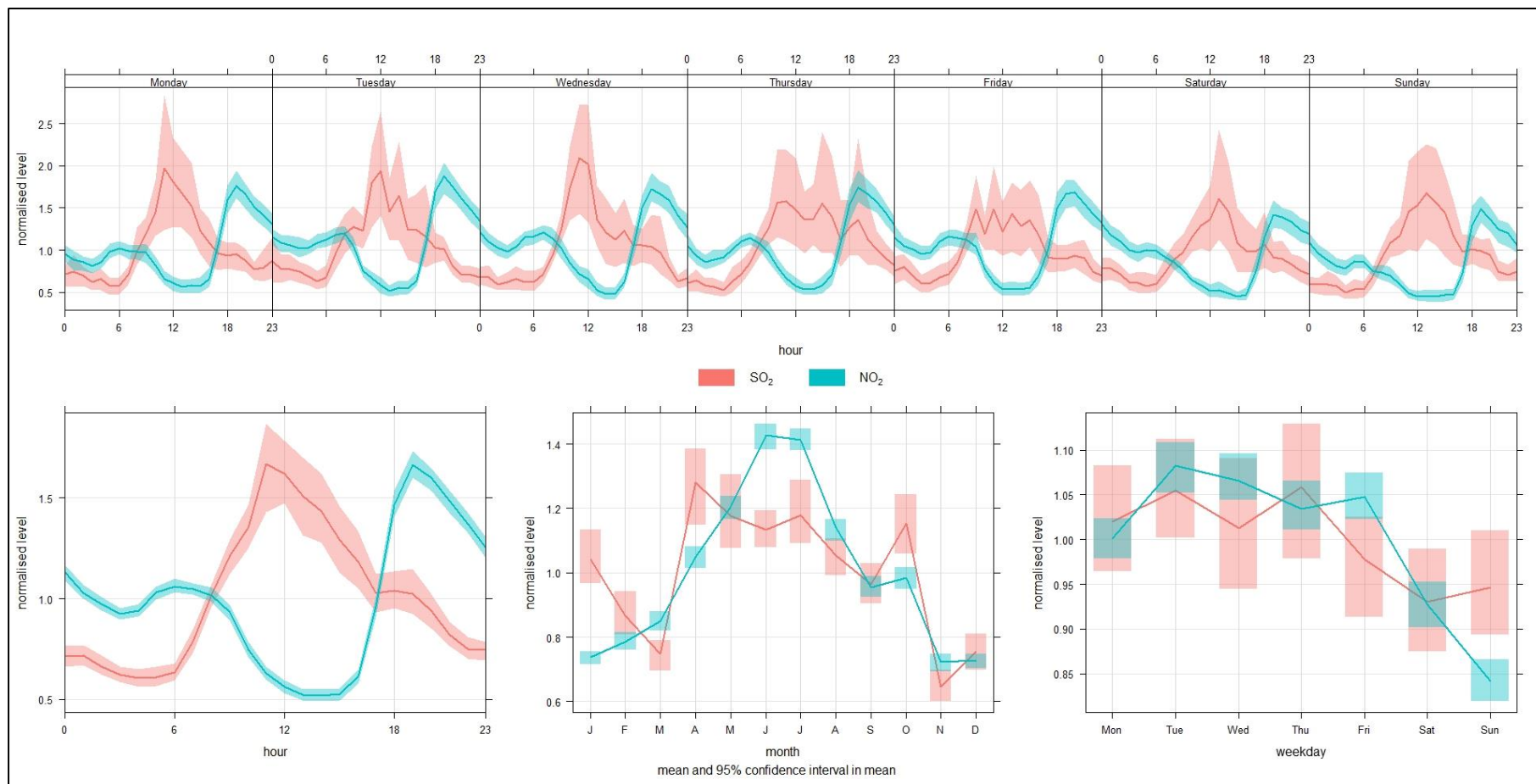


Figure 5-44: Time variation plot of observed SO₂ and NO₂ concentrations at Three Rivers (shaded area indicates 95th percentile confidence interval)

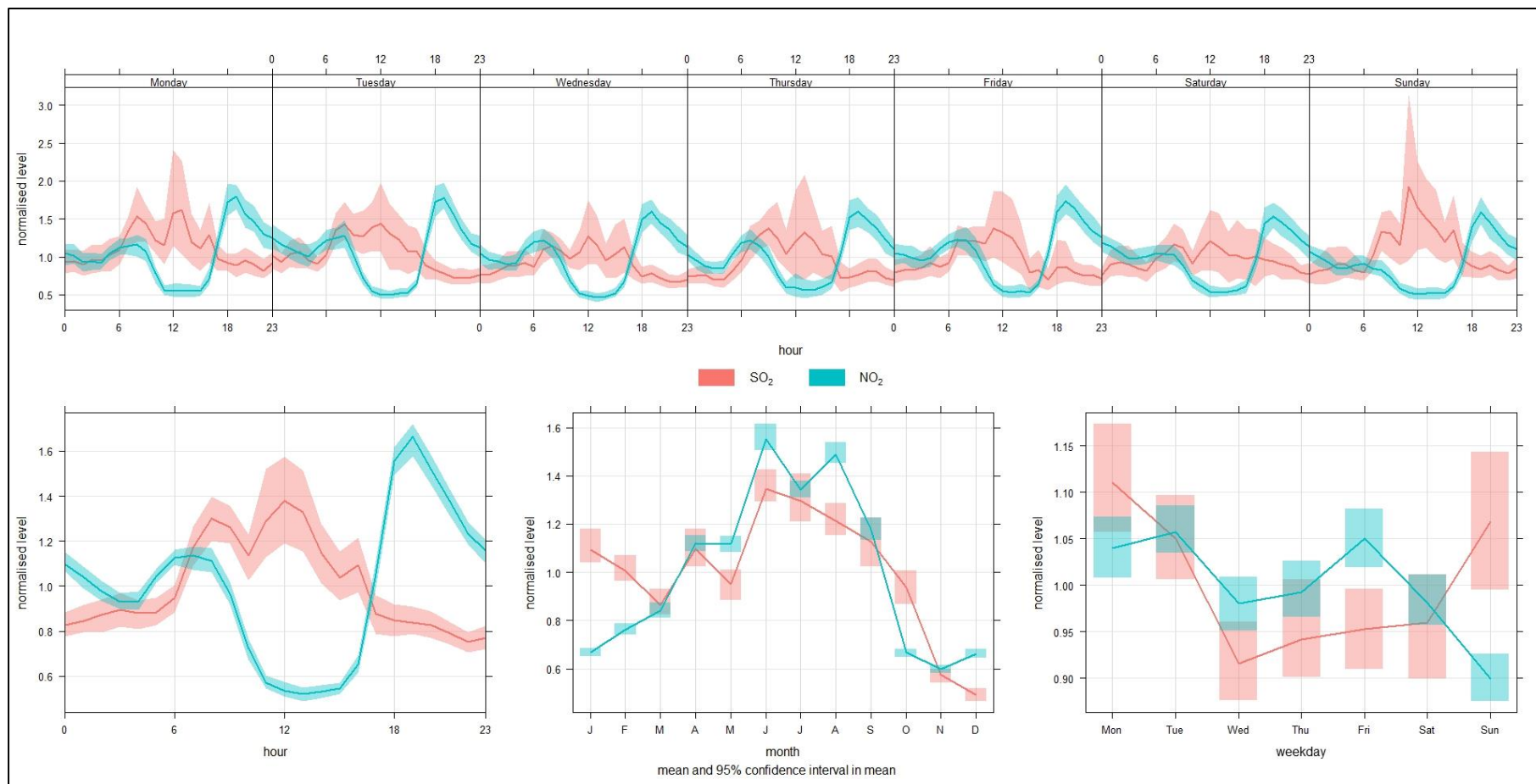


Figure 5-45: Time variation plot of observed SO₂ and NO₂ concentrations at Sharpeville (shaded area indicates 95th percentile confidence interval)

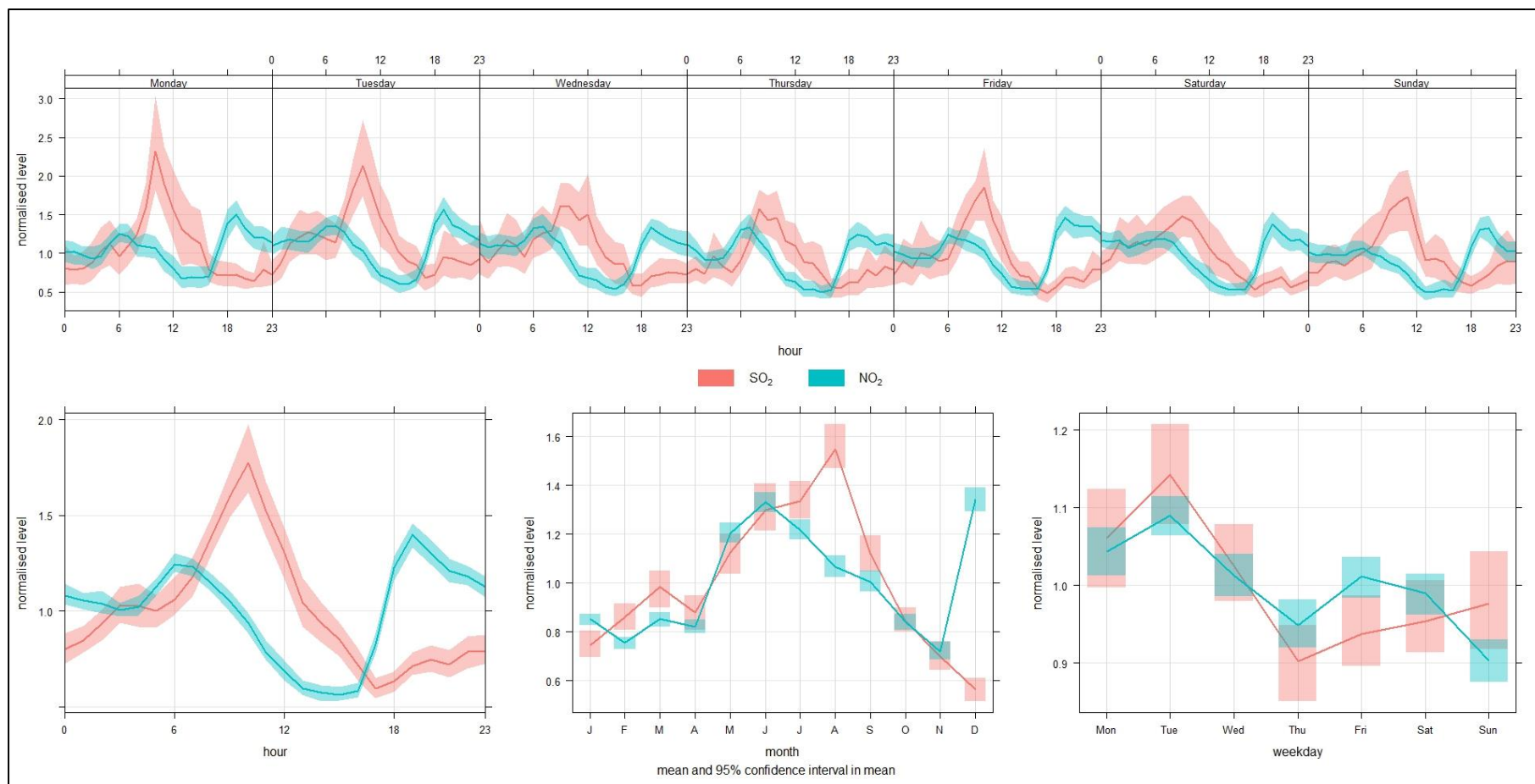


Figure 5-46: Time variation plot of observed SO₂ and NO₂ concentrations at Zamdela (shaded area indicates 95th percentile confidence interval)

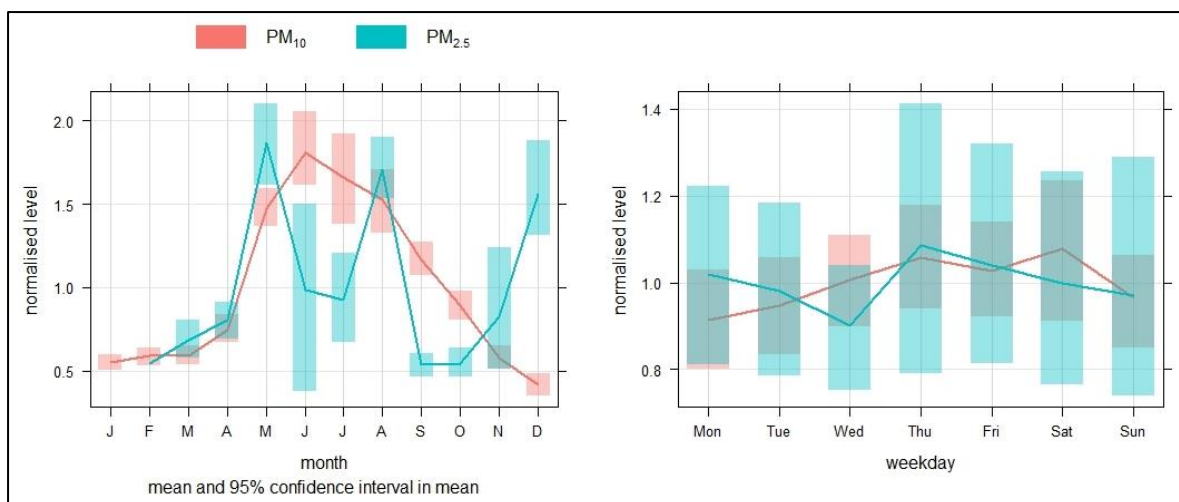


Figure 5-47: Time variation plot of normalised observed PM₁₀ and PM_{2.5} concentrations at Leitrim

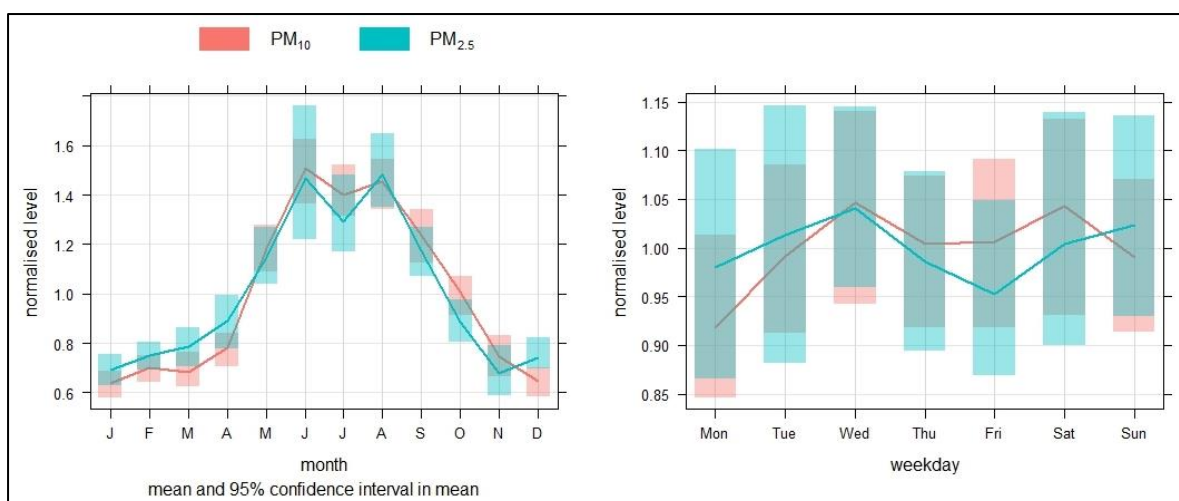


Figure 5-48: Time variation plot of normalised observed PM₁₀ and PM_{2.5} concentrations at AJ Jacobs

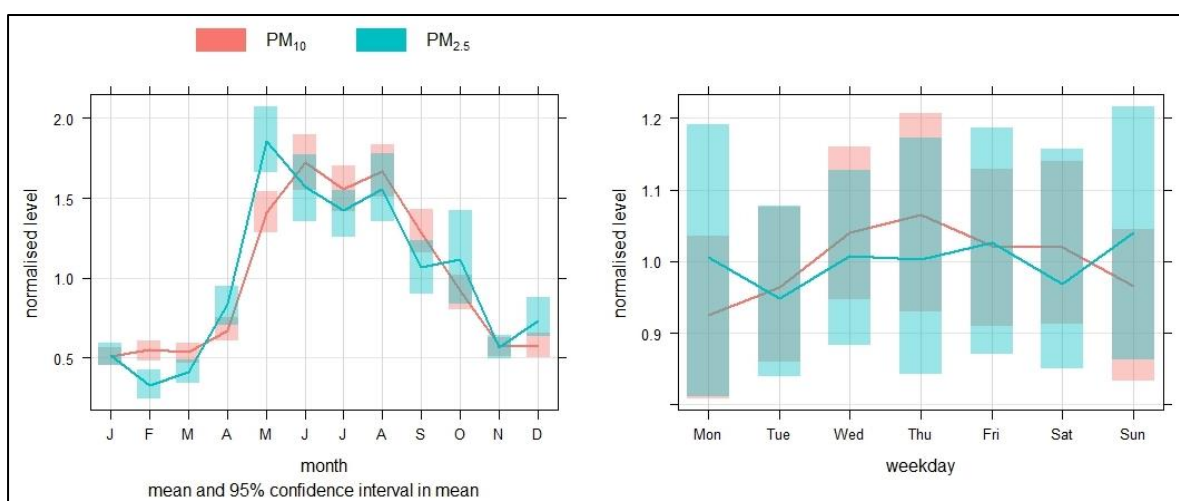


Figure 5-49: Time variation plot of normalised observed PM₁₀ and PM_{2.5} concentrations at Eco Park

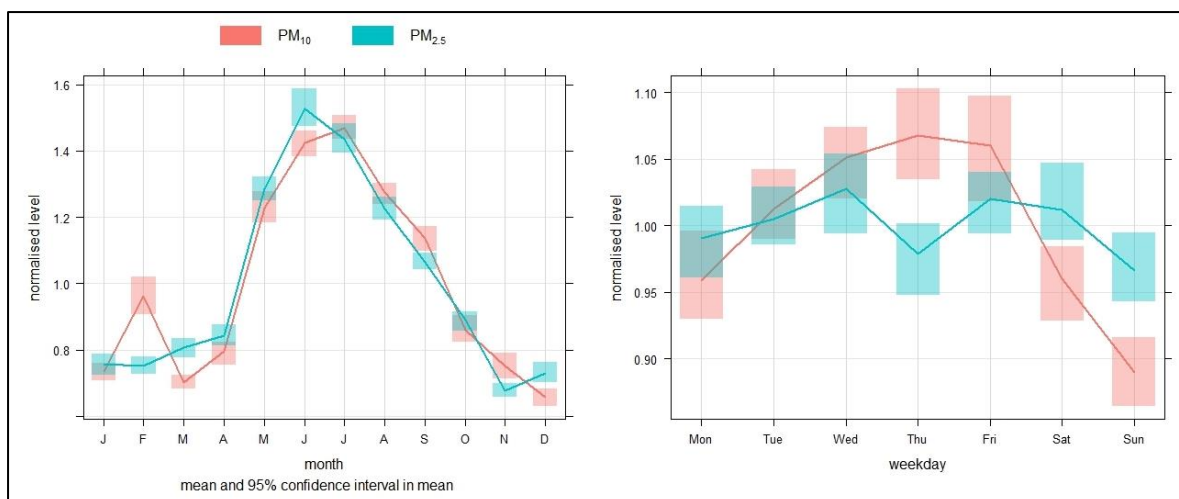


Figure 5-50: Time variation plot of normalised observed PM₁₀ and PM_{2.5} concentrations at Three Rivers

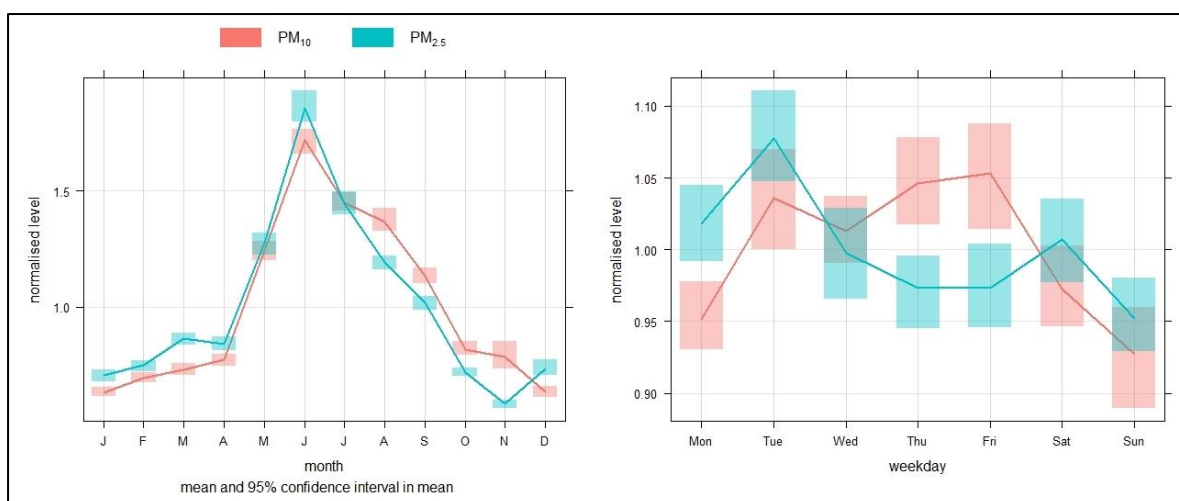


Figure 5-51: Time variation plot of normalised observed PM₁₀ and PM_{2.5} concentrations at Sharpeville

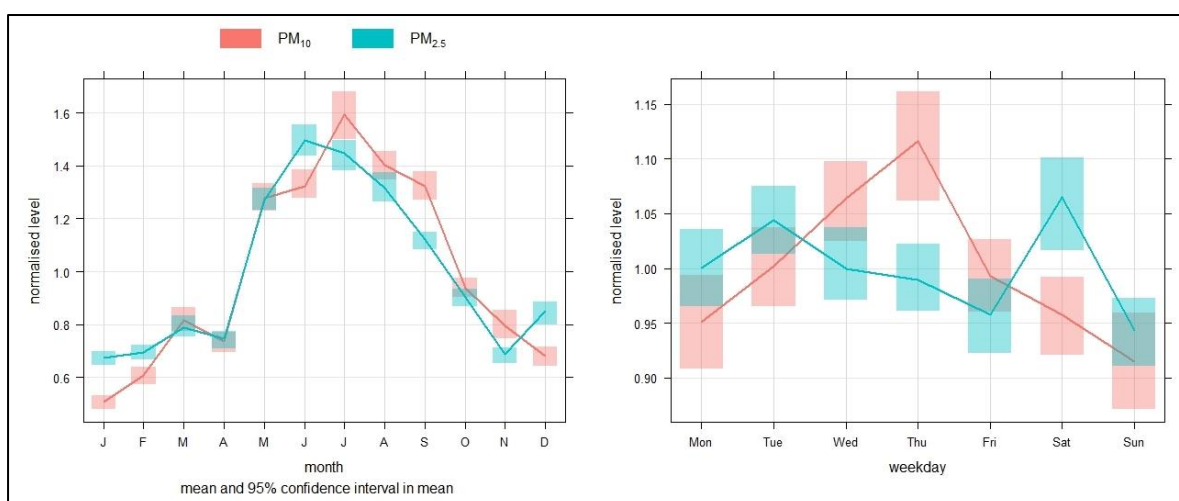


Figure 5-52: Time variation plot of normalised observed PM₁₀ and PM_{2.5} concentrations at Zamdela

5.1.6 Model Performance