USE OF AIR DISPERSION MODELLING TO DETERMINE THE IMPACT OF GAS EMISSIONS FROM COAL-FIRED BOILERS IN SOUTH DURBAN BASIN

By

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Declaration

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Prof. Sammy Kiambi **(Supervisor)**

Abstract

The use of fossil fuel due to industrialisation has increased over time and resulted to atmospheric pollution. Industrial facilities utilise fossil fuel as a boiler fuel, pollutants like Sulphur Dioxide, Nitrogen Dioxide, Particulate Matter and Carbon Monoxide are generated from the combustion process. Air pollution has been and continues to be a significant health hazard over the world. Exposure to air pollution is an issue of concern due to human health and the environment. Considering that air pollution is associated with a series of adverse health effects, it is important to predict emissions from boiler stack. The purpose of this study was to analyse the distribution of atmospheric emissions emanating from boilers in the South Durban Industrial Basin. Three boilers i.e. boilers 1, 3 and 4 were considered during this research. The study focuses on the distribution of Sulphur Dioxide, Nitrogen Dioxide, Particulate Matter and Carbon Monoxide concentration emitted from coal fired boilers using Gaussian Dispersion Modelling. In this research, AERMOD, which is the dispersion modelling program approved by the US EPA, was used. The results of these modelling scenario were compared with the National Ambient Air Quality Standards. The results depicted that the concentrations of sulphur dioxide and nitrogen dioxide emissions from coal fired boilers were below the national ambient air quality standard, whereas the concentration of Particulate Matter emission in the vicinity of the receiving environment exceeded the National Ambient Air Quality Standards. Nitrogen Oxide was released at 7.91 g/s whereas sulphur dioxide and particulate matter were released at 40.86 and 18.35 g/s respectively. However, the temperatures at which these gases were released were all the same (450.20 K). Boilers 3 and 4 shared a stack i.e. emission emanating from both boilers are emitted through a single point source. The stack diameters for boilers 3 and 4 (0.8 m and 1.2 m respectively) were lower than that of boiler 1 (2.6 m). Similarly, boilers 3 and 4 had less stack heights (27.5 m and 30.5 m respectively) in comparison with boiler 1 (47.5 m). For boiler 3, the rates at which nitrogen dioxide, sulphur dioxide and particulate matter were released were 2.26, 0.12 and 3.84 g/s respectively. On the hand, for boiler 4, nitrogen oxide was released at 14.5 g/s whereas sulphur dioxide and particulate matter were released at 5.54 and 26.23 g/s respectively. The exit velocities for boilers 1, 3 and 4 were 12.2, 7.1 and 17.5 m/s respectively. These velocities were achieved at temperatures of 450.2, 320 and 504 K respectively.

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Nomenclature

List of Abbreviations and Acronyms

AEL	Atmospheric Emissions License
AERMAP	AERMOD terrain pre-processor
AERMET	AERMOD meteorological pre-processor
AERMOD	AMS/EPA Regulatory MODel
APPA	Atmospheric Pollution Prevention, 1965 (Act No. 45 of 1965)
AQMP	Air Quality Management Plan
AQMN	Air Quality Monitoring Network
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CME	Compliance Monitoring and Enforcement
CO	Carbon Monoxide
EDTEA	Economic Development, Tourism and Environmental Affairs
DEA	Department of Environmental Affairs
GPS	Global Positioning System
GG	Government Gazette
GLC	Ground Level Concentration
GN	Government Notice
NAAQS	National Ambient Air Quality Standards
NAEIS	National Atmospheric Emissions Inventory System
NEM: AQA	National Environmental Management: Air Quality Act No. 39 of 2004
NHI	Net Heat Input
SDB	South Durban Basin
PCRM	Pollution Control and Risk Management
PM10	Particulate Matter of Aerodynamic Diameter less than 10 µm
PM2.5	Particulate Matter of Aerodynamic Diameter less than 2.5 µm
SAAELIP	South African Atmospheric Emissions Licensing and Inventory Portal
SAAQIS	South African Air Quality Information System
SANAS	South African National Accreditation System
SANS	South African National Standards
SAWS	South African Weather Service

SDB	South Durban Basin
US EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator geographic grid
VOC	Volatile Organic Compound
WHO	World Health Organisation
USA	United State of America
UK	United Kingdom
PM	Particulate Matter
MW	Mega Watts
GNR	Government Notice Regulation
SANS	South African National Standard
t/hr	Tonnes per hour
KJ/Kg	Kilojoules per Kilogram
TSP	Total Suspended Particles
PPM	Parts Per Million
G	Grams
FEV1	Forced Expiratory Volume
Mg/m3	Milligrams per cubic meters
NIOSH	National Institute for Occupational Safety and Health
PPB	Parts Per Billion
NSW	New South Wales
GHG	Green House Gases
WMO	World Meteorological Organisation
GCOS	Global Climate Observing System
HAP	Hazardous Air Pollutants
ESP	Electrostatic Precipitator
PEM	Periodic Emission Monitoring
CEMS	Continuous Emission Monitoring System
QA QC	Quality Assurance and Quality Control
ISO	International Standard Organisation
BSI	British Standard Institution
CEN	European Committee for Standardization

VDI	The Association of German Engineers
ASTM	American Society for Testing &Material
HSE	Health Safety Executive
MS	Meter per Second
SDIB	South Durban Industrial Basin
MM5	Mesoscale Model
M	Mass
KM	Kilometre
NM3/h	Normal cubic meter per hour
Kg/h	Kilogram per hour
G/S	Grams per second
SON	September, October & November
DJF	December, January & February
MAM	March, April & May
JJA	June, July & August
ADM	Air Dispersion Model/Modelling
TPH	Tonnes per Hour

List of Symbols

H2S	Hydrogen Sulphide
NO2	Nitrogen Dioxide
NOx	Oxide of Nitrogen
O3	Ozone
SO2	Sulphur Dioxide
K	Kelvin
kPa	Kilopascal
SO3	Sulphur Trioxide
µg/m3	Micro gram per cubic meter
µm	Micrometre
0C	°
NO	Nitrogen Oxide
CO2	Carbon Dioxide

CH4	Methane
CaSO4	Calcium Sulphate
NaOH	Sodium Hydroxide
Na2CO3	Sodium Carbonate
NaSO3	Sodium Sulphite
M3/S	Cubic meters per second
SOX	Sulphur Oxide
%	Percentage
µm/m3	Micrometre per cubic meters
µ	Micro
H2SO4	Sulphuric Acid

Thesis layout

Chapter one is an introduction which provides the background information to the research area. This chapter includes the challenges of air pollution which the community and the regulating authorities are confronted with. It makes further provisions to the main and specific objectives of the research.

The legislative context pertaining to the stack emission testing and atmospheric dispersion models applicable to South Africa is discussed in Chapter two, under the literature review. This includes the pollutants of concern in the research area which are SO_2, NO_2 and PM. This chapter further provides a general background to the dispersion models used worldwide as well as approved models in the South Africa.

The methodology used during the stack emission testing including the emissions inventory is discussed in Chapter three. This chapter further provides a discussion of data which was obtained during the stack emissions testing.

The data obtained during the stack emissions testing in Chapter three is then used in Chapter four, which provides a detailed methodology used for air pollution dispersion.

The results obtained during dispersion of emission concentrations are further analysed and discussed to identify the receptors that are impacted by emission as a result of emission emanating from coal-fired boilers.

The conclusions and recommendations drawn from this research are eventually discussed in Chapter five.

CHAPTER ONE

1. Introduction

This is an introduction chapter which provides the background information to the research area. The challenges of air pollution which the community and the regulating authorities are confronted with are discussed here. Further provisions to the main and specific objectives of the research are presented in this chapter.

1.1. Background Information

The South Durban Industrial Basis South is no exception to the air pollution problem caused by industrialisation (Guastella and Mjoli, 2005). The basin is the industrial hub of Durban, situated in the KwaZulu-Natal province. It stretches from the Port of Durban in the north to eZimbokodweni. The basin includes 2 (two) large petrochemical refineries, a large paper mill, and entails 5000 businesses, 22 000 households and 200 000 residents. The residential areas include Bluff, Clairwood, Wentworth and Merebank. During the 1930s, the South Durban Basin was planned as an industrial centre. Figure 1-1 shows the South Durban Industrial basin

Figure 1-1: South Durban Industrial basin

The air quality management in South African has recently advanced from evaluating the impact of emissions through visual monitoring to sophisticated management methods that take cognisance of spatial and temporal impacts of air pollutants from various sources and provide assimilation of emission concentrations. Industrialisation has led to elevated sulphur emissions, leading to various air pollution impacts such as acidification of the water sources (Pham et al., 1996). Elevation of sulphur dioxide (SO_2) emissions has led to global as well as localised deterioration in air quality with meteorology and topographical factors contributing to emission dispersion (Nunnari et al., 2004). The ambient air quality is regulated through compliance with ambient air quality standards (NAAQS), which are designed to protect human health and environment. NAAQS are set by legislation and the achievement or compliance with ambient air quality standards forms part of an air quality management planning process. An Air Quality Management Plan (AQMP) usually comprises of a point source, ambient air monitoring data, meteorological data; emission monitoring, emissions inventory, air dispersion modelling results and emission reduction measures.

To establish an AQMP strategy for a specific area, the atmospheric emission concentration of pollutants should be determined. There are two methods that can be used to determine ambient air quality concentrations, namely, the ambient air quality monitoring or emissions dispersion modelling.

Ambient air quality monitoring requires a range of equipment and instruments that are capable of continuous and consistently detecting gaseous and particulate matters including meteorological conditions. These equipment must be housed in temperature controlled environment and must be calibrated and maintained periodically. The continuous data output from the analysers require validation, interpretation and reporting (Ministry for the Environment, 2009).

This technique of determining ambient air quality compliance is expensive and the results are area specific. The accuracy of ambient monitoring is dependent on the limitations of the type and instruments used, as well as human error during maintenance and calibration of analysers. The disadvantage of ambient monitoring is the fact that during the upset conditions emanating from industrial processes, ambient monitoring may not capture upset conditions unless the incident occurs in the exact location of or upwind of an ambient monitoring station (European Environmental Agency, 2004).

Data collected during continuous monitoring is used for emission dispersion modelling. Emission dispersion modelling utilises software that requires data input from emissions inventories and meteorological data to calculate the concentrations of pollutants in ambient environment. Modelling can provide spatial and temporal patterns of air pollutants and allows for simulation of pollutant concentrations from a single to multiple sources. The real time modelling is capable of detecting major sources of pollution in the case of air pollution incidents. The results obtained from air emission dispersion modelling can be used to measure existing and future air quality impacts, to assess the potential for reduction measures when ambient guidelines are exceeded, to determine an appropriate location for a monitoring station when developing an ambient air quality monitoring system, to estimate air pollution episodes, to assess the impact of incidents caused by the emergency release of emissions from industrial sources, and to estimate the emission reduction measures required in order to comply with ambient guidelines (Centre for Environmental Rights, 2019).

Single sources of pollution can also be modelled to assess their contribution or impact to ambient air quality. In this way modelling can be used as a prioritization tool to focus on the most significant sources pollution contributing to poor air quality in a specific area. Ambient monitoring and atmospheric dispersion modelling are complementary components of an air quality management system, where ambient measurements can be used to validate and confirm air dispersion modelling results at specific locations (Ministry for the Environment, 2009).

The objectives of ambient air quality standards aimed at the protection the environment, public health and are established by the United States Environmental Protection Urgency (US EPA). In South Africa primary National Ambient Air Quality Standards (NAAQS) have been set for seven common criteria pollutants which are carbon monoxide (CO), nitrogen oxide (NO), sulphur dioxide (SO_2), ozone (O_3), particulate matter (PM), lead (Pb) and benzene (C_6H_6). These pollutants provide both the community and environmental protection, this include protecting the health of vulnerable populations such as children, asthmatics and the elderly.

In the South Durban Basin (SDB) concerns about community health and environment among communities and the increased demand and expansion of industry have caused serious disputes and conflicts between residents and local industries**.** The basis of conflicts were disagreements between local residences and industries, on perceptions and concerns regarding the disagreeable distribution of consequent costs, so that most of the cost often had to be borne by the communities. The absence of sound political control and in order to prevent further bad decisions in the future has further exacerbated the local crisis.

The disputes on environmental issues and conflicts arise not only from communities' perceptions and concerns about potential adverse consequences of proposed developments and upgrades of industry, but also from a perceived disrespect of the legal rights of individuals and communities, which are institutionalised constitution of the Republic of South Africa. The anticipated responses to the adverse impacts of air pollution have often been delayed due to political, social and economic factors. However, people's awareness, their interpretation of the adverse effects of air pollution and their willingness to tolerate a certain degree of air pollution has progressively changed. The struggle between local industries and communities ascended when certain industry purchased land from the Durban Council during the apartheid era and began its operations without consulting local communities including interested and affected parties (I&A). Local residences alleged that there were inadequate emission mitigation measures in place. This resulted to industries and community members distrust (Naidoo et al., 2006).

According to the eThekwini Health Department (2009), SO_2 emissions levels below guidelines were recorded at all relevant stations. However, analysis of the correlations between wind direction and incidences of elevated emissions showed that industrial facilities are the main offenders in relation to SO_2. When analysed over a five-year period, the number of times that guidelines standards for 10-minute averaged SO_2 concentrations were exceeded remained the same at all relevant stations. In 2007 however, exceedances can be noticed at the Settlers and Wentworth monitoring stations. Thirty-nine (39) of the forty-one (41) times that guideline levels were exceeded. But some also came from the Jacobs's area. The monitoring stations at Ganges and Prospection also displayed elevated concentrations of SO_2, which supports the evidence pointing towards industries as the biggest contributors to SO_2 emissions concentration.

There was a 40% reduction in SO_2 from due to fuel switching and reduction control strategies (Department of Environment Affairs and Tourism, 2007). These include installation of a scrubber to reduce SO_2 emissions by 50% and reduce particulate matter emissions from the coal fired boilers. Additional focus is still required to decrease downtime on the scrubber and the usage of gas instead of coal; the usage of heavy fuel oil is characterized by high sulphur content. The Environmental Improvement Programme, an agreement between local industry and South Durban Community Environmental Alliance (SDCEA), which commenced in 1998, lead to reduction of SO_2 by 65%, a 70% reduction in PM_{10} emissions, as well as reductions in NO_X and flaring (Department of Environment Affairs and Tourism, 2007). Emissions of NO_X increased by 48% from 863tpa (tons per annum) to 1300 tpa during the period of 2000 to 2007.However, Volatile Organic Compounds (VOC) emissions decreased by 47% since 1999 (Department of Environment Affairs and Tourism, 2007). This was the result of implementation of best available technology for instance conversion of coal fired boilers to electricity.

A joint study concentrating on school children, conducted by the University of Natal and University of Michigan and the Durban Institute of Technology, researched the health costs associated with air pollution at the Settlers Primary School. The duration of the study was 18-day period from 19 April to 6 May 2001 and revealed that 52% of the study population had upper respiratory illnesses including asthma. This is the highest rate recorded in scientific literature (Naidoo et al., 2006).

During the study period, emissions were measured on the school grounds. The study population consisted of 248 school learners and 25 teachers. The baseline health status of all participants was determined by means of interviews. A record of symptoms was kept every two hours during the school day and the breathing function of the participants was measured as well. Signs reported by participants indicated that 52% of school learners in Grade 3 to 6 had asthma and 26% had persistent asthma. The breathing tests exposed similar results. Data revealed SO_2 as the major emissions major contributing factor. The strongest relationship occurred when SO_2 reached the school from a north-north-east direction (Robins et al., 2002).

The University of KwaZulu Natal and University of Michigan USA undertook a health risk analysis epidemiological study in 2004 and 2005. The objective of the study was to ascertain if there was association between respiratory illnesses and ambient air pollution. Participants from South Durban were compared with participants of North Durban, where it was allegedly less polluted. It measured levels of over 20 outdoor contaminants at 23 different sites. Meteorological data was also collated. The study revealed that the exposures to air pollutants such as SO_2, PM_{10}, NO_2 and NO results in poor lung functioning among children who have persistent asthma and those participants who are hereditarily predisposed to respiratory illnesses especially asthma. The elevated incidence of this was depicted in the South Durban Basin.

Figure 1-2 shows a view of the southern portion of the Engen refinery from the residential area of Austerville with Merewent in the background.

Figure 1-2: View of the southern portion of the Engen refinery (Department of Environment Affairs and Tourism, 2007)

The South Durban Industrial Basin flanks one of the busiest ports in the Southern Hemisphere. It has long been an area of concern with regard to air quality. Industrial development existed, with little or no consideration for atmospheric pollution or the cumulative effects on air quality (Department of Environmental Affairs and Tourism, 2007b). Besides the fact that it one of the more heavily polluted industrial areas of South Africa, particularly with respect to sulphur dioxide it's is in close proximity to residential areas (Matooane et al., 2004).

It is noted that the studies conducted in the South Durban Industrial Basin focus on emissions from the refineries. There has been no study conducted on the cumulative impact of emission emanating from various small boilers or controlled emitters in the South Durban Industrial. For the purpose of this study, a cumulative impact is, *"the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions".* Cumulated impact resulting from coal-fired boilers come with substantial costs to environment including human health (Centre for Environmental Rights, 2016). Combustion of coal releases emissions of sulphur dioxide (SO_2), nitrogen oxide (NO), particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs) and various traces of metals like mercury, through stack (Golder Associates, 2015). These pollutants can disperse over large areas and adversely impact the receiving environment or community (Council of Scientific and Industrial Research, 2013).

The Minister of Water and Environmental Affairs, Mrs Edna Molewa declared small boilers resulting in atmospheric emissions as controlled emitters and established emission standards, in terms of section

23(1) and section 24 of the National Environmental Management: Air Quality Act, 2004 (Act No.39 of 2004) (Air Quality Act), in Gazette No. 36973 (Government Gazette, 2013). All boilers manufactured before November 2013 are given until November 2018 to comply with the Minimum Emission Standards.

According to The Clean Air Journal (2010), emissions from small boilers fall in a group of small scale emission sources that, as a result of their technological limitations, the scale of population as well as their operation which is at close proximity to residential dwellings, poses a significant risk to human health and the environment. The industrial basin comprises residential areas in close proximity to industry. This Air Quality Impact Assessment is to therefore assess the air quality impacts generated by flue gases emitted from industrial boilers (Clean Air Journal, 2016).

In order to safeguard the right to an environment that is safe to health and wellbeing, there is a need for close monitoring and control of these emitters, as among others, industrial boilers were identified as significant sources of pollution (Centre for Environmental Rights, 2016).

It’s for the above reason that the National Department of Environmental Affairs through Mrs Edna Molewa declared small boilers resulting in atmospheric emissions as controlled emitters and established emission standards, in terms of section 23(1) and section 24 of the National Environmental Management: Air Quality Act, 2004 (Act No.39 of 2004) (Air Quality Act), in Gazette No. 36973. All boilers manufactured before 1st November 2013 are given until November 2018 to comply with the Minimum Emission Standards (Government Gazette, 2013).

It is ideal to ensure that emissions are prevented or reduced at sources as far as is practicable in order to achieve compliance with the Minimum Emission Standards. Further treatment of pollutant laden gas stream is required when source reduction is unable to meet the stipulated minimum emission standards. Abatement control technologies ranges from multi-cyclones, bag filters, scrubbers and electrostatic precipitators. The selection of abatement technology to meet emission limits and requirements is dependent amongst other things on the type of pollutants to be removed, the physical and chemical characteristics of the gas stream and pollutants to be treated. The chemical characteristics includes temperature, moisture content, abrasiveness, pH, chemical composition and reactivity, corrosively, flammability solubility, dew point, and volatility (Department of Environmental Affairs, 2010).

Multi-cyclones are commonly used in South Africa to reduce particulate emissions. Centrifugal force may cause particulate matter (PM) which is friable, to degrade into finer PM. This may cause an additional problem by creating very fine PM which is more detrimental to the environment and to human health.

When conducting emissions testing, the industries are required to use the approved methods, for sampling and analysis of flue gases. The pollutants that are usually measured are Sulphur Dioxide, Nitrogen Oxide, Nitrogen Dioxide and Particulate Matter (Department of Environmental Affairs, 2010).

The National Environmental Management: Air Quality Act (Act number 39 of 2004) permitted the Minister of Environmental Affairs to declare certain appliance as Controlled Emitters. The Declaration of Small Boilers as Controlled Emitter was promulgated in November 2013 and classified boiler with a net heat input of between 10 but < 50 MW as controlled emitters. This legislation requires the users of boilers to conduct annual stack emissions testing and verify compliance with Minimum Emission Standards.

In terms of Section 23 of the regulation declaring small boiler as a controlled emitter. The users of boiler must prove compliance with Minimum Emission Standards in relation to sulphur dioxide (SO_2) - (mg/Nm^3 at 273K, 101.3 kPa and 10%) for solid fuel-fired boiler. Sulphur Dioxide is a gas which is formed when the sulphur present in the fuel is burnt in the presence of oxygen. Emission of SO_2 from boilers is completely dependent on the quantity of sulphur in the fuel. Fuel with low sulphur content produces less sulphur emissions.

The oxidation of SO_2 to SO_3 occurs at lower temperatures during and after being emitted from the boiler stack. The SO_3 combined with the water present in the flue gas and in the atmosphere to form sulphuric acid (H_2SO_4) is known as “acid rain” is also known to aggravate asthma (WSP Environment & Energy South Africa, 2015). Sulphur dioxide is a major respiratory irritant, resulting in respiratory illnesses, alterations in pulmonary defences and aggravation of existing cardiovascular disease. SO_2 may also create sulphuric acid as a result of its water solubility, producing acid rain. Once emitted, SO_2 may oxidize in the atmosphere to produce sulphate aerosols, which are also harmful to human health (Arup Consulting Engineers, 2004).

Table 1-1 shows the composition of sulphur in different fuels in South Africa. It can be seen that; methane rich gas has a sulphur content of 0.0 % while normal heavy furnace oil has the highest content of sulphur (3.5%). On the other hand, A and B grade coal, has a sulphur content ranging between 0.5 to 0.7 %.

Table 1-1: Composition of sulphur in different fuels in South Africa

Fuel	Sulphur Content
A and B Grade Coal	0.5 – 0.7 %
Normal Heavy Furnace Oil (HFO)	3.5 %
Low Sulphur HFO (LSO)	1.5 %
Methane Rich Gas	0.0 %

Biomass	0 – 0.08 %

1.2. Research problem and Significance

The South Durban Industrial Basin is dominated by large scale industries. Most of these industries use coal to generate steam for boilers. The use of coal as energy source has negative impact in the community and the environment at large. The use of coal emits various gases which when inhaled triggers health illnesses. In addition to the usage of coal usage is the proximity of residential areas to these industries. In 2004, eThekwini Metropolitan stipulated that the South Durban Basin is environmentally degraded due to elevated levels of pollution (KMT Enterprise, 2004). This research focused on the analysis of the distribution of atmospheric emissions emanating from boilers in the South Durban Industrial Basin.

1.3. Aims and objectives

1.3.1. Main objective

The main objective of this study was to assess the contribution of atmospheric emissions to air quality management in the South Durban Industrial basin residential areas using SO_2, PM and NO_2 as indicators of pollutants.

1.3.2. Specific objectives

The specific objectives of the study were:

- To quantify coal boiler stack emission concentrations for SO_2, PM and NO_2.
- To simulate maximum 1-hour, 24-hour and annual average concentrations of SO_2 over the study area based on current SO_2 emissions
- To simulate maximum 1-hour, 24-hour and annual average concentrations of PM over the study area based on PM permitted or allowable values
- To simulate maximum 1-hour and annual average concentrations of NO_2 over the study area based on NO_2 permitted or allowable values
- To compare predicted model results with the South African Ambient Air Quality Standards (SAAQS) for SO_2, PM and NO_2.

CHAPTER TWO

2. Literature review

The legislative context pertaining to the stack emission testing and atmospheric dispersion models applicable to South Africa is discussed in this Chapter two. This includes the pollutants of concern in the research area which are SO_2, NO_2 and PM. This chapter further provides a general background to the dispersion models used worldwide as well as approved models in the South Africa.

2.1. Air quality legislation

The Government Gazette (2004) which repealed the Atmospheric Pollution Prevention Act of 1965, came into effect on 11 September 2005, with the promulgation of regulation in terms of certain section resulting in the APPA being repealed entirely on 1 April 2010. The key features of the NEMAQA include:

- A decentralisation of air quality management responsibilities;
- The identification and quantification of significant emission sources that then need to be addressed;
- The development of ambient air quality targets as goals for driving emission reductions;
- The use of source-based measures in addition to alternative measures, including market incentives and disincentives, voluntary programme, and education and awareness;
- The promotion of cost-optimised mitigation and management measures;
- Stipulation of air quality management planning by authorities, and emission reduction and management planning by source; and
- Access to information and public consultation.

The National Environmental Management: Air Quality Act introduced a management system based on ambient air quality standard and corresponding emission limits to achieve such standard. Subsequently, two significant regulations stemming from the NEMAQA have since been promulgated, namely: GNR 1210 on 24 December 2009 (Government Gazette 32816) National Environmental Management: Air Quality Act, 2004 (Act No. 39 0f 2004) National Ambient Air Quality Standards; and GNR 248 on 31 June 2010 (Government Gazette 33064) National Environmental Management: Air Quality Act, 2004 (Act No. 30 of 2004) List of Activities which result in Atmospheric Emissions which have or may have a significant detrimental effect on the Environment, including Health, Social Conditions, Economic Conditions, Ecological Conditions or Cultural Heritage.

The National ambient air quality standards for air quality were based primarily on guidance offered by two standards set by the South African National Standards (SANS), namely: SANS 69:2004 Framework for implementing National ambient quality standard; and SANS 1929:2005 Ambient air quality limits for common pollutants. SANS 69:2004 makes provisions in sans 69 to establish air quality objectives for the protection of human health and the environment as a whole. Such air quality objectives include limit values, alerts thresholds and target values. Furthermore, SANS 1929:2005 uses the provisions in SANS 69 to establish air quality objectives for the protection of human health and the environment, and stipulates that limit values are initially set to protect human health. The setting of such limit values represent the first step in a process to manage air quality and initiate a process to ultimately achieve acceptable air quality nationally. The limit values presents in the standard are to be used in air quality standards for criteria pollutants generally have specific averaging periods; compliance timeframes, permissible frequencies of exceedance and reference methods (Department of Environment Affairs, 2004; Liebenberg-Enslin et al., 2005; The Clean Air Journal, 2010).

The relevant South African ambient air quality standards (Government Notice 1210 of 2009, Government Gazette 32816): (Act No. 39 of 2004) are presented in Table 2-1.

Table 2-1: South African Ambient Air Quality standards (Government Gazette, 2004)

South Africa Ambient Air Quality Standards				
Pollutant	Averaging Period	Concentration (µg/m3)	Frequency of Exceedance	Compliance Timeframe
Particulate Matter (PM10)	24 - hour	120	4	Immediate – 31 Dec 2014
		75	4	01 Jan 15
	1 year	50	0	Immediate – 31 Dec 2014
		40	0	01 Jan 15
Particulate Matter (PM2.5)	24 - hour	65	4	Immediate – 31 Dec 2015
		40	4	01 Jan 2016 – 31 Dec 2029
		25	4	01 Jan 30
	1 Year	25	0	Immediate – 31 Dec 2015
		20	0	01 Jan 2016 – 31 Dec 2029
		15	0	01 Jan 30

Sulphur Dioxide (SO2)	10 Minutes	500	526	Immediate
	1 – hour	350	88	Immediate
	24 – hour	125	4	Immediate
	1 year	50	0	Immediate
Nitrogen Dioxide (NO2)	1 – hour	200	88	Immediate
	1 – year	40	0	Immediate
Carbon Monoxide (CO)	1 – hour	30000	88	Immediate
	8 – hour	10000	11	Immediate
Benzene (C6H6)	1 – Year	10	0	Immediate – 31 Dec 2014
	1 – Year	5	0	01 Jan 15

The effect of air pollution on human health occur in a number of ways with short term, or acute effect and chronic, or long term effect. Factors that link the concentration of an air pollutant to an observed health effect are the concentration, as well as the frequency and duration of the exposure to that particular air pollutant.

Criteria pollutants occur in urban and industrial environments. Their effects on human health and the environment are well documented(World Health Organization, 2000, 2013). South Africa has accordingly established National Ambient Air Quality Standards (NAAQS) for the criteria pollutants, i.e. sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), particulate matter ≤ 10µm in diameter (PM_{10}), ozone (O_3), lead (Pb) and benzene (C_6H_6) (DEA, 2009) and particulate matter ≤ 2.5µm in diameter ($PM_{2.5}$) (DEA, 2012a). The NAAQS for SO_2, NO_2, PM_{10} and $PM_{2.5}$ are listed in Table 2-1.

The NAAQS consists of a 'limit' value and a permitted frequency of exceedance. The limit value is the fixed concentration level aimed at protecting human health against the harmful effects of a pollutant. The permitted frequency of exceedance represents the acceptable number of exceedances of the limit value expressed as the 99th percentile. Compliance with the ambient standard implies that the frequency of exceedance of the limit value does not exceed the permitted tolerance. Being a health-based standard, ambient concentrations below the standard imply that air quality poses an acceptable risk to human health, while exposure to ambient concentrations above the standard implies that there is an unacceptable risk to human health.

2.2. Controlled emitters

In 2004, the National Environmental Management Air Quality Act (NEMAQA) (Act No. 39 of 2004) as amended, was promulgated. Section 23 of this act provided the minister to declare appliances that contribute to Atmospheric Pollution as Controlled Emitters. As such, on 01 November 2013, the Declaration of Small Boilers as Controlled Emitters came into effect. The requirements of this act were that all users of boilers larger than 10 MW but smaller than 50 MW of Net Heat Input (NHI) to comply with visual smoking regulations and conduct annual stack emissions testing and to comply with minimum emissions standards.

B-grade of coal has a gross calorific value of (GCV) of 26500 kJ/kg. The gross calorific value of coal can be converted to a net calorific value and then to a Net Heat Input using the following formulas. The following formulas were written as part of the Draft Legislation declaring Small Boilers a Controlled Emitters, however they were omitted from the final legislation because legislation is not permitted to include calculations.

2.3. Impacts of Key Pollutants on the Receiving Environment

2.3.1. Particulate Matter (PM)

Particulate matter is generally divided into three broad fractions which are:

- Total Suspended Particulate Matter (TSP);
- Particulate Matter of less than µm in aerodynamic diameter (PM_{10}); and
- Particulate Matter of less than 2.5 µm in aerodynamic diameter ($PM_{2.5}$).

$PM_{2.5}$ is a sub-class of PM_{10}, which in itself is a sub-category of TSP. Whilst the definition of TSP comprises smaller size fractions, it is commonly used to define the larger fraction (between 10 µm and 30 µm diameter) that, because of its aerodynamic diameter and density, drops more quickly from the air than smaller fractions. Given adequate time, however, PM_{10} will also settle out of suspension in the atmosphere. The size of TSP means that the majority of this material will not enter the human body thorough inhalation, as it is stopped by the cilia in the nose and throat. Impacts of TSP are primarily limited to nuisance and may only affect health via annoyance reactions.

PM_{10} is recognised as a pollutant of concern due to its capability to be inhaled into the lungs. Due to this effect PM_{10} has been considered as part of this study. Gas turbine emissions using natural gas as source of fuel generally contain very low concentrations of particulate matter due to the fuel type and combustion process. The United State Environmental Protection Agency recognises that all particulate matter from gas combustion in gas turbines is less than 1 µm. The major natural sources of background particulate matter include forest fires, pollen and wind-blown dust from exposed areas. Anthropogenic sources include stationary and mobile combustion sources, road dust, agriculture, mining, major fires and emissions from industrial processes. Background levels differ widely depending on location, meteorology and proximity of major sources (United States Environmental Protection Agency, 2018b).

Particulate matter (PM) is a widespread pollutant comprising of solid and liquid particles suspended in the atmosphere. Particulate Matter that is relevant to health are considered to be particles with an aero diameter of less than 10µm, referred to as PM_{10}, and particles with a diameter less than 2.5 µm of PM (World Health Organization, 2013). Particulate Matter finer than 10 µ are the one which poses the greatest health impact as these finer particles are able to penetrate deep into the lungs, with the finest of potentially entering the bloodstream. Numerous scientific studies have conducted and linked particulates matter to premature death in people with heart or lung related disease, nonfatal heart attack, irregular heartbeat, aggravated, asthma, decreased lung function and increased respiratory symptoms such as irritation of the airways, coughing or difficulty in breathing (United States Environmental Protection Agency, 2018b). Additional environmental impact of particulate matter includes visibility impairment, especially as a result of particles of $PM_{2.5}$ which are often the main cause of reduced visibility (John Abbott, 2008). Environmental damage occurs due to the disposition of contaminated fine particles and aesthetic damage due to events such as staining of stone, brinks and statues.

2.3.2. Total suspended particulates (TSP)

This is another type of Particulate Matter which consist of all particles smaller than 100µm suspended within the air. TSP is useful for understanding nuisance effects of PM, e.g. settling on houses, deposition on and discolouration of buildings and reduction in visibility (Woollatt, 2017).

PM_{10} describes all particulate matter in the atmosphere with a diameter equal to or less than 10µm. Sometimes referred to simply as coarse particles, they are generally emitted from motor vehicles, factory and utility smokestacks, construction sites, tilled fields, unpaved roads, stone crushing, and burning of wood. Natural sources include sea spray, windblown dust and volcanoes. Coarse particles tend to have relatively short residence times as they settle out rapidly and PM10 is generally found relatively close to the source except in strong winds.

PM2.5 describes all particulate matter in the atmosphere with a diameter equal to or less than 2.5 µm. They are often called fine particles, and are mostly related to combustion (motor vehicles, smelting, incinerators), rather than mechanical processes as is the case with PM10. PM2.5 may be suspended in the atmosphere for long periods and can be transported over large distances. Fine particles can form in the atmosphere in three ways: when particles form from the gas phase, when gas molecules aggregate or cluster together without the aid of an existing surface to form a new particle, or from reactions of gases to form vapours that nucleate to form particles.

Particulate matter may contain both organic and inorganic pollutants. The extent to which particulates are considered harmful depends on their chemical composition and size, e.g. particulates emitted from diesel vehicle exhausts mainly contain unburned fuel oil and hydrocarbons that are known to be carcinogenic. Very fine particulates pose the greatest health risk as they can penetrate deep into the lung, as opposed to larger particles that may be filtered out through the airways' natural mechanisms.

In normal nasal breathing, particles larger than 10μm are typically removed from the air stream as it passes through the nose and upper respiratory airways, and particles between 3μm and 10μm are deposited on the mucociliary escalator in the upper airways. Only particles in the range of 1μm to 2μm penetrate deeper where deposition in the alveoli of the lung can occur (World Health Organization, 2013). Coarse particles (PM10 to PM2.5) can accumulate in the respiratory system and aggravate health problems such as asthma. PM2.5, which can penetrate deeply into the lungs, are more likely to contribute to the health effects (e.g. premature mortality and hospital admissions) than coarse particles.

2.3.3. Sulphur Dioxide (SO_2)

Sulphur Dioxide is formed during fuel combustion processes. The primary health effect due to exposure to SO_2 is upon the respiratory system, producing irritation, airway resistance and respiratory illnesses. These effects are particularly evident in at-risk respiratory population including children, the elderly and asthmatics (Badenhorst, 2007). Sulphur Dioxide also forms sulphuric acid as result of its water solubility, producing acid rain. Once emitted SO_2 oxidise in the atmosphere to produce sulphate aerosols, which are also harmful to human health, limit visibility and in the long term have an effect on global climate (United States Environmental Protection Agency, 2018c). Sulphur Dioxide is a colourless, pungent (burning match odour), irritating and reactive gas which is detected by taste at 0.3 ppm. It's noted that above 0,5 ppm (odour threshold) it imparts a burning acrid sensation to the nose. SO_2 originates mostly from fossil fuel combustion process in industry and power plants. Most SO2 comes from coal (Coal contains ~0.5-7% Sulphur) and to lesser extent from oil (Oil contains ~0.3% S). SO_2 can be transported long distances as a result of emissions from high stack. SO2(g) can dissolve in water droplets to form SO_2(aq) and then fall to surface as precipitation. This process is known as wet deposition and is depicted in the Figure 2-1 SO_2 is highly soluble in water, forming a week acidic sulphurous acid (H_2SO_3). In clear air it oxidizes slowly to form SO_3. In moist air and in presence of nitrogen oxide, hydrocarbons and particulates, SO_2 reacts much more quickly to form SO_3 (Lethabo Air Quality Specialists, 2013).

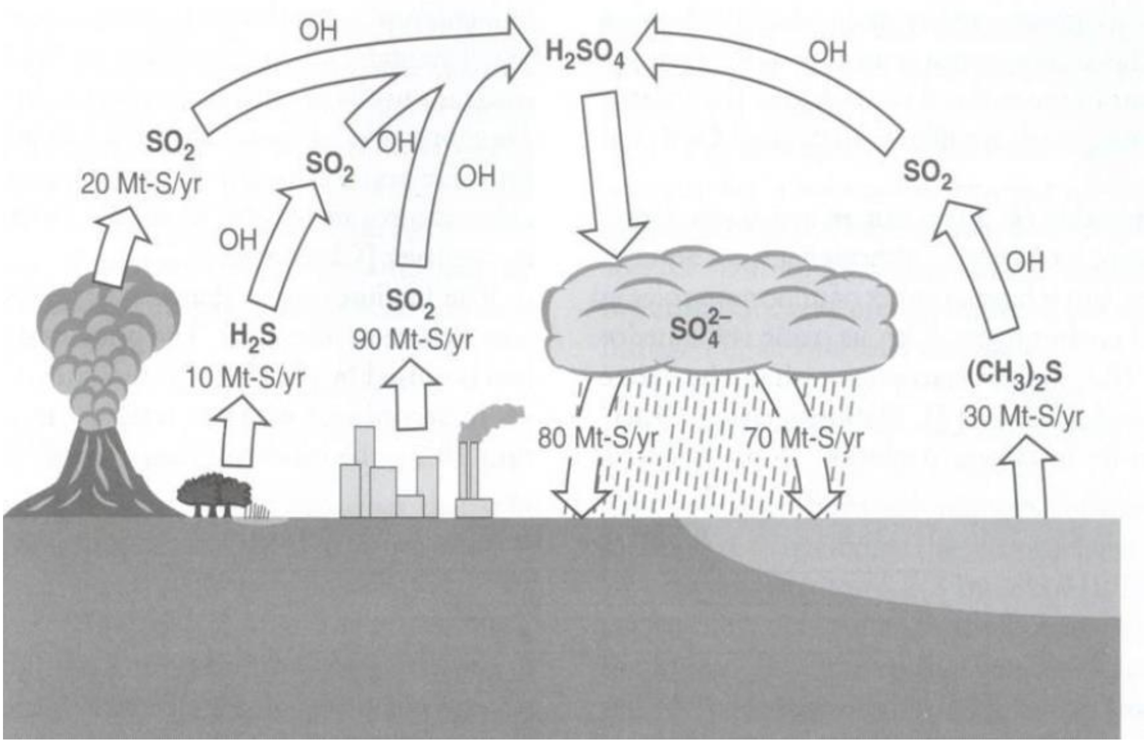


Figure 2-1: Global sulphur budget (Granat et al., 1976)

Sulphur Dioxide is absorbed in the mucous membrane of the nose and respiratory track because it is soluble in water. Thus a range of health effects occur depending on exposure time.

A number of controlled studies in human have indicated that exposure to sulphur dioxide can result in lung function changes indicative of bronchoconstriction. The exposure also stimulates sensory receptors in the airways by irritants and chemicals such as sulphur dioxide produces reflects bronchoconstriction that is mediated primarily via cholinergic pathways (Cairncross and Mtiya, 2013). Exercising asthmatic, in particular, are sensitive to the pulmonary effect of sulphur dioxide at concentration as low as 01.ppm. According to the World Health Organisation (WHO), it is estimated that asthmatic represent a subset of approximately 10 million people, or 4% of the population. It is further estimated that exposure to 0.2 – 0.5 sulphur dioxide during moderate exercise would lead to substantial respiratory effect, in only about 10 – 20% of mild to moderate asthmatic, but the most sensitive individual could likely experience incapacitating effects.

The exposure of children is totally different from adults and differ in their susceptibility to hazardous substances. As such, children's unique physiology and behaviour can influence the extent of their exposure. Children may be more or less susceptible to than adults to health effects and the relationship may change with developmental age.

Clinical studies were conducted to examine respiratory function in healthy, atopic, or asthmatic adolescents (n=8 – 9), aged 12 – 17 years). Furthermore, 10 health males seniors (aged 55-73 years), following a mouth only exposure to a mixture of 1 ppm sulphur dioxide and 1mg/m^3 sodium chloride aerosol (Deppeler, 1982; Rondinelli et al., 1987). Selected adolescents exercised for 10 min of a 40 minute exposure period and the senior exercised for 10minute of a 30 minute exposure period. A significant decrease in forced expiratory volume in 1 second (FEV$_1$) were noticed in asthmatic adolescents (-23%), atopic adolescents (-18%), seniors (-8%) and healthy adolescents (-6%). As a result the study concluded that respiratory health status and not age is the primary factor in determining susceptibility to sulphur dioxide in adolescents and adults because asthmatic adolescents were most sensitive to sulphur dioxide and normal adolescent were least sensitive (Rondinelli et al., 1987).

Table 2-2 presents a summary of the health effects associated with sulphur dioxide.

Table 2-2: Summary of health effects of sulphur dioxide (Sunyer et al., 2003)

No	Concentration (ppm)	Effects
1	≥ 0.1	Bronchoconstriction in sensitive exercising asthmatics
2	0.3 - 1	Possibly detected by taste or smell
3	1 – 2	Lungs function changes in healthy non-asthmatic individual
4	3	Easily detected odour
5	6 – 12	May cause nasal and throat irritation
6	10	Upper respiratory irritation, some nosebleeds
7	20	Definitely irritation to eyes, chronic respiratory symptoms develop at this level; respiratory protection is necessary
8	50 – 100	Maximum tolerable exposure for 30 – 60 minutes
9	≥ 100	NIOSH recommend immediate danger to life

The primary route of exposure to sulphur dioxide is through inhalation. In the atmosphere sulphur dioxide occurs with a number of air pollutants including sulphuric acid, sulphur trioxide, ozone, nitrogen dioxide and particulate matter (Katestone Environmental Pty Ltd, 2014). It’s noted that sulphur dioxide undergo transformation to form sulphur trioxide and sulphuric acid. It’s evident that as a result of industrialisation sulphur dioxide has tend to be a problem in urban areas, particularly those areas where industrial activities use the combustion of fuel (Kirsten Collett-WSP House, 2013).

2.3.4. Nitrogen Dioxide (NO2)

Oxides of nitrogen (NOx) is the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). In gas turbines the main mechanism for NOx formation is termed "thermal NOx". This happens in the combustion zone, where elevated temperature allows the dissociation of atmospheric nitrogen (N_2), after which the nitrogen may combine with excess oxygen. Generally, the NOx emissions from a combustion source comprise approximately 90% NO and 10% at the source.

In the atmosphere NO and NO_2 are interconnected in a circular reaction with oxidants such as ozone, which generate NO_2 from NO and sunlight which breaks down to NO. Due to this reaction sequence, the precise amount of NO and NO_2 within the emissions is often unknown, and therefore the sum emission of both species is quoted. The ambient concentration of NO_2 to a NOx is dependent on the amount of oxidant and sunlight at the time.

In ambient concentration usually found within the atmosphere, NO has no adverse effect on either human health or the environment. Conversely, it is acknowledged that short term concentration of NO_2 greater than 200ppb (411µgm/m^3) have the ability to cause irritation in certain individuals (National Environment Protection Council, 1998). To ensure that individuals are protected from potential health impacts of short-term concentrations, maximum short-term exposure is set within New South Wales (NSW) at 246 µgm/m^3 (120ppb). The long-term adverse effects of NO_2 are well known although some evidence suggests poor lung function of residents of areas with high NO_2 concentrations. To address the potential long-term effects of NO_2 an annual average limit of 62µgm/m^3 has been set by the Department of Environment, Climate and Water.

There are three approved methods for assessing NOx impacts, which are listed in order of increasing complexity. The first Method is 100% Conversion of nitrogen oxide (NO) to nitrogen dioxide (NO_2). This method assumes all NOx emissions are emitted as nitrogen dioxide (NO_2) and that the highest recorded background of nitrogen dioxide (NO_2) level is constant. The second Method is nitrogen oxide (NO) to nitrogen dioxide (NO_2) conversion limited by ambient ozone concentration. This method presumes all available ambient O_3 will react with nitrogen oxide (NO) to form nitrogen dioxide (NO_2). The third Method is nitrogen oxide (NO) to nitrogen dioxide (NO_2) conversion using empirical relationship. According to the research carried out by Janssen et al. (1988), more than 95% of NOx from plant emissions will be in the form of NO and less than 5% is in the form of nitrogen dioxide (NO_2). In this assessment it has conservatively been assumed that all emitted NOx exists in the form of nitrogen dioxide (NO_2).

Nitrogen Dioxide belongs to the family of gases called nitrogen oxides (NO_X). These gases form when fuel is burnt at high temperatures, predominantly from motor vehicles and stationary sources such as electric utilities and industrial boilers (United States Environmental Protection Agency, 2018a). Recent scientific evidence suggests short-term exposure to NO_2 can cause adverse respiratory effects, including airway inflammation and increased respiratory symptoms in people with asthma. Long-term or frequent exposure to elevated concentrations can increase the incidence of acute respiratory illness, particularly in children (United States Environmental Protection Agency, 2018a). Exposure to high concentrations of NO_2 (150 – 200 ppm) causes *bronchiolitis fibrosa obliterans*, which is fatal within 3 – 5 weeks of exposure. Death generally occurs 2 – 10 days after exposure to 500 ppm or more NO2 may lead to biological imbalances and mutations in vegetation limits visibility and contributes to the formation of acid rain via the production of nitric acid (HNO3). Further oxidation of NO2 may lead to the formation of nitrate aerosols, which limit visibility. NOx contributes to the formation of tropospheric O_3, an important atmospheric oxidant, a major air pollutant as well as a key greenhouse gas (Fenger, 1999; Seinfeld and Pandis, 2012; United States Environmental Protection Agency, 2018a).

2.3.5. Carbon Monoxide (CO)

Carbon monoxide (CO) is one of the most commonly and widely distributed air pollutants. CO is colourless, odourless and tasteless, and is poorly soluble in water. Anthropogenic emissions of CO are mainly due to the incomplete combustion of carbonaceous fuels (World Health Organization, 2000), with the largest of these being internal combustion engines, such as motor vehicles. CO is easily absorbed into the bloodstream through the lungs, where approximately 80 – 90% of the absorbed CO binds with haemoglobin which causes a reduction in the oxygen carrying capacity of the blood. CO has no direct effects on lung tissues, although its toxic effects on humans are due to hypoxia, which is evident in organs with high oxygen consumption, such as the brain, heart and exercising skeletal muscle (World Health Organization, 2000).

2.3.6. Benzene

Benzene is a volatile, colourless, highly flammable liquid that dissolves in water. The odour threshold of benzene is 12 ppm. Benzene is emitted into the air from fossil fuel burning; handling and storage of industrial solvents and evaporation from gasoline. Inhalation accounts for more than 99% of the total daily intake of benzene (50% of inhaled benzene is absorbed, and once absorbed is metabolised in the liver to harmful metabolites such as phenol, muconic acid, and S-phenyl-mercapturic acid and is temporally stored in the bone marrow and fat) (AGL, 2017).

Chronic inhalation of benzene causes disorders in the blood, such as aplastic anaemia (not found at concentrations found in the general environment). Excessive bleeding and damage to the immune system (by changes in blood levels of antibodies and loss of white blood cells) may develop. This condition can make individuals more susceptible to infections. Benzene can cause leukaemia (cancer of the blood-forming organs), especially acute myeloid leukemia (AML).

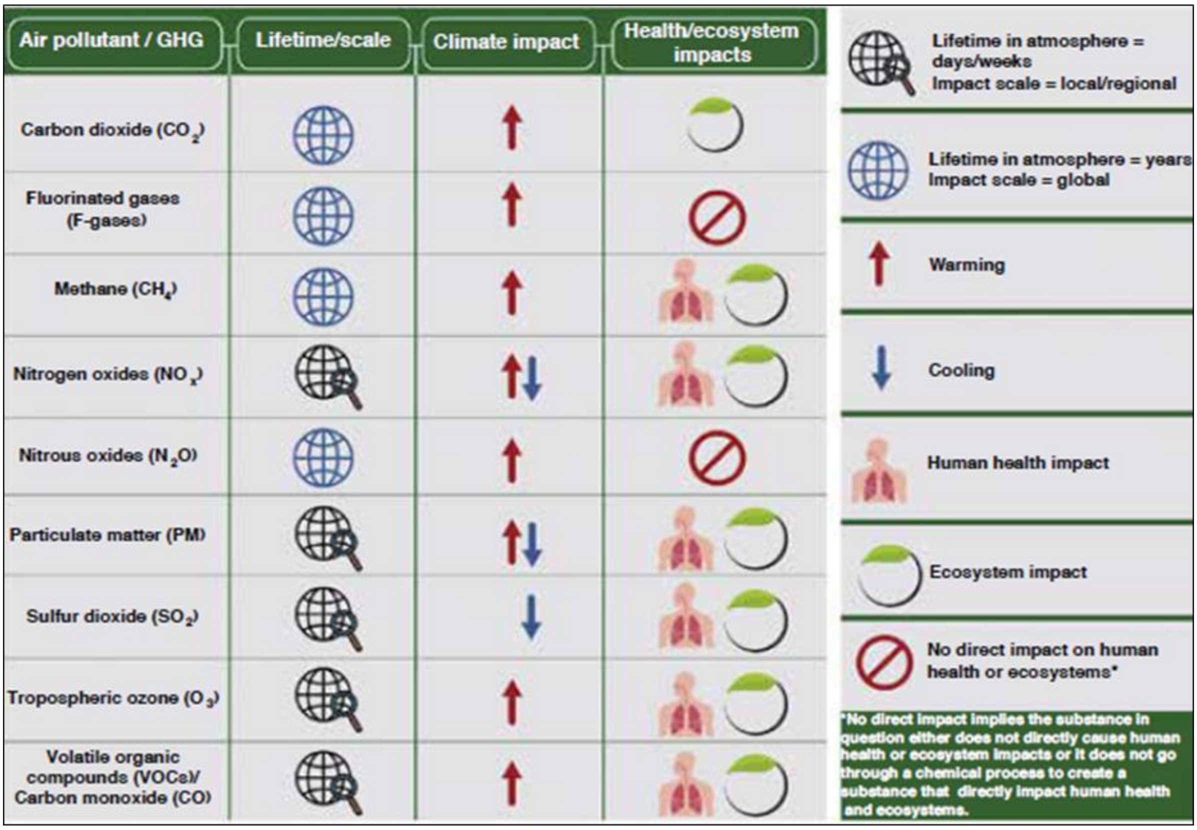
South Africa has established an annual ambient air quality standard for benzene of 10 $\mu g/m^3$. This standard will became stricter and reduced to 5 $\mu g/m^3$ on 1 January 2015. There is no WHO non-cancer ambient air quality guidelines for benzene. The minimum Risk Level (MRL) for chronic inhalation of benzene is 0.003 ppm (10.46 $\mu g/m^3$). The chronic non-cancer risk for benzene includes aplastic anaemia, a condition where the body's bone marrow does not produce enough blood cells) (U.S. Department of Health and Human Services Public Health Service, 2007).

2.3.7. Air pollution and climate change

Climate change and air pollution are two environmental challenges that are closely linked. However, these two challenges are viewed as separate environmental challenges and dealt with different science communities and within different policy frameworks.

However, it is impossible to separate the anthropogenic emissions into two clear categories which relate atmospheric pollutants and climate-active species as many air pollutants, such as tropospheric ozone or aerosol, both have direct or indirect impacts on climate change. Air pollution itself has negative effects on human health and the environment.

According to a report by World Health Organisation (WHO), 1 out of 90% of the urban population of the entire world inhales air containing levels of outdoor air pollutants that is above WHO guidelines. Climate change and air quality are not only determined by similar elements, they are also closely interlinked through diverse atmospheric. The effects, both direct and indirect, of air quality on climate change are interrelated to the interactions of atmospheric emissions with solar radiation. The worldwide average radiative forcing of ozone is similar to that of methane (CH_4), and about one quarter of that due to carbon dioxide (CO_2). Tropospheric ozone adversely affects ecosystem and reduce the ability to absorb carbon dioxide. Another indirect effect of ozone on radiative forcing has the opposite effect: production of the hydroxyl radical increases with increasing ozone concentration, reducing the lifetime of methane in the atmosphere. Particulate matter, which has negative effects on the environment and human health, has both direct and indirect influences on radiative forcing. Based on its composition, particulate matter can scatter or absorb incoming radiation directly, but particles can also act as cloud condensation nuclei and thereby affect radiative forcing and weather patterns indirectly. Deposition of the particles on snow and ice changes their albedo. Climate change also affects air quality through variation in meteorology for instance temperature, precipitations, boundary-layer dynamics and humidity through the effect it has on natural emissions. Increasing temperatures result to increasing emissions of volatile organic compounds (VOCs) that are the precursors of tropospheric ozone and aerosols. Elevated temperatures exacerbate ozone formation. As the climate varies, ozone in peak periods is anticipated to rise – the so-called "climate penalty". Climate change is also associated with changing transport patterns, mixing and can lead to more frequent extreme pollution events due to immobility. Changes in wildfire frequencies could result to cumulative levels of pollution, particularly aerosols. Varying precipitation patterns affect the deposition of emissions. Notwithstanding a growing recognition of the strong links between the two areas, policies addressing atmospheric pollution and those focusing on climate change remain weakly associated. The main challenge is to identify policies that provide "win–win" solutions, as not all climate policies are beneficial for atmospheric emission reduction and vice versa. Distinct example is the use of biofuels that leads to a reduction of carbon dioxide but contributes to increasing levels of tropospheric ozone. An integrated approach is consequently needed to evaluate the air quality and climate policies. Those policies are likely to constitute the best environmental policy strategies relating to social and economic costs.



Air pollutant / GHG	Lifetime/scale	Climate impact	Health/ecosystem impacts
Carbon dioxide (CO_2)	🌐	↑	🍃
Fluorinated gases (F-gases)	🌐	↑	⊘
Methane (CH_4)	🌐	↑	🫁 🍃
Nitrogen oxides (NO_x)	🔍	↑↓	🫁 🍃
Nitrous oxides (N_2O)	🌐	↑	⊘
Particulate matter (PM)	🔍	↑↓	🫁 🍃
Sulfur dioxide (SO_2)	🔍	↓	🫁 🍃
Tropospheric ozone (O_3)	🔍	↑	🫁 🍃
Volatile organic compounds (VOCs)/ Carbon monoxide (CO)	🔍	↑	🫁 🍃

🔍	Lifetime in atmosphere = days/weeks Impact scale = local/regional
🌐	Lifetime in atmosphere = years Impact scale = global
↑	Warming
↓	Cooling
🫁	Human health impact
🍃	Ecosystem impact
⊘	No direct impact on human health or ecosystems*

*No direct impact implies the substance in question either does not directly cause human health or ecosystem impacts or it does not go through a chemical process to create a substance that directly impact human health and ecosystems.

Figure 2-2: Air Pollutants and their impacts on Climate, human and health and ecosystem. (Melamed et al., 2016)

The existing indicators produced by climate change scientists are useful for several specific technical and scientific purposes. These indicators are therefore not all equally appropriate for helping non-specialists to understand how the climate is changing. Classifying a subset of key indicators that capture the components of the climate system and their essential changing behaviour in a comprehensive way helps non-scientific audiences to comprehend the behaviour of key parameters of the climate system.

The World Meteorological Organization (WMO) uses a list of seven state-of-the-climate indicators that are drawn from the 55 Global Climate Observing System (GCOS) Essential Climate Variables, including surface temperature, ocean heat content, atmospheric carbon dioxide (CO_2), ocean acidification, sea level, glacier mass balance and Arctic and Antarctic sea ice extent (World Meteorological Organization, 2018c). In addition, indicators are usually evaluated to allow a more comprehensive picture of the behaviour in the respective domain. These include includes precipitation, greenhouse gases (GHGs) excluding CO_2, snow cover, ice sheet, extreme events and climate effects (Von Schneidemesser et al., 2015).

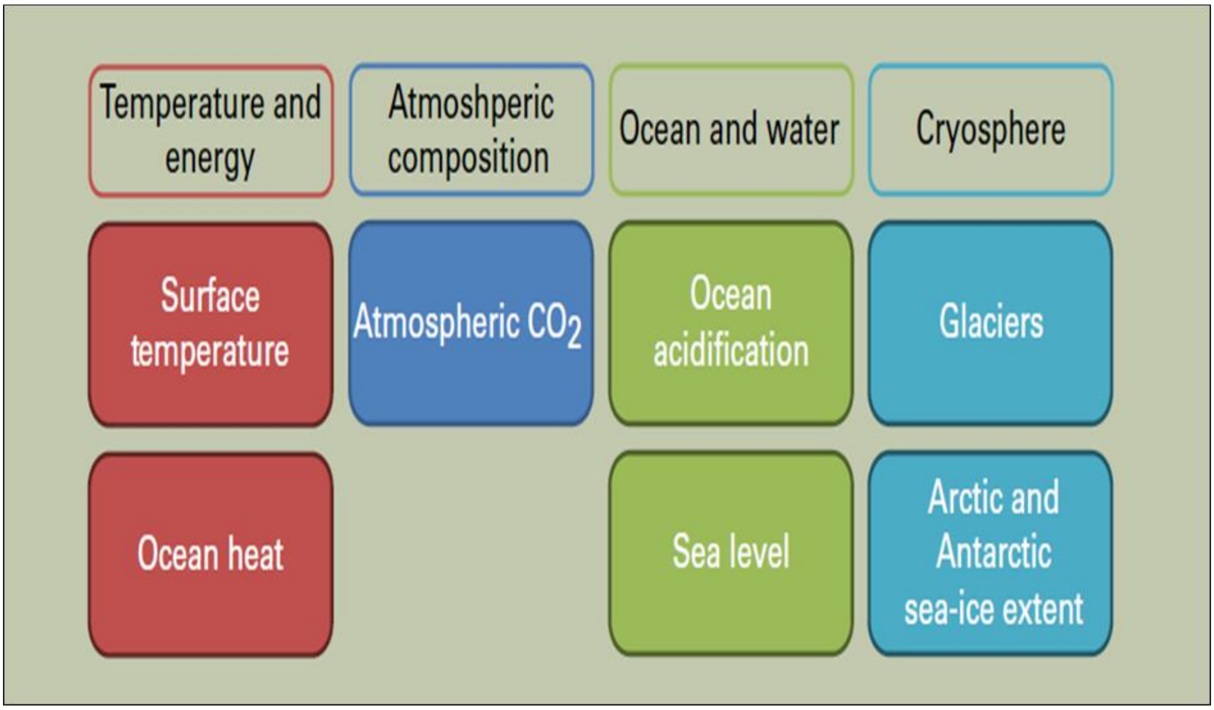


Figure 2-3: State-of-the-climate indicators used by WMO for tracking climate variability (World Meteorological Organization, 2018b)

2.3.7.1. Greenhouses Gases and Ozone

Increasing levels of greenhouse gases in the atmosphere are key determinants of climate change. Atmospheric emission concentrations reflect a balance between sources including emissions due to human activities and sinks for instance the uptake by the biosphere and oceans. In 2017, greenhouse gases concentrations reached new highs, with worldwide averaged mole fractions of CO_2 at 405.5 ±0.1 parts per million (ppm), methane (CH_4) at 1 859 ± 2 parts per billion (ppb) and nitrous oxide (N_2O) at 329.9 ± 0.1 ppb (Figure 2-4). These values combined constitute, respectively, 146%, 257% and 122% of pre-industrial levels (before 1750). The IPCC *Global Warming of 1.5 °C* report revealed that limiting warming to 1.5 °C above pre-industrial temperatures implies reaching net zero CO_2 emissions globally around 2050, and this with concurrent deep reductions in emissions of non-CO_2 forcers and particularly CH_4.

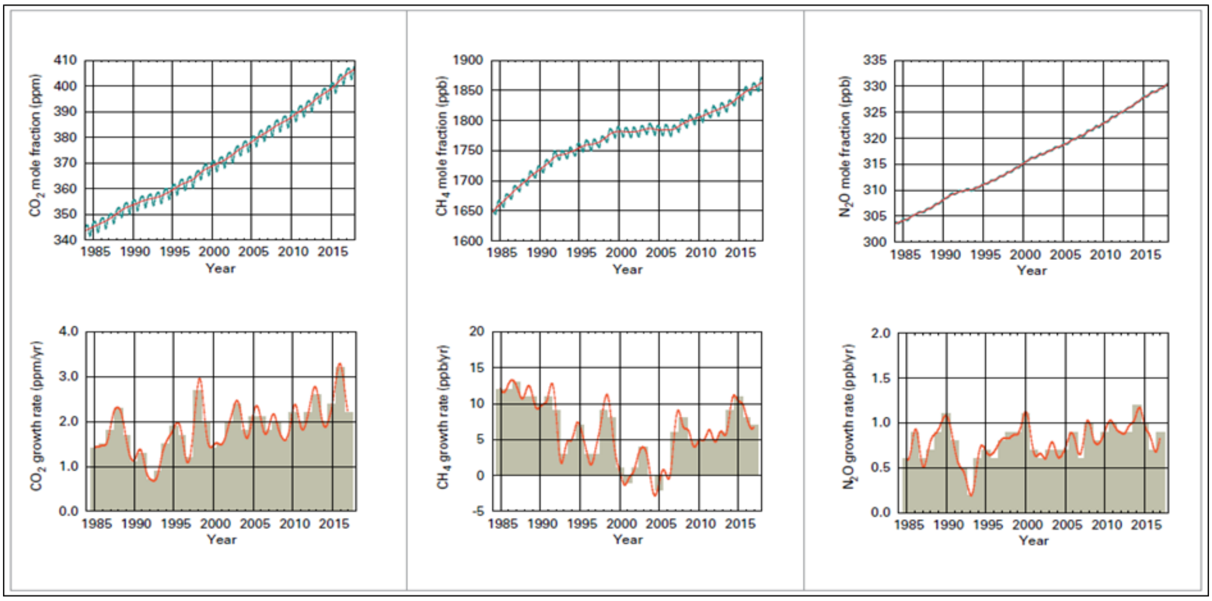


Figure 2-4: Greenhouse Gas Concentrations (World Meteorological Organization, 2018a)

Top row depicts globally averaged mole fraction this is measure of concentration from 1984 to 2017 of CO_2 (ppm; left), CH_4 (ppb; centre) and N_2O (ppb; right). The red line demonstrates monthly mean mole fraction with the seasonal variations removed; the blue dots and line show the monthly averages.

Bottom row demonstrates the growth rates representing increases in successive annual means of mole fractions for CO_2 (ppm per year; left), CH_4 (ppb per year; centre) and N_2O (ppb per year; right).

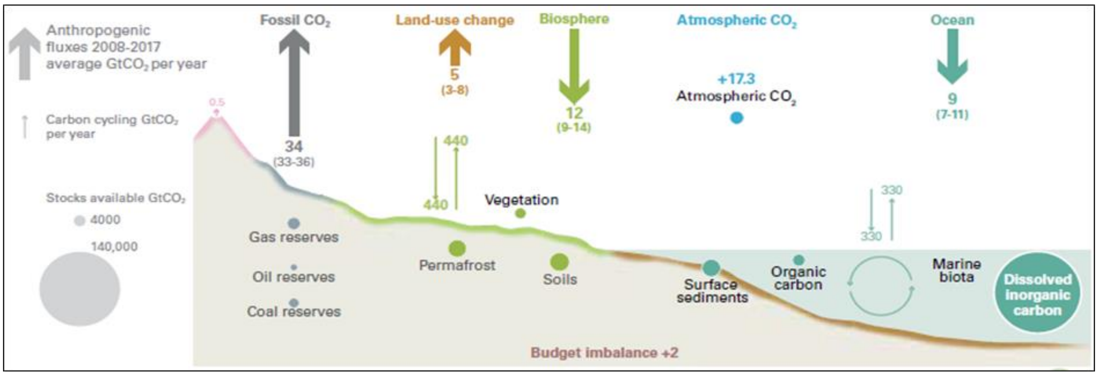


Figure 2-5: The rise in atmospheric Carbon Dioxide

2.3.7.2. Heat and human health

A heatwave is defined as a period of more than 3 days during which the minimum temperature is greater than the 99th percentile of the historical minima (Jacob et al., 2014). Between the period of 2000 and 2016, the number of people exposed to heatwaves was estimated to have increased by around 125 million (Figure 2-6), as the average length of individual heatwaves was 0.37 days longer, compared to the period between 1986 and 2008. In 2015 alone, a record 175 million people were exposed to 627 heatwaves. Each event at the local level translates to significant and varied impacts; for instance, in Karachi, Pakistan, this same year, 65 000 people were taken to hospital with heat-related symptoms.

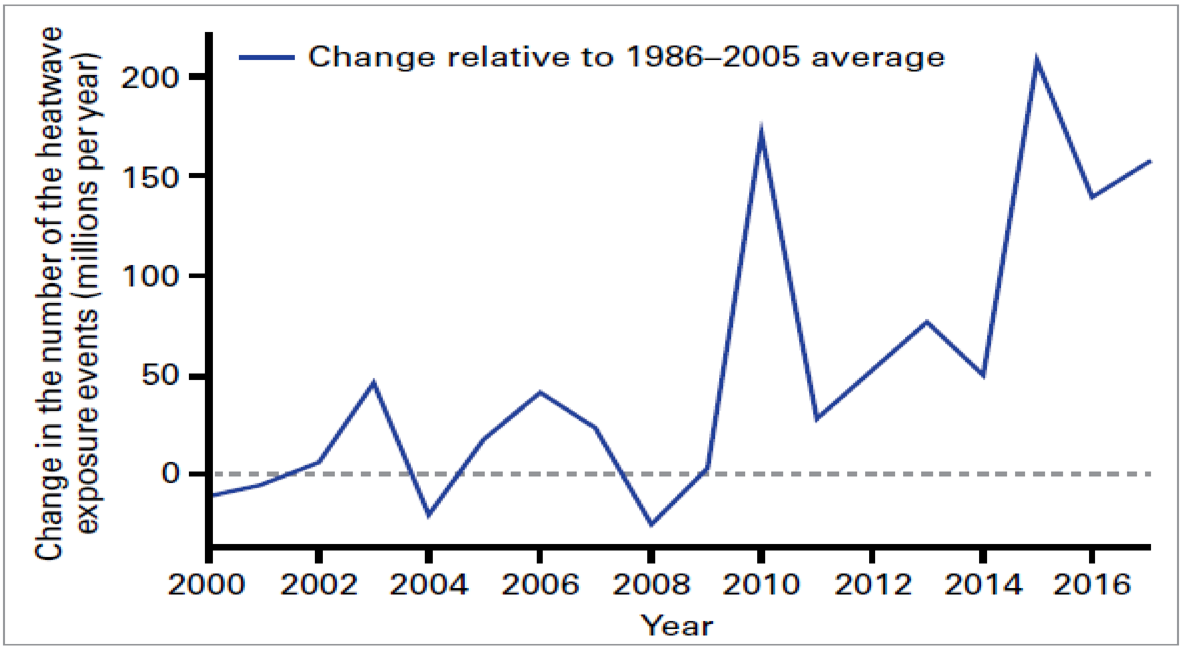


Figure 2-6: Heat wave exposure between the year 2000-2016 (Watts et al., 2018)

Heat stress is a serious health threat for humans. Heat is a principal cause of weather-related death, and can aggravate underlying morbidities for instance cardiovascular disease, diabetes, psychological distress, asthma, as well as increasing the risk of accidents and infectious diseases. Studies conducted across all six populated continents in recent years clearly demonstrate that high outdoor and indoor temperatures have an impact on mortality rate (Gasparrini et al., 2015). The example includes daily mortality spikes observed for the heatwave days that happened in England during the summer of 2016. The duration of a single heatwaves can be a week, occurring consecutively and result in significant excess mortality. In the year of 2003, 70 000 people in Europe died as a result of the June– September heatwave event. In 2010, 55 000 excess deaths occurred during a 44-day heatwave in the Russian Federation (Shaposhnikov et al., 2014). Exposure to heat has extensive ranging physiological effects for all humans, with extreme exposures resulting in a cascade of illnesses, including heat cramps, heat exhaustion, heatstroke and hyperthermia. Heat gain in the human body can be a combination of external heat from the environment and internal body heat produced from physical activity – therefore, people working outside are at risk and may not have the choice to stop working or have access to suitable cooling opportunities. Elevated temperatures can also intensify a wide range of existing health conditions leading to a risk of premature mortality. Heatwaves can also affect health indirectly, by altering human behaviour, the transmission of diseases, the capability for health service delivery, air quality, and the functioning of critical social infrastructure such as energy, transport and water. The scale and nature of negative health impacts of heat depend on the timing, intensity and duration of a temperature exposure, and how well adapted buildings and behaviour are to the prevailing climate. The precise threshold at which temperature represents a hazardous condition varies by region and over time (Shaposhnikov et al., 2014).

2.4. Emissions Abatement Equipment

2.4.1. Nature of discharge

The coal fired boilers produces hot exhaust air stream containing combustion product and particulate Matters. The latter arise due to a wide range of processes including fly ash carry over, un-combusted carbon and from the condensation of un-combusted organic volatiles.

The main portion of emissions released consists of nitrogen and residual oxygen from the combustion air. The primary product of combustion include carbon, sulphur dioxide, nitrogen dioxide and water vapour. There is also a range of products of incomplete combustion that may include volatile organic compound, carbon monoxide, nitrogen oxide and nitrous oxide.

The condensation of volatile organic compounds within the boiler stack and unburnt carbon particulate are a key source of fine respirable particulate ($PM_{2.5}$), whereas PM_{10} and larger suspended particulates are derived from these sources as well as larger fractions of fines fly ash and coal fines. Volatile organic compounds also include trace levels of poly aromatic hydrocarbon and dioxin like compounds. The metal and mineral composition of coal also results in race levels of various heavy metals being discharged, mainly in association with particulate emission, however, a significant proportion of metals are captured in the recovered fly ash. However, mercury is volatile and mostly discharged with the exhaust air as either a gas or as a condensed component of the particulate emissions. Given the above, the primary air pollutant impacts that were assessed included SO_2, PM_{10}, NO_2. Metals were excluded as there are no ambient air quality standard in South Africa. While the discharge of $PM_{2.5}$ was not directly modelled, its ambient impact can be established from the PM_{10} results and knowledge of the PM_{10} to $PM_{2.5}$ discharge ratio that was established via ambient monitoring data. Ambient air quality impacts of CO from coal fired boiler plants are very low when compared against ambient health guidelines and standard and therefore are not assessed in this assessment. The emissions of greenhouse gases, such as CO_2, do not cause local health effect and are not included in the scope of this assessment.

2.4.2. Combustion Stoichiometry

The stack exhaust flow rates (actual and normalised to standard atmospheric pressure and temperature) for each coal fired boiler were calculated using stoichiometric equation that utilises the coal's elemental composition air or residual coal usage rates. These calculation, combined with knowledge of the excess combustion air or residual exhaust oxygen content (vol. % dry), can be used to accurately calculate the exhaust air flows per unit mass combusted coal. The maximum coal usage rate for coal fired boiler is established from their respective energy output (tonnes / hour of steam corrected to 8 bar Pressure), the thermal efficiency of the coal fired boiler and the reported energy content (calorific value) of the as-received coal. Historical stack emission results for particulate emissions typically report normalised and actual exhaust air flows including the associated oxygen content. These results were used to confirm that the calculated boiler exhaust flow rate were accurate.

2.4.3. Cyclones

Solid Fuel-fired boiler (Coal or Biomass) emit significantly high levels of PM than boilers fired on liquid fuel (Heavy Fuel oil, diesel or paraffin) or gaseous fuel. For this reason, controlled emitters combusting solid fuels are equipped with particulate matter abatement equipment. The most commonly use abatement control equipment is multi-cyclone (Department of Environmental Affairs, 2010).

Multi-cyclone uses the principle of inertia and centrifugal force to separate PM from boiler flue gas streams. Particulate-laden flue gas enters the top of a cyclone through inlet guide vanes. These vanes cause the gas to spiral downwards towards the apex of the cyclone. As a result of centrifugal force, the particles in the gas move radially towards the outer walls and then slide downwards towards the apex where collection takes place. The clean gas reverses its downwards spiral and moves upwards in a second, smaller spiral before it exits from the top of the cyclone. Cyclones are used as pre-treatment to further abatement process as this technology can easily removes larger particulates from flue gas, thereby increasing efficiencies of subsequent abatement process.

2.4.3.1. Cyclone efficiency

Cyclones are capable of removing particulates with an aerodynamic diameter larger than 10μm down to 2.5μm diameter. It’s generally recommended that particulate matter of aerodynamic diameter larger than 200 μm could be removed using a gravity or momentum settler instead. It is noted that because a separation cyclone uses centrifugal force to separate particulates matter, larger particles are easier to remove than smaller ones, as smaller particulate matter will have a higher fluid friction factor (which drags it along with the air flow) compared to the centrifugal force (which separates it from the air flow) acting on it. The efficiency of cyclone increases with decreasing cyclone diameter. In order to treat larger quantities of gas with a high efficiency it is most effective to group numerous cyclones with small diameters together (Multi-cyclone). The operation principle of cyclone is shown in Figure 2-7. This figure presents the basic representation of a tangential inlet, axial discharge separation cyclone and its expected airflow.

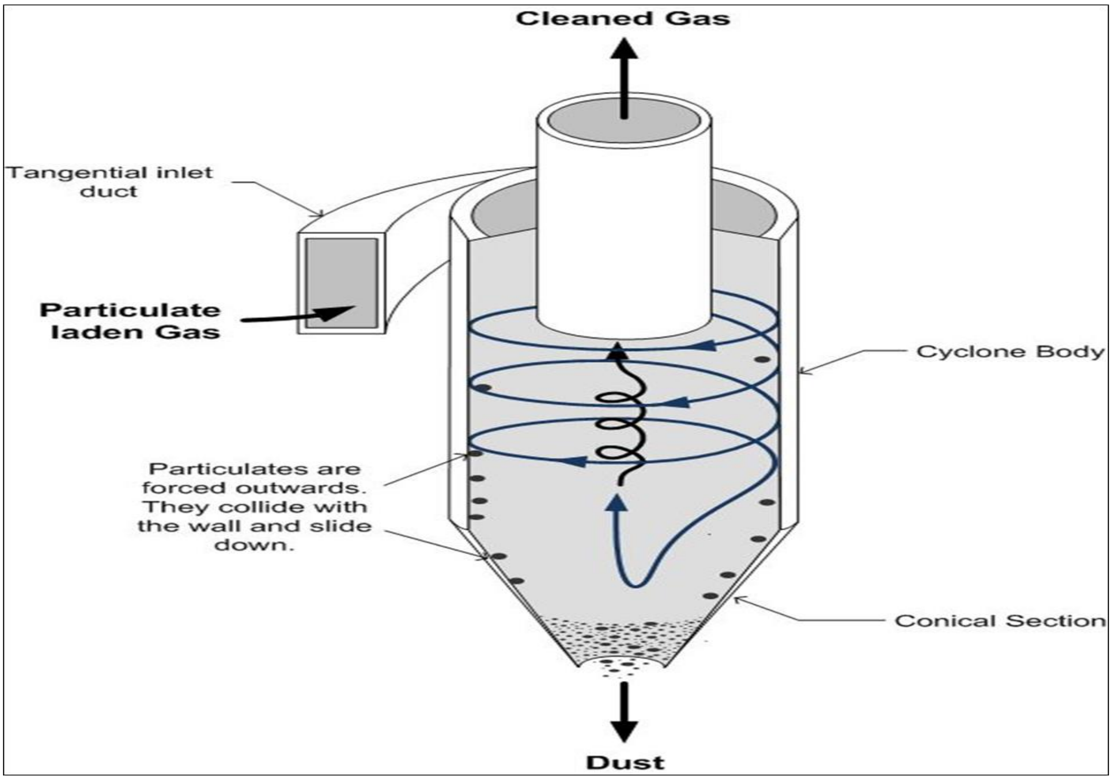


Figure 2-7: The principle of operation of a cyclone

2.4.4. Bag-house

Bag filters are also known as fabric filters or baghouses. Baghouses use fabric bags to filter a range of particles from gas streams. Figure 2-8 shows the Photograph of a baghouse in which the airflow is split into two, which suggests that it is a multi-compartment unit. The filters can be in the form of sheets, cartridges or bags and made from a variety of materials ranging from natural and synthetic fabrics to Teflon and metallic materials (Department of Environmental Affairs, 2010). Bag filter collects PM by passing a particle-laden gas stream through a filter medium of woven cloth, felt or porous cloth. Reverse pulse bag filters are the most common bag filter design for high temperature boiler processes. A baghouse most often operates under suction and the negative pressure draws flue-gas through the fabric filter, leaving the dust particles behind on the surface of the fabric. Single baghouse may contain multiple compartments each with several fabric filters to provide the required filtration surface area. In multiple compartment baghouse, the compartments are isolated from each other and periodically on of the compartment may be closed-off to suction and dust adhering to the bags can be pulsed off the bags with compressed air, mechanically shaken or removed by the shape deformation of the bag under positive pressure. The dust falls to the bottom of the chamber and is removed mechanically by various methods which include screws, rotary air lock, chain conveyer etc. The cleaning cycle of compartments can be scheduled according to a specific frequency of cleaned on demand when the pressure drop across the bags exceeds a certain limit. In the latter case, pressure is measured on the inside and on the outside of a filter and as dust builds up on the fabric the pressure different increases. This enables the operator to set a pressure limit at which the bags must be cleaned.

Bag filters are extremely efficient at arresting PM as small as 0.2µm in size and will reduce PM emissions to between 10 and 50mg/Nm^3. A bag filter would be the best environmental solution for the HFO fired boiler. For biomass fired boilers bag filters are not considered appropriate abatement equipment for use due to fire risk. Particulate Matter from biomass combustion is light and fibrous and burning embers are often present in the flue gas, even downstream of multi-cyclone which creates the fire risk (Yellow Tree Environmental Consultants, 2017).

Figure 2-8: Photograph of a baghouse showing the airflow into the unit

2.4.4.1. Bag-house Efficiencies

Typically, baghouse filtration efficiency ranges between 99% and 99.9% but as the equipment ages and bags become infiltrated with particulates, the efficiency drops to 95%. Factors influencing efficiency include filtration velocity, particle characteristics, fabric characteristics, cleaning cycles and cleaning methods. Collection efficiency is related to particle size, however the collection efficiency generally increases with increased filtration velocity and increased particle size.

2.4.5. Electrostatic Precipitation (ESP)

This type of an abatement control technology functions by charging the particles in as off-gas stream as they pass close to the charge plate. The charge plate creates a corona (an area where gas breaks down electrically) which charges the particles as these particles move further into the unit, they pass between charged collector plates causing the particles to move and stick to that collector (Petkova et al., 2013). Figure 2-9 shows the basic principle of operation of an electrostatic precipitator. The particles reach the collector plates and discharge in the moment of contact (neutralize) causing them to drop out of the gas flow. The ESP’s effectiveness relies heavily on the particulate matter in question as different particles have different conductivity which cause them to charge and discharge at different rates. If the PM has a very high charge rate it will not reach the collection plate but instead lose its charge as it gets close to the plate and be re-entrained in the off-gas stream. If on the other hand its conductivity is too low (meaning it has a high resistivity) it will accumulate on the collector plate as it won’t lose its charge, forming a layer that will reduce the attractive force of other particles to the collector plate.

The fabric filter unit is a mechanical flue gas cleaning operation. Particulate matter and hazardous air pollutants (HAPs) that are in particulate form such as many trace metals. This operational unit may be used as a second particulate removal stage after cyclone, which is more apt for removal of larger particulate matter.

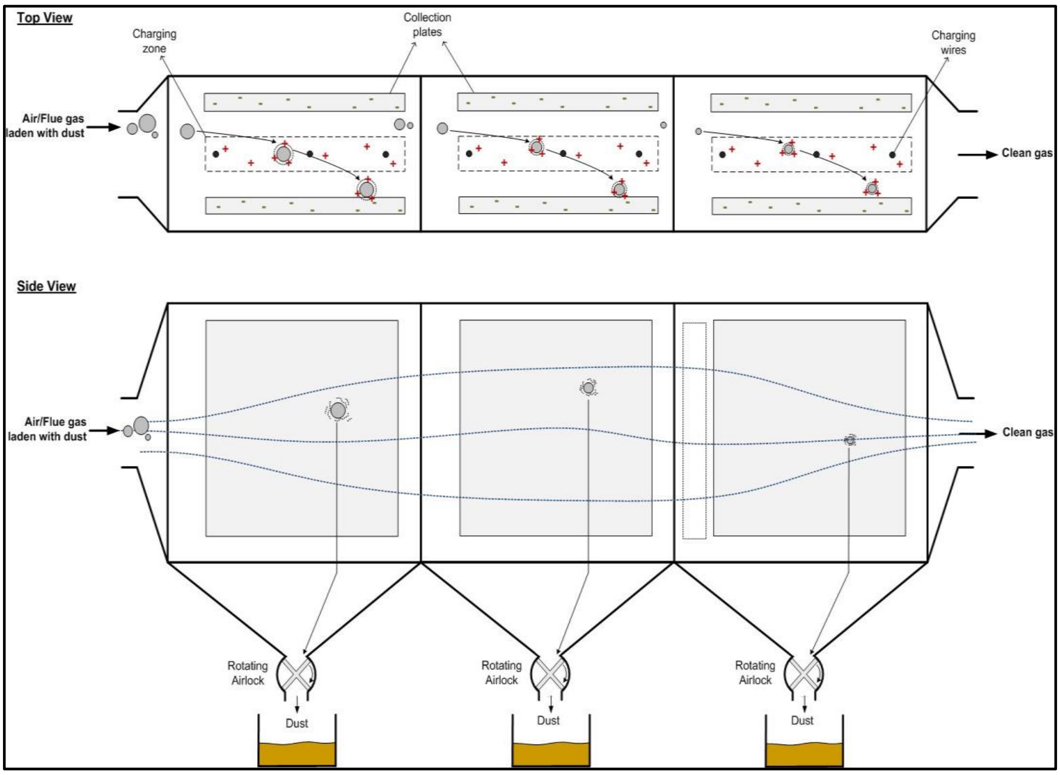


Figure 2-9: Electrostatic precipitator

2.4.5.1. Electrostatic Precipitation Efficiencies

New equipment typically has design efficiency ranging from 99% to 99.99%, while older equipment has actual operating efficiency of 90 % to 99%. The biggest factor in the efficiency is the size of the ESP equipment as it will increase the residence time of the particulate thereby increasing the probability of that it will reach a collection plate. The second greatest influence on efficiency is the field strength as this will increase the attraction force of the particle to the collection plate and decrease the charge time.

2.4.6. Scrubbers

Scrubbers are separation equipments that use absorption as the primary mechanism to remove air pollutants. Some scrubber can be used to remove both PM, gaseous acids, volatile organic compounds (VOCs) as well as other dissolvable gasses such as SO_2. Scrubbers are divided into three main groups depending on their usage of water i.e dry scrubbers, semi-dry scrubbesr and wet-scrubbers (Tătar, 2013). Figure 2-10 shows the mechanism of operation of a wet scrubber.

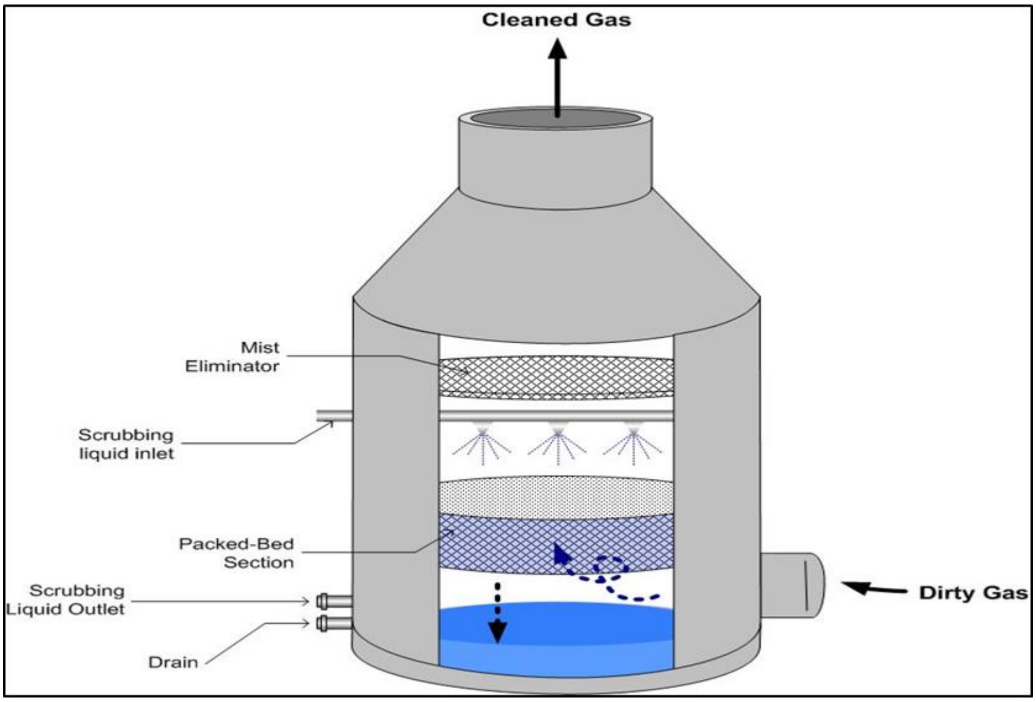


Figure 2-10: Diagram showing a wet scrubber

2.4.6.1. Dry-scrubbers

Dry-scrubber design can either be of a fixed or fluidized bed of sorbent material where the flue gas is blown through the material for contact or the sorbent can be injected in powder or particulate form into flue gas. Where the sorbent is injected or used in a fluidised bed, care should be taken that proper particulate handling equipment is used to remove any entrained sorbent which would contribute to particulate loading in the outlet gas. Some applications allow for in situ injection into the reaction area such as the case with some coal combustion processes. Dry-scrubbers usually use an alkali material to absorb the SO_2 and other acidic material while wet-scrubber have the option of using such a material or not, with water. Based on the composition of pollutants removed and the type of sorbent used the resulting chemical may be of value (then called a renewable process) for instance in the case of $CaSO_4$ obtained from using lime as a sorbent and oxidation.

Common sorbents include calcium containing mineral for instance lime and limestone or sodium compound (NaOH, Na_2CO_3, and $NaSO_3$). When a sodium alkali is used, it is usually regenerated using lime and then returned to the scrubber in what is called a dual-alkali scrubbing process. Using the sodium as the sorbent decreases clogging and scaling in the scrubber and its sprayers as the calcium alkali (especially lime) requires more stringent concentration control to prevent scaling. Absorption enhancing reagent (magnesium ions) may also be used with sorbent to increase its efficiency.

2.4.6.2. Semi-dry scrubbers

Semi-dry scrubbing adds a small amount of moisture to the sorbent particles to assist in the removal of pollutants. Dry and semi-dry scrubbers produce little to no steam plumes and have the advantage of having a dry (or almost dry in the case of semi-dry scrubbing) waste product making handling quite easy. In addition, cooling of the flue gas is minimal.

2.4.6.3. Wet Scrubbers

Wet-scrubbing uses either water or slurry with a sorbent added to the water. In either case the scrubber is similar in design but the processing of the existing slurries differs depending on what type of sorbent is used. Wet-scrubber designs include spray nozzle, venturi, orifice and mechanical scrubbers. These technologies are all focused on increasing the mixing of the flue gas and droplets for increased efficiency. An alternative to using a slurry to distribute the sorbent, the water can be sprayed over a packed bed of the sorbent.

Wet-scrubbers do not employ additional sorbent, rely primarily on the physical impact of water droplets on particulate matter and the solubility of gaseous components in water (a liquor purge and fresh supply is necessary to enable continuous removal from the gas stream before equilibrium concentration are reached). Additional sorbent assists in increasing the liquor’s chemical capacity for absorbing gaseous components from the gas stream, as a pollutant is absorbed into the liquor phase a chemical reaction serves to remove the species and thereby allow further absorption.

During wet-scrubbing the off-gas is cooled, increasing its humidity. In addition, high temperature flue gas aids evaporation of water from the wet scrubber which adds moisture to the existing flue gas, increase the gas stream volume and result in further cooling which may have significant impact upon dispersion of the plume. If the dew point is reached the SO_2 may form sulphuric acid which could cause corrosion on any of the equipment in the process line after the scrubbing process. This may be mitigated by reheating the existing gas stream by a variety of means such as combustion of a clean fuel in the presence of the flue gas or using steam heat exchangers. It should be noted that using any equipment that can cause severe heat exchange may increase the corrosion on those specific equipment pieces until the temperature is raised (Liu et al., 2011).

The packed bed spray scrubber is the best suited to gaseous pollutants absorption due to its high surface area but can get blocked if there is high PM loading in the off-gas. The other scrubbers, on the other hand are better suited to handle PM but are not quite as efficient as the packed bed spray scrubber. For gaseous absorption temperatures should be between 4 and 38 °C to avoid sorbent evaporation and decrease solubility of the gas pollutants in the water.

Gaseous hazardous air pollutants (HAP) removal is not recommended unless accompanied by a burner, as extreme column design would be needed for efficient removal.

2.5. Emissions monitoring approaches

Emissions standards set out in the emission standards may be articulated in absolute terms or comparative terms. In the situation of gaseous pollutants, the standard may be specified in volumetric rather than gravimetric terms (Vallero, 2014). As such, numerous methods to monitoring of emission limits have been established; including direct emission measurements, mass balances, emission factors and parametric replacement methods (European Commission, 2003). Some factors influence the selection of the method used to calculate pollutants, comprising the likelihood of exceedances, the emission standard, the consequences of exceeding the emission standard, the required accuracy, costs, simplicity, rapidity, reliability, suitability etc. (Ministry of Infrastructure and the Environment Netherlands, 2012). In-stack measurement is defined as "specific quantitative emission determination of emissions at the source" (European Commission, 2003). This is further separated into two techniques, periodic emission monitoring **(**PEM) and continuous emission monitoring (CEM).

2.5.1. US EPA Methods for Sampling and analysis

2.5.1.1. US EPA Method 1: Determination of sampling sites and traverse points

This method aids in the representative measurement of pollutant emissions and/or total volumetric flow rate from a stationary source. A measurement site where the effluent stream is flowing in a known direction is selected, and the cross-section of the stack is divided into a number of equal areas. A traverse point is then located within each of these equal areas. The method recommends that the ideal sampling port should be located at least eight (8) stack diameters away from an upstream flow disturbance, and at least two (2) stack diameters away from a downstream flow disturbance to minimise variations in the velocity profile.

2.5.1.2. US EPA Method 2: Determination of stack gas velocity and volumetric flow rate

The gas volumetric flow rate must be determined where flue-gas is non-homogenous and where emission rates are required. Determination of the volumetric flow rate requires that the velocity be measured at numerous points across the sampling plane. The volumetric flow rate expressed as cubic meters per second (m^3/s) and can be obtained by measuring the weighted-average gas velocity multiplied by the inside diameter of the duct. The average of the velocity measured at the traverse points provides an acceptable weighted-average velocity for the system. This has to be achieved equal cross-sectional areas. The velocity of flue-gas may be obtained by measuring either the gas kinetic or the velocity pressure. The approved and applicable standards for measuring velocity and volumetric flow rate are:

2.5.1.2.1. ISO 10780 Stationary Source Emissions - Measurement of velocity and volume flow rate of gas streams in ducts

“This ISO standard specifies manual methods for determining the velocity and volume flow rate of gas streams in point sources vented to the atmosphere. The standard stipulates two types of Pitot tubes that can be used, these are type L und type S, both used for determining the velocity and the volume flow rate for each type of Pitot tube. This standard applies to gas streams with essentially constant density, temperature, flow rate and pressure at the sampling point” (International Organization for Standardization, 1994).

2.5.1.2.2. ISO 14164 Stationary Source Emissions - Determination of the volume flow rate of gas streams in ducts - Automated method

This Standard defines the operating principles and the most significant performance characteristics of automated flow-measuring systems for assessing the volume flow rate in the ducts of stationary sources. It also describes the procedures for determining the performance characteristics of automated volume flow-measuring systems. The performance characteristics are general and not limited to specific measurement principles or instrument systems” (International Organization for Standardization, 1999).

2.5.1.2.3. USEPA Method 2 - Determination of stack gas velocity and volumetric flow rate (Type S Pitot Tube)

The USEPA Method 2 is applicable for the determination of the average velocity and the volumetric flow rate of a gas stream. The method is not applicable at measurement sites that fail to meet the criteria of USEPA Method 1. It is further noted that the method cannot be used for direct measurement in cyclonic or swirling gas streams (United States Environmental Protection Agency, 1991a). Isokinetic source sampling is achieved when the velocity of gas entering the sampling nozzle is exactly equal to the velocity of the approaching gas stream. This method provides a uniform, unbiased sampling of emitted pollutants. For isokinetic sampling requires water vapour determination where emission concentrations are to be expressed at standard conditions and for use in adjustment of the flow rate and when a dry gas flow rate-metering device is used (Irish Environmental Protection Agency, 2018). The method BS EN 14790 for stationary source emissions – determination of the water vapour in ducts is used for the determination of the humidity or moisture content of the flue gas:

2.5.1.2.4. BS EN 14790 Stationary Source Emissions - Determination of the water vapour in ducts

This is a European Standard which stipulates the standard reference method based on a sampling system with a condensation method to determine the water vapour concentration in the flue-gases released to atmosphere from point sources. The standard prescribes the performance characteristics to be determined and performance criteria to be achieved by measuring systems based on the measurement method. It further applies to periodic monitoring and to the calibration or control of automated measuring systems permanently installed on a stack.. The method specifies the criteria for demonstration of equivalence of an alternative method to the SRM by application of (NationalStandards Authority of Ireland, 2017).

US EPA Method 2, which dictates that a preliminary velocity traverse should be carried out before sampling, is performed to establish that the sampling location is suitable and to ensure that the most appropriate sample nozzle dimensions are selected for the flow range in the duct. Measurements of gas velocity are carried out at specifically-spaced points along a traverse of the duct.

The duct flow was calculated from the measurement of:

- the differential pressure at each of the points.
- the stack gas molecular density.
- the stack gas temperature.
- the stack gas pressure.
- the stack gas moisture content

It should be noted that the operator monitors duct flow and manually adjusts the sample flow rate at the start of each traverse point, as per US EPA Method 5, in order to maintain an average isokinetic flow for the duration of each traverse point.

2.5.1.3. US EPA Method 3: Determination of gas composition and molecular weight

A Testo 350 Flue Gas Analyser was used to perform dry gas composition measurements of the gas stream. The method of analysis is by means of electrochemical cells, which record concentrations of oxygen, carbon monoxide, nitrogen oxides and sulphur dioxide. Carbon dioxide is calculated for combustion processes. These values are used to calculate the dry gas molecular weight of the gas stream in the duct. The oxygen concentration also provides a measure of the dilution of the gases from the process.

2.5.1.4. US EPA Method 4: Determination of moisture content of stack gas

USEPA Method 4 Determination of moisture content in stack gases is applicable for the determination of the moisture content of stack gas. The reference method is used for accurate determinations of moisture content. This method provides estimates of moisture percentage to aid in setting isokinetic sampling rates preceding a pollutant emission measurement run. The approximation method defined herein the method is only a suggested approach; alternative means for approximating the moisture content for instance drying tubes, wet bulb-dry bulb techniques, condensation techniques, stoichiometric calculations, previous experience are also acceptable. The reference method is often conducted simultaneously with a pollutant emission measurement run. When it is conducted, calculation of percent isokinetic, pollutant emission rate shall be based upon the results of the reference method or its equivalent. These calculations shall not be based upon the results of the approximation.

The moisture content of the stream was determined by drawing a sample through a condenser and measuring the accumulated condensate and the total dry gas flow. The moisture content is re-calculated after each sample run

2.5.1.5. US EPA Method 5: Determination of Particulate Matter from Stationary sources

"This technique is applicable for the determination of PM emissions from stationary sources" (United States Environmental Protection Agency, 1991a).

2.5.1.5.1. BS EN 13284-1 Stationary Source Emissions - Determination of low range mass concentration of dust: manual gravimetric method

"BS EN 13284-1 specifies a reference method for the measurement of low dust concentration in ducted gaseous streams with emission concentrations below 50 mg/m^3 standard conditions.

The method is validated with distinct emphasis around 5 mg/m^3 on an average half hour sampling period. The standard is primarily developed and validated for gaseous streams emission generated by waste incinerators. However, it may be applied to gases emitted from stationary sources, and to elevated concentrations. Should the constituents of gases comprise unstable, reactive or semi-volatile substances, the measurement then depends on the sampling and filter treatment conditions" (European Committee for Standardization, 2017). Visible pollutants are expressed either in terms of their appearance of the plume in case of smoke density, or in terms of the mass concentration of the PM.

This method is applicable for the determination Particulate Matter (PM) emissions from stationary sources. Due to the wide range of particle sizes normally present in process emission streams, it is necessary to sample isokinetically to ensure that a representative sample of the particulate emission is obtained. A leak test is performed before and after sampling to ensure the sample is not diluted. Isokinetic sampling is achieved when the gas enters the sampling nozzle at the same velocity and direction as the gas travelling in the duct. In addition, to allow for the non-uniformity of particulate distribution, samples must be obtained from multiple sample points across the sampling plane in order to give an overall average of the emissions.

2.5.1.6. US EPA Method 6c: Determination of Sulphur Dioxide Emissions

Sulphur dioxide (SO_2) measurements were conducted using US EPA Method 6 – Determination of sulphur dioxide emissions from stationary sources. Samples were extracted isokinetically from the stack into 10% hydrogen peroxide solution, which was subsequently analysed turbidimetricaly.

The isokinetic sampling train for SO_x sampling consist of the following components:

- Quartz glass sampling probe, filter and nozzle (For in-stack filtration).
- High-efficiency glass fibre filter.
- Quartz glass impinge set for the collection of condensation and removal of water vapour.
- Teflon tunes for connection between sampling train components.
- Dry gas meter.
- Control box fitted with calibrated orifice, thermocouple and vacuum gauge.
- Vacuum pump.

2.5.1.7. US EPA Method 7e: Determination of Nitrogen Oxide (NOx)

Nitrogen Oxides (NO_X normally reported as NO_2) measurements were conducted using US EPA conditional test Method 034 – Determination of oxygen (O_2), carbon monoxide (CO) and oxides of nitrogen (NO_X) from stationery sources (Potable electrochemical analyser procedure).

(a) ISO 10849 Stationary Source Emissions - Determination of the mass concentration of nitrogen oxides. Performance characteristics of automated measuring systems

This method stipulates the fundamental structure and the most significant performance features of automated measuring systems for oxides of nitrogen which to be used on emissions of stationary sources, for instance combustion installation plants. The procedures to determine the performance characteristics are also stipulated (ISO, 1996).

(b) BS EN 14792 Stationary Source Emissions - Determination of mass concentration of nitrogen oxides (NOX). Reference Method: Chemiluminescence

The European Standard defines the chemiluminescence technique, which includes the sampling and conditioning of gas emitted from ducts and stacks to the atmosphere. It is the standard reference method (SRM) for periodic monitoring and for calibration of automatic measuring systems permanently installed on a stack. The method is also used for regulatory and other purposes for instance calibration. When used as the Standard Reference Method, the user should assess that the performance characteristics of the method are better than the performance criteria defined in this European standard and that the uncertainty of the method is less than + 10 % relative at the daily Emission Limit Value" (British Standards Institution, 2017b).

2.5.1.8. US EPA Method 8: Determination of sulphuric acid and sulphur dioxide emissions from stationary sources

2.5.1.8.1. ISO 7935 Stationary Source Emissions - Determination of the mass concentration of sulphur dioxide. Performance characteristics of automated measuring methods

This is an internationally used standard which specifies a complete set of values of performance characteristics for automated measuring systems relating to continuous measurement of the mass concentrations of SO_2 in stationary source emissions. This standard is applicable to extractive and non-extractive automated SO_2 measuring method (International Organization for Standardization, 1992).

2.5.1.8.2. BS EN 14791 Stationary Source Emissions - Determination of mass concentration of sulphur dioxide. Reference method

This is a European standard which describes a manual technique for sampling and determining sulphur dioxide content in ducts and stacks emitting to the atmosphere by two analytical methods:

These are Ion chromatography and the Thorin method. Both are used as Standard Reference Methods for periodic monitoring and for calibration or control of automatic measuring systems permanently installed on a stack. These methods are used for regulatory purposes. When used as the Standard Reference Method (SRM), the user should demonstrate that the performance characteristics of the technique are better than the performance criteria defined in this European standard and that the overall uncertainty of the method is less than +20,0 % relative at the daily Emission Limit Value (ELV)" (British Standards Institution, 2017a). Gaseous SO_2 emissions from stationary sources" (United States Environmental Protection Agency, 1991b).

2.5.1.9. US EPA Method 9: Visual Opacity

This technique enables visual measurement of smoke densities from stationary sources. The technique necessitates the training of observers to recognize plume opacities and behaviour. The observer should be capable of reading the smoke plume over a test period and report the results (United States Environmental Protection Agency, 2017). Owing to the subjective nature of this method, and considerations of importance of any non- compliance to emission standards, it is not recommended for use in South Africa. Optical devices for continuous opacity measurement are regularly used and recommended for use in the assessment of opacity requirements in South Africa. The monitors used utilise the similar principles as extractive technique for PM and methods for quality assurance of automated measuring systems and are calibrated using these methods.

2.5.2. Emission Testing Methodology for Air Pollution

Air pollution continues to be one of the top environmental concerns not only in South Africa, but worldwide. Regulating Authorities and industries can use air monitoring program to assist in addressing the environmental responsibilities relating to emissions impacting on the receiving environment (Piketh and Burger, 2016). Industries perform monitoring to enable the industrial plant to be managed in an environmentally friendly and sustainable manner, and to meet the requirements of the National Environmental Management: Air Quality Act (Act No 39 of 2004), as amended. The primary purpose of industry performance monitoring is to provide scientific evidence or data to the

Regulating Authority to compare emissions against the Minimum Emissions Standards.

Stack emission testing for gas and/or particulate emissions must be done to achieve compliance with National Environmental Management: Air Quality Act (Act No 39 of 2004) methods for sampling and analysis. Any deviation or variation to the requirements of the approved methods by the license holder must have prior approval from the National Air Quality Officer from the Department of Environmental Affairs.

Industrial performance and compliance monitoring provide the regulating authority with reliable, timely and accurate information to enable scientific decisions to be taken (Visy Pulp and Paper, 2007). The information provided to the regulating authority includes the composition and rate of pollution to the receiving environment. To fulfil the requirements of accurate reporting emission testing through stack requires comprehensive planning. The planning include designing and planning a monitoring program, stack emission sampling, health & Safety precautions for technical staff. Technical staff responsible for testing are responsible to ensure the safety of all involved in testing. All site safety requirements and procedure must be followed.

Emission sampling must be the representative of the gas stream being tested in the stack. Therefore, the main objective of the stack emission sampling technique is to ensure that the sampled gas stream is representative of either the total or a known portion of the source emissions. In additions to requirements stipulated in terms of the National Environmental Management Act (Act No. 39 of 2004) as amended, the risks associated with stack emissions testing require assessment to achieve compliance with Occupational Health and Safety Act (Act No.85 of 1993) as amended. The risks may arise from a number of hazards associated with stack emissions testing and the prevailing physical conditions. The following hazards taken into consideration during stack emission testing included working at height on temporary platforms, exposure to toxic gases, electrical hazards, trip hazards, noise and heat hazard for the plant equipment, flammable substance and any falling objects.

Sampling program must consist a minimum of three test runs per pollutant unless agreed otherwise with the Regulating Authority. Each test specifies the minimum sampling time at each sampling point in a transverse across a stack or duct. Another factor that’s taken into consideration is the sampling volume, as the volume required to obtain sufficient sample for analysis will depend on concentration existing in the emissions. In addition, this ensure that sufficient volume is taken to the laboratory and the amount of emissions captured are suitable for the analysis method being used.

To achieve iso-kinetic sampling which require a representative sample of the gas stream containing solid or liquid particles, the sample must be taken withdrawn from the emission source at a rate where the velocity and direction of the gas entering the sampling nozzle is the sample as that of the gas in the duct as the sampling point. However, the number of points sampled is dependent on the cross-sectional area of the stack and distance of the sampling plane from flow disturbance within the stack (Van Breugel et al., 1969).

All stack emission monitoring was performed utilising internationally validated methodologies. For this project, our sampling team utilised the United States Environmental Protection Agency (US EPA) methods for stack emission monitoring, as required by section 21 of the National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004), Annexure A – Methods for Sampling and Analysis. EPA Method 5 forms the basis for isokinetic sampling procedures. This method outlines the requirements that need to be adhered to for the purposes of reporting on particulates and gas emissions from stationary sources. In order to perform this method, it is necessary to execute Methods 1– 4 in advance.

2.5.3. Periodic emission monitoring

PEM determines the magnitude and nature of pollutant through taking on-stack samples over a limited period of time (UBA, 2008). Samples are obtained for a period of time as specified in the standards which ranges from minutes known as grab sampling to hours. Dependent on the type of instrument utilised, analysis of the emissions measured can be directly executed in the flue gas or later in a laboratory, away from the site (Environment Agency, 2012).

The advantage of in-situ measurement is that the values of parameters measures are known immediately after the measurement is complete, this eliminate transportation errors and laboratory charges. This method is used in determination of physical flue-gas parameters, such as temperature, pressure and velocity.

The shortcoming is that the flue-gas conditions and the existing measurement principles, often prevent an in-situ analysis in the flue gas. For instance, optical methods are disturbed by elevated emission concentrations of dust in the flue gas and infrared methods as a result of the presence of water vapour. In this case an extractive measurement with an external technique of analysis is then the alternatively used.

With a probe partial flow of the flue gas is extracted, transported and analysed outside the flue-gas duct, In general, extractive sampling is used in determining the nature of chemical in flu-gas. Another major factor to be considered in extractive measurements is the manner in which the sample is transported. During sample transportation errors can occur in the concentration determination due to dilution of the flue-gas due to leakages, and chemical reactions or adsorption of the component onto surfaces within the transport system or container. It is therefore significant that the leak- tightness of the sampling system is monitored and that it is inert with respect to the components to be determined. The choice of materials to be used for instance quartz, teflon and stainless steel are often used. Furthermore, the conditioning of the sample with regard to particulates and water vapour is important (Ministry of Infrastructure and the Environment Netherlands, 2012).

2.5.4. Continuous emission monitoring

Continuous emission monitoring systems (CEMS) are defined systems that are proficient to carry out emission measurements continuously thereby producing comprehensive data, with limited faults. These systems vary from handheld emission testing equipment to permanently installed in-stack. Measurements are carried out in-situ in the stack or extractive using with an instrument permanently located at or near the stack (Environment Agency, 2012). These monitoring systems are entail several sub-systems. These several sub-systems are the sampling interfaces composed of sampling probes and flow meters, the gas analysers, and the data acquisition systems.

2.5.5. Surrogate parameters

Surrogate parameters are measurable or predictable measures, which can be closely linked, directly or indirectly, to conventional direct measurements of emissions, and which may be monitored and used in the place of direct pollutant values for practical purposes. Surrogate parameters provide complementary information relating to the plants' pollutants behaviour. The surrogate provide an indication of whether the emission standard value can be fulfilled if the surrogate parameter is maintained within a certain range (European Commission, 2003). Each time a surrogate parameter is proposed to establish the value of another parameter of interest, the association between the surrogate and the parameter of interest must be depicted clearly and documented properly. The traceability of the parameter's assessment on the basis of the surrogate is required (Ministry of Infrastructure and the Environment Netherlands, 2012).

2.5.6. Mass balances

Mass balances are utilised for an approximation of the emissions to the receiving environment from a facility, unit process, or machinery. The technique normally takes cognisance of inputs, accumulation, outputs and generation or destruction of the substance of interest, and the difference is accounted for as a release to the environment (European Commission, 2003).

Mass balances are based on the application of the law of conservation of mass to the process. Essentially, if there is no accumulation within the system, then all the materials that go into the system must come out. Fuel analysis data provide a good illustration of the mass balance methodology in predicting emissions. For instance if the concentration of a pollutant or pollutant precursor in a fuel is known, emissions of that pollutant can be calculated by assuming that all of the pollutants are emitted prior to the application of an emission control (Guideline NPRI, 2006).

This method utilises physical or chemical characteristics, for instance vapour pressure of the substance and mathematical associations (such as ideal gas law). Theoretical models for specific processes can also be used, although these can be complex.

2.5.7. Emission Factors

Emission factors are defined as numbers that can be multiplied by an activity rate or by throughput data, such as the production output, fuel consumption in order to determine the emissions from the plant. They are applied under the hypothesis that all industrial process units are of the same production line and have similar emission patterns. These emission factors are commonly used for determination of emissions emitted from small installations (European Commission, 2003).

Emission factors are developed from different facilities operating within an industry category representing distinctive values for an industry, but not representing a specific emission source. These factors are merely averages of existing data of acceptable quality, and are generally predicted to be illustrative of long-term averages for all facilities in the source category (United States Environmental Protection Agency, 2003).

2.5.8. Data quality control

Data obtained from emission measurement to be reliable for use in scientific decision-making, it has to comply with certain requirements confirming consistency and comparability. It is therefore a standard to set a system for data quality control as part of the overall quality control (QA) and quality check (QC) programme. Konieczka and Namiesnik (2016) describes QC as a sophisticated system of actions to attain measurements with the mandatory quality level. QA concerns the data measurement process itself, whilst QC refers to post-collection activities for optimization of data accuracy and precision (Heard, 2006). QC activities would comprise the calibrations, linearity checks, leak test, and comparison to the standard reference methods.

2.5.9. Data reporting

Quality control measures are conducted to confirm the consistency and comparability of the emission results. Subsequently the results are documented and reported to authorities for compliance valuation and decision-making processes. Regulations generally provide provisions on the procedure to be followed. Elements of emission reporting such as normalization, units of expressions, averaging periods are typical some of the specifications required by regulating authorities. Further considerations are on data recording and logging requirements that meet the regulating authority's and system requirements have to be observed. This is critical in ensuring that data recorded or used are compatible with the regulators' reporting systems and requirements. In situations where manual reporting exists, emission reporting templates should be provided by the regulators.

2.5.10. Measurement of pollutants

Periodic emission measurement or continuous emission monitoring are prescribed as minimum requirements for determination of compliance with emission standards as specified under the section 21 listed activities. It is further noted that there are other monitoring approaches used as alternative measures where the prescribed approaches are not practicable, or as additional measures. Once of an alternative method includes the use of mass balances between reporting periods (Department of Environmental Affairs, 2010).

The section 21 listed activities provide a list of internationally recognised and approved methods for use in determination of compliance with the emission standards. The methods for determination of most of the regulated pollutants are not specified, thus the purpose of this section is to consider and identify relevant methods for each regulated pollutant.

It is noted that currently, there are no nationally established emission measurement techniques developed and or adopted by the international bodies that are accepted for the purpose of section 21 compliance determination. International bodies for determination of emission standards include:

- International Standardization Organization (ISO)
- United States Environmental Protection Agency (USEPA)
- British Standards Institution (BSI)
- European Committee for Standardization (CEN)
- The Association of German Engineers (VDI)
- American Society for Testing and Materials (ASTM)

Where no methods for sampling or analysis of certain pollutants established for stationary sources, acceptable occupational health methods may be used, taking into account all relevant measures.

Occupational health methods from the following bodies are accepted:

- National Institute for Safety and Health (NIOSH)
- Health and Safety Executive (HSE)

Section 21 Notice does not establish criteria for prioritization of measurement methods. As such, the related to fit-for-purpose method selection taken into consideration when choosing the monitoring method, and the associated equipment. The following factors are also considered:

- Instrument certified ranges
- Analytical limit of detection
- Linearity
- Instrument response speed
- Measurement uncertainty

2.5.10.1. Periodic emission measurement (PEM)

Under PEM, emanation measurements can either be directly executed in the flue-gas passage (in situ) by using mechanical techniques or by removing a fractional stream with a sampling system (extractive) and examining it in a laboratory. Wherever PEM is conducted, formed criteria for illustrative sampling must be followed, and confirmation that the monitoring techniques is relevant for the pollutant, and that the results shall be noticeable to the standard reference system. Additionally, the condition and material (for example temperature) of the sample/measurement systems must be sustained such that there is neither loss of contaminant nor accumulation of interfering pollutant. Any supporting measurements that are essential such as oxygen, volumetric flowrate and moisture must be run instantaneously with the sampling/measurement process, using appropriate techniques.

2.5.10.2. Continuous emission monitoring

CEM involves the usage of mechanical measurement systems to take measurements of contaminants in actual–time, “with few - if any - gaps “in the data are produced. Measurement may be carried out in situ in the stack (frequently called cross-stack or cross-duct monitoring), or extractive sampling may be used with an instrument permanently situated at or near the stack (Environment Agency, 2012). Where CEM is needed, only certified CEMS must be installed for acquiescence purposes. The three-part standard that has been adopted **under S.21 Notice for certification of CEMS is BS EN 15267**. This standard is described as:

- BS EN 15267-1 Air Quality - Certification of automated measuring systems. General principles (BSI Shop, 2009a)
- BS EN 15267-2 Air Quality - Certification of automated measuring systems. Initial assessment of the AMS manufacturer's quality management system and post certification surveillance for the manufacturing process (BSI Shop, 2009b)
- BS EN 15267-3 Air Quality - Certification of automated measuring systems. Performance criteria and test procedures for automated measuring systems for monitoring emissions from stationary sources (BSI Shop, 2007)

Over and above certification, the S.21 notice needs that CEMS be calibrated and assessed (i.e. correlation tests using standards reference methods) every two years as a minimum, or per manufacturer's specifications where it is required more frequently. Auditing and correlation tests of CEMS shall be done using BS EN 14181:2014- Stationary Source Emissions. Quality assurance of automated measuring systems (BSI Shop, 2014).

2.5.10.3. Particulate Matter: Extractive Sampling

After sampling particulate matter in a flue gas stream it is authoritative to sample isokinetically in order to ensure that data generated is illustrative. Isokinetic sampling is attained by drawing the sample into the sample probe at a velocity equal to the gas velocity in the duct where the sample's tip is positioned. Gas samples are drawn uniformly, which means that as the gas flow in the duct changes, the sample rate is changed proportionately to provide appropriately weighted results. Which means that duct velocities must be taken simultaneously with the samples and at the same positions. It is vital to be able to associate sample meter flow rates to probe-tip flow rates by accounting for temperature, pressure and moisture changes,

Prerequisites on siting of the location of suitable sampling points for this purpose and on isokinetic sampling in general are detailed in the standard methods listed below:

(a) ISO 9096 Stationary Source Emissions - Manual determination of mass concentration of particulate matter

"ISO 9096 defines a reference method for the measurement of particulate matter concentration in waste-gases of concentrations from 20 mg/m^3 to 1000 mg/m^3 under normal operating conditions. The standard is applicable and to the calibration of automated monitoring equipment. If the composition of the released gas comprises of unstable, reactive or semi-volatile substances, the measurement depends on the percolation temperature. In-stack the methods may be more applicable than out-stack methods for the calibration of automated monitoring systems" (International Organization for Standardization, 2003).

(b) ISO 12141 Stationary Source Emissions - Determination of mass concentration of particulate matter (dust) at low concentrations - Manual gravimetric method

"ISO 12141 defines a reference technique for the measurement of low dust content in ducted gaseous streams at concentrations below 50 mg/m^3 under standard conditions. This technique has been validated with special emphasis on the region around 5 mg/m^3. ISO 12141 has been established and validated for gaseous streams emissions by waste incinerators. It may be applied to emissions from stationary sources, and to higher concentrations. If the gases contain unstable, reactive or semi-volatile substances, the measurement depends on the sampling and filter treatment conditions" (International Organization for Standardization, 2002).

(c) ISO 10155 Stationary Source Emissions - Automated monitoring of mass concentrations of particles. Performance characteristics, test methods and specifications.

"This standard stipulates conditions and criteria for the automated monitoring of the mass concentration of PM in stationary source gas streams. It includes performance characteristics and testing techniques. This includes provisions for the field evaluation test program and application to automated monitoring systems. **ISO 10155** is applicable to on a site-specific basis by direct correlation with the manual testing method in ISO 9096" (International Organization for Standardization, 1995).

2.5.10.4. Compliance monitoring

Compliance monitoring normally encompasses a statistical comparison between the measurements, or a summary data estimated from the measurements; the uncertainty of the measurements; and the relevant emission standard value or equivalent parameter (European Commission, 2003). It is a normal practice to consider any exceedances of emission standards as non-compliance, irrespective of the extent of exceedance. Alternatively, additional procedure may be included, which determine compliance on risk band approach. Under this method, a level of statistical likelihood or confidence above which measurements are deemed to be non-compliant is applied by comparing the variances between measurements and the standard with the certainty in the measurements. Three compliance bands are then established to represent compliance, borderline and non-compliance status (European Union Network for the Implementation and Enforcement of Environmental Law, 2001).

2.5.10.5. Measurement site requirements

The location of sampling ports is a crucial element of emission testing aimed at addressing representativeness of the sample and safety consideration. One of the requirements for the measurements to be carried safely and efficiently is the necessity to have free access to the sampling plane and have appropriate sampling ports and working platforms for typical sampling equipment.

2.5.10.5.1. Sampling requirements

The fundamentals of sampling principles state that a small amount of collected material be a representative sample of the overall character of the material, must always be observed when sampling for emissions, regardless of the monitoring method or equipment used for this purpose.

For the purpose of compliance monitoring, sampling for emissions must be conducted on the stack. Where individual listed activity units share a common stack, sampling must be carried out in the appropriate listed activity duct and this should be prior to the point release or stack. Adequate planning prior to sampling includes determination of the point of compliance. This is determined when the point of compliance under common stack activities, interference of the duct bends, duct branching and any other obstructions might affect the representativeness of the emissions and should be prevented. It’s important that these factors are taken into consideration when reporting emissions.

When sampling for PM emissions, consideration should be given to the homogeneity of the flue-gas. This include the representative number of samples required and locations need to be considered to make up a representative sample depending on the nature of homogeneous the flue-gas. Only a few samples may be required if the flue-gas is homogeneous, as opposed to the non-homogeneous flue gas, which require more samples and sampling points.

There are various factors that affect homogeneity of the flue-gas. These factors include differences in chemical composition for instance where the flue-gas is also carrying particulates along and the differences in temperature. It is noted that temperature variations results in poor mixing of flue-gas. On the other hand the velocity of flue-gas results in short residence time in the installation, which may lead to stratification and swirling. Percentage iso-kineticity must therefore be determined and reported in the emission report.

2.6. Meteorology

2.6.1. Study Location and Prevailing Weather Conditions

Meteorological conditions affect how pollutants emitted into the atmosphere are directed, diluted and dispersed within the atmosphere. Dispersion comprises vertical and horizontal components of motion. The stability of the atmosphere and the depth of the mixing layer control the vertical component. The horizontal dispersion of pollution in the boundary layer is primary a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution as the plume ‘stretches’ away from its source. Mechanical turbulence is influenced by wind speed in combination with surface roughness.

South Africa is situated in the subtropical high pressure belt and is influenced by three high pressure cells, the South Atlantic High Pressure, South Indian High Pressure off the east coast, and the Continental High Pressure over the interior. In addition to circulation systems in adjacent tropical and temperature latitudes.

High pressure cells are characterised by areas where cold air converges in the upper of the troposphere, and sinks throughout the troposphere to where it diverges in the near surface with field. This is because as the air descend, the air pressure increases. In the southern hemisphere the air is diverged anticlockwise. The result is a mean anticyclonic upper air circulation over South Africa. Such airflow result in subsidence inversion, fair atmospheric conditions and little to no rainfall.

High pressure cells vary seasonally, moving towards the north in the winter and the south in the summer. The seasonal variation of the position and intensity of these high pressure cells are important in determining the extent to which westerlies impact the atmosphere over a region.

In winter, the high pressure belt strengthens and moves northward and the upper level westerlies are able to impact significantly on the region. During summer months, the belt weakens and shifts southwards, reducing the influence of the westerlies.

In contract to calm weather conditions associated with the high pressure cells, westerlies are associated with strong wing and upwards vertical motion that disrupt the persistence of inversion. The continual uplift produced by westerlies result in the moist war air to rise throughout the troposphere and cool to form clouds and the potential for precipitation.

2.6.1.1. Temperature inversions

Temperature normally decreases with altitude. This is because most of the sun’s rays is converted into sensible heat at the earth’s surface, which in turn warms the air on the earth’s surface. The warm air rises, expands and cool with increasing altitude. However, a situation may occur where temperature profile of the atmosphere in “inverted” from its usual state, where the temperate of air increases with altitude. This “inverted” state where warm air overlies cooler air, is referred to as a temperature inversion.

2.6.1.2. Impact of temperature inversion on air quality

A temperature inversion act as a barrier, suppressing vertical mixing and trapping the cooler air at the surface, resulting in the pollutants in the air also being trapped near the ground. This leads to poor air quality. These trapped pollutants can only be removed by strong horizontal winds. Due to the fact that subsidence temperature inversions are located higher in the troposphere, they are not easily disrupted and may persist for long period over an area. The long residency of subsidence temperature inversion over an area, combined with the fair atmospheric conditions with little to no rainfall of high pressure systems may result in episodes of severe ground level concentration of pollutants in areas that experience major atmospheric pollution industrial areas.

Due to warm air rising through the atmosphere, Westerlies disrupt the persistence of inversions. This facilitates the dispersion and dilution of accumulated atmospheric pollution. When this ward air cools, it forms clouds which then results in the potential for precipitation and removal of pollution through wet deposition.

2.6.1.3. Seasons

Table 2-3 shows the seasonal calendar obtained from the South African Weather Service’s website which is adopted for the southern hemisphere.

Table 2-3: Seasonal calendar for South African weather

Season	Calendar Dates
Autumn	01 March to 31 May
Winter	01 June to 31 August
Spring	01 September to 30 November
Summer	01 December to 28/29 February

Durban is situated at approximately 30 ºS and is characterised by a subtropical climate. It is strongly influenced by the warm Aguhulas Current and the relative position and strength of the Indian Ocean Anticyclone (IOA). The most representative climatologically data for Durban is from the South African Weather Service (SAWS) station at the old airport. Meteorological monitoring is also conducted by the eThekwini Municipality, but covers a relatively short period.

Summer temperatures are warm and winters are mild with average daily temperatures ranging from 24 °C in summer to 16 °C in winter. The maximum summer temperatures may exceed 30 °C, and winter minimums seldom fall below 10 °C (Figure 2-11). The average annual rainfall at Durban is 1009 mm. Although rainfall occurs throughout the year the majority occurs in summer with an average of 675 mm between October and March.

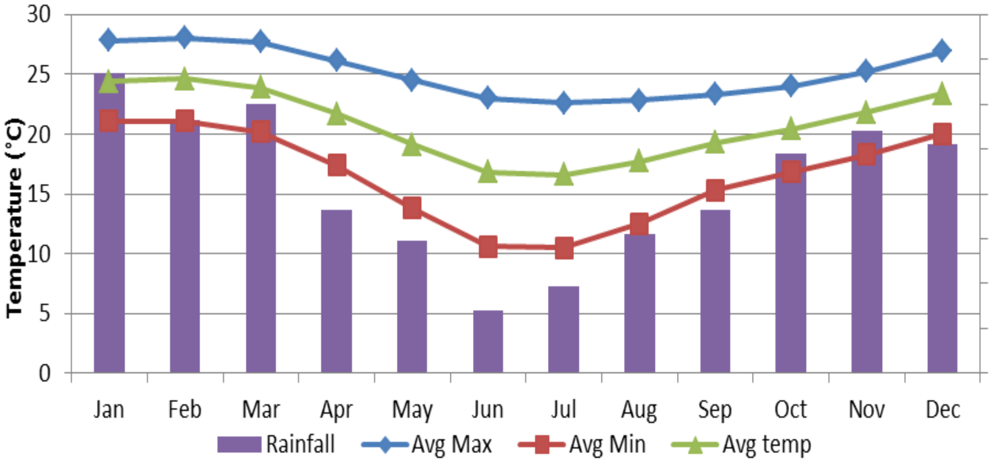


Figure 2-11: Average monthly maximum, minimum and daily temperature at Durban the average monthly rainfall in mm (South African weather service, 2018)

2.6.1.4. Wind

The dispersion of pollution is largely a function of the wind speed and wind direction, in combination with surface roughness.

The wind is the most important parameter of the meteorological condition for the transportation of and dispersion of pollutants. The wind influences air pollutants either by wind or speed, its influence on air pollution being high variable, depending on the source of position (Cretu et al., 2010).

Wind roses simultaneously depict the frequency of occurrence of wind from the 16 cardinal wind directions and wind speed classes, for a single site. Wind direction is given as the direction from which the wind blows, i.e., south-westerly winds blow from the southwest. Wind speed is given in m/s, and each arc represents a percentage frequency of occurrence.

The north to north-north-easterly winds result from the anticyclone circulation associated with the IOA. They occur mostly from late August throughout the summer to April, accounting for more than 30% of all winds. The strength of the winds is mostly related to the strength of the IOA and its relative position to the KwaZulu-Natal coast. The southerly to south-westerly winds are mostly associated with the westerly movement of frontal systems and their associated coastal lows. These occur mostly in winter and result in the strongest winds, which are short-lived and are usually just prior to the front passing through.

The KwaZulu-Natal coast also experiences so-called thermo-topographical winds. These mesoscale winds result firstly from the temperature differences between the land mass and the adjacent Indian Ocean. This results in the on-shore (easterly) sea-breeze at night in winter with the returning land-breeze (westerly) during the day. Secondly, they result from the steady decease in topographical elevation from the Drakensberg escarpment to the coast. This results in a regional-scale north-westerly wind, from the interior towards the coast.

2.6.1.5. Dispersion of pollutants

The air pollution dispersion of an area refers to the ability of atmospheric processes, or meteorological mechanisms, to disperse and remove pollutants from the atmosphere (Resources and Environmental Consultants Ltd, 2012). Dispersion comprises both vertical and horizontal components of motion. The vertical component is defined by the stability of the atmosphere and the depth of the surface mixing layer. The horizontal dispersion of pollution in the boundary layer is primarily a function of the wind field. The wind speed determines the rate of downwind transport and wind direction and the variability in wind direction determines the general path of pollutant. Atmospheric stability, or instability, determines the ability of the atmosphere to mix and dilute pollutants. Stability is a function of solar radiation (thermal turbulence) and wind speed and surface roughness which induce mechanical turbulence. The dispersion potential of an area therefore experiences diurnal and seasonal changes.

By day with strong insolation (incoming solar radiation) and stronger winds the dispersion potential is generally efficient through vertical dilution and horizontal dispersion. The dispersion potential is generally better on summer days than winter days. At night as the surface temperature inversion develops the lowest layer of the atmosphere becomes more and more stable, reaching a maximum at sunrise. As a result, the dispersion potential typically becomes less efficient during the night and the poorest conditions generally occur at sunrise. Thermal turbulence disappears when the sun sets, and mechanical turbulence decreases as the wind speeds drops at night. Pollutants tend to accumulate near the point of release under these conditions, particularly if these are released close to ground level. The dispersion potential is generally poorer on winter nights than summer nights.

Measurement of wind speed and wind direction is important in air monitoring. It assists in identification of the emission sources. In addition, it also provides better overall picture of what is happening in the air. The wind rose groups wind direction and speed over a period of time and provides visual presentation. Wind rose bars represent the direction in which the wind is blowing from. It’s noted that they are broken into segments, representing increasing speed groupings as move out of the centre. The length of the segments indicates the percentage of time that the wind blows from that direction, at that speed. In this regard the longest bars indicate the prevailing wind directions. The central part of the wind indicates the percentage of calm wind for the specified period of time. The ranges and explanations of different wind speeds are shown in Table 2-4.

Table 2-4: Ranges and explanations of wind speeds

Range (m/s)	Explanation
< 0.4	Calm winds
0.4 - 2	Breeze
2.1 - 4	Light winds
4.1– 6	Moderate wind
> 6	Strong winds

The primary winds emante from the North-East, South-West and Northerly directions, the general wind direction that prevails over Durban is North-Easterly as it has the highest total frquency of ~1300 hours per year. These wind range from 1.5m/s to the strongest >8.2 m/s with the largest portion of wind speed ranging between 3.1m/s and 8.2m/s. the highest total frquency of strong wind is >8.2m/s emanates from the south-westerly direction. These are associated with the passage of cold fronts that pass the east coast of South Africa during winter months.The third most prevalent wind direction is from a noertherly direction and has a gentle wind speed of <3.1m/s. Wind do emanate from other directions, but under lower frequencies. During spring which is Septermber to November and Summer, December to February, winds predominately originate from the North-east and south-west directions. In terms of wind speed, most winds are moderate to strong, exceeding 5.1m/s. the strong north-easterly and south-westerly winds favour the dispersion of air pollutants within the South Durban Industrial

Basin (SDIB). Due to these strong winds, the dispersion of air pollution within the SDIB is graeater during summer as compared to winter.

During autumn and winter, three main wind directions prevail namely, north-east, south-west and northerly. Winds are relatively calmer, with the majority of wind occuring between 3.1m/s – 5.1m/s. with respect to the dispersion of air polllution, during winter months, conditions are calmer, so more stable condition will be experienced over the SDIB. The dispersion of pollutants in these condions is low, which can potentially lead to a greateer impact of emissions across a wider area. These calm conditions can also potentially lead to the creation of inversion layer, which further inhibits the dispersion of emissions with the basin. The break-up of an inversion can result in fumigation of trapped pollutants to ground level, and is easily recognised as peaks on diurnal pollution (Simpson and McGee, 1996).

The dispersion of pollutants in the South Durban Industrial basin is relatively good. This is as a result of warm temperatures and high frequency of moderate strong winds. These conditions are effective for dispersion of emissions released from any stack with an effective height. It is noted that during the day in winter and summer, the daytime temperatures promote effective dispersion of pollutants. In summer during the rain period temperatures act as a catalyst in removing pollutants. At night, the formation of surface temperature inversion creates stable layer at the ground level. Winds are de-coupled from the overlying atmosphere and below the conditions are calm. The dispersion potential is poor under these conditions and pollutants that are released closed to ground level tend to accumulate close to the point of release rather to than disperse. Surface dispersion in Durban are shallow and weak and dissipate soon after sunrise.

2.6.2. Meteorological data

AERMOD utilises hourly sequential upper atmospheric meteorological data for the calculation of vertical profiles of wind turbulence and temperature. There is a preference to use meteorological data for dispersion modelling that has been collected as close as possible to the Project site, however, the meteorological measurements should be inclusive of the various parameters necessary for incorporation into the model and suitably quality-assured. The nearest meteorological station in the vicinity of the Project site is the old Durban Airport station, however, this station was decommissioned in 2009. In order to make use of more recent meteorological data, and in accordance with the Code of Practice, site specific MM5 data for the years 2015-2017 was used for assessment purposes.

2.7. Dispersion modelling

The use of dispersion modelling focuses on mathematical equations to describe atmospheric dispersion of emissions and processes within the plume. This calculation further computes concentration at various locations. Whilst, there have been numerous studies conducted on dispersion modelling, only few have focussed on modelling of gaseous emissions (Ellis et al., 2001; Sivacoumar and Thanasekaran, 2001; Caputo et al., 2003). It's further noticeable that few studies measured particles concentration with gases. Most studies depicted differences in correlations between the concentration of gases and particulate matters. This is more evident on PM_{10} concentration and NO_2 concentration specifically in an urban environment (Hall et al., 2002).

Dispersion models are utilised by regulatory authorities for a number of reasons, but the outstanding use and significant one is an indication of ambient pollution levels. The regulation of emission is achieved by one of two approaches. This include controlling emissions directly or by setting the emission limit values on a specific pollutant. The limit setting includes the likelihoods of combinations of contaminant concentration including exposure time. Second method includes statistically-based exposure limits. The limit ranges from 15 minute (the 99-percentile sulphur dioxide), 24 hours (100 percentile hourly averaged limit). These limits also include annual averages set for deposition of sulphur and nitrogen oxide to the ground.

The AQMP must identify and reduce pollutants that may have a negative effect on human health and environment through industrial reduction strategies and fossil fuel emissions. An annual performance report on the implementation of the AQMP must be compiled by the regulating authority and be submitted to the EDTEA with relevant information that includes; air quality monitoring activities, compliance with ambient air quality standards and the air quality management initiatives undertaken for an annual period. A component of the AQMP may include air dispersion modelling which can be used in conjunction with ambient air quality monitoring to determine compliance with ambient standards. The AQMP should consider trans-boundary air pollution and international agreements such as the Montreal Protocol and the Stockholm Convention on Persistent Organic Pollutants (Department of Environmental Affairs and Tourism, 2007a)

Emissions discharged into the atmosphere are transported and remain airborne over long distances by large-scale air-flows and dispersed by small-scale air-flows or turbulence, which mix pollutants with clean air. This dispersion of emissions by the wind is a complex process due to the existence of various-sized eddies in air-flow. Under ideal circumstances in a laboratory the dynamics of turbulence and turbulent dispersion are some of the most difficult in fluid mechanics to model. There is no complete theory in existence that defines the association between ambient air concentrations of emissions and the causative meteorological factors including the processes. However, an atmospheric emission dispersion model which is a mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere attempt to simulate ambient air concentration. It estimates downwind emission concentrations based on the information provided about the pollutant and nature of the atmosphere using Gaussian-plume model.

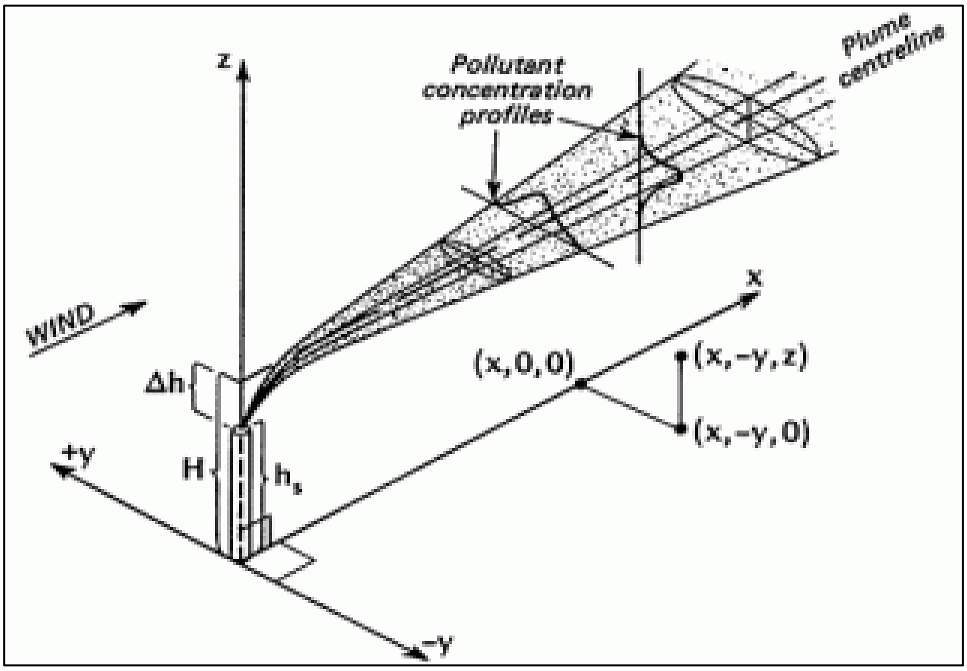


Figure 2-12: Gaussian plume distributions of pollutants from a stack source (Centre for Environmental Rights, 2019)

Gaussian-plume models are commonly utilised, well understood, easily applied, and until more recently been granted world-wide authorisation. The assumptions, errors and uncertainties of these models are understood, although they still suffer from misuse. Gaussian-plume models play a major role in compliance monitoring. However, they may not always be the best models to use and Hurley (2000) noted which particular models are not always selected on an objective scientific basis.

The Gaussian-plume formula is a resultant of assuming 'steady-state' conditions. That is, the Gaussian-plume dispersion formulae are not dependent on time, although they do represent an ensemble time average. The weather conditions are assumed to remain unchanged during the dispersion of emission from source to receptor, which is efficiently instantaneous. Emissions and climatological conditions can differ from hour to hour but the model calculations in each hour are independent of those in other hours. Owing to this mathematical derivation, it is common to refer to Gaussian-plume models as steady-state dispersion models. In practice, however, the plume characteristics do change over-time, because they depend on varying emissions and climatological conditions. One consequence of the plume formulation is that each hour the plume extends promptly out to infinity. Emission concentrations may then be found at points aloof for emitted pollutants to have reached them in an hour.

Steady-state models calculate emission concentrations for each hour from an emission rate and meteorological conditions that are uniform across the modelling domain. Consequently, they simulate hourly-average emission concentrations. The Gaussian-plume and advanced modelling are time-varying, changing from hour to hour. The term 'steady-state' should not be misinterpreted to mean that conditions are steady from hour to hour. The plume formula has the uniform wind velocity in the denominator and hence breaks down in calm conditions. It is usual to stipulate a minimum allowable wind velocity for the model (Ross, 2001).

Gaussian-plume models provide assumption that pollutant material is transported in a straight line instantly to receptors that may be several hours or more in transport time away from the source of emission. This assumption takes no cognisance of the fact that wind may only be blowing at 1 m/s and will only have travelled 3.6 km in the first hour. This means that plume models cannot account for causality effects. This feature becomes significant with receptors located at a distances of few kilometres from the source of emission. Gaussian-plume models 'break down' during low wind speed or calm conditions due to the inverse wind speed dependence of the steady-state plume equation, and this limits their application. Unfortunately, in many circumstances it is these conditions that produce the worst-case dispersion results for many types of sources. These models usually set a minimum wind speed of 0.5 or 1 m/s and sometimes overwrite or ignore input data below this with this lower limit. In moderate terrain areas, these models will typically overestimate terrain impingement effects during stable conditions because they do not account for turning or rising wind caused by the terrain itself. CTDM and SCREEN are designed to address this issue (Godfrey and Scire, 2000).

Gaussian steady-state models have to assume that the atmosphere is uniform across the entire modelling domain, and that transport and dispersion conditions exist unchanged long enough for the material to reach the receptor. In the atmosphere, truly uniform conditions rarely occur. Water bodies, hills and other terrain features, differences in land use, surface characteristics, and surface moisture (e.g. irrigated vs unirrigated agricultural fields) all produce in homogeneities in the structure of the boundary layer which can affect pollutant transport and dispersion.

Convective conditions are one example of a non-uniform meteorological state that Gaussian-plume models cannot emulate. For tall stacks (>100 m) under convective conditions - overseas studies have shown that under prediction can occur in the near field (Luhar and Hurley, 2002). The notable exception to this is AERMOD, which has a specially developed, 'add-on' probability density function.

In calculating each hour's ground-level concentration, the plume model has no memory of the contaminants released during the previous hour(s). This limitation is especially important for the proper simulation of morning inversion break-up, fumigation and diurnal recycling of pollutants over cities. Advanced Dispersion Models are commonly used for regulatory impact assessments, other less restrictive dispersion models are available. These have been in use for scientific research for decades, and are now beginning to enter the regulatory arena. Their use avoids most of the limitations associated with steady-state models. Although their demands on resources (human, computational and data) are far higher than those of Gaussian-plume models, computer power is also increasing rapidly, making this aspect less of an issue. However, the use of advanced models does involve much greater meteorological input data demands. Advanced dispersion models may be grouped into three categories depending on the way the air pollutants are represented by the model.

Particles; Pollutant releases, especially those from point sources, are often represented by a stream of particles (even if the pollutant is a gas), which are transported by the model winds and diffuse randomly according to the model turbulence. Particle models are computationally expensive, needing at least 105 particles to represent a pollutant release, but may be the best type to represent pollutant concentrations close to the source.

Puffs; Pollutant releases can also be represented by a series of puffs of material which are also transported by the model winds. Each puff represents a discrete amount of pollution, whose volume increases due to turbulent mixing. Puff models are far less computationally expensive than particle models, but are not as realistic in their description of the pollutant distribution. However, they are often more than adequate, and are used for regulatory purposes.

Grid; Pollutant distributions are represented by concentrations on a (regular) three-dimensional grid of points. This is the cheapest formulation computationally, but difficulties arise when the scale of the pollutant release is smaller than the grid point spacing. This method is commonly used for airshed modelling and the simulation of chemical transformations is most straightforward in a grid model.

Efforts to increase computational efficiency while still retaining a realistic description of pollutant dispersion mean that many models are a combination of the above-mentioned types. For example, the 'PARTPUFF' approach, according to Hurley (1994), represents the pollutants as Gaussian puffs in the horizontal and particles in the vertical, particle models usually convert particles to a gridded distribution when the particles have dispersed sufficiently (Lyons et al., 1994), and grid point models often represent sub-grid-scale releases as particles or puffs.

The dispersion of pollutants in the atmosphere is noticeable by looking at the pattern of the plume once emitted from the stack. Noticeably, is the size of the plume carried out by the wind due to dispersion. Dispersion of pollutants leads to the minimization of pollutants concentration in the smoke along with the increase of the distance from the emission source (Turner, 1994; Matthias et al., 2006).

2.7.1. Gaussian Model

Gaussian model is mostly used on emission dispersion especially for regulatory purposes. This model form part of Lagrangian and Eurelian Models, both models are formulated on basis of Gaussian distribution of plume in vertical and horizontal directions under steady state conditions. The normal distribution of plume is affected by turbulence reflection for the surface of earth. The size of the plume specifically the width determined by σ_y and σ_z, this is defined either by stability classes or travel time from the sources (Pasquill, 1961). The disadvantage of plume modelling in relation to modelling of dispersion of particulate matter is the use of steady state approximation which do not consider the time required for the pollutant to travel to the sensitive receptors. In this regard, aerosol dynamics should be calculated using post-processing treatment of the results. Gaussian models which consider diffusion and advection of the pollutants are now developed and consider the physical processes such as deposition and chemical reactions. The equations used from Gaussian plume indicates no interaction between plumes, which can become significant within urban environment. The chemistry and physical processes within the plume and dispersion around the building are modelled using algorithms. The modification of dispersion coefficient, σ_y and σ_z, determines the effect of wakes from buildings. It's further noted that Gaussian equation is unable to calculate recirculation effect which results from multiple buildings or where multi-intersections exist. The restraint understood in the Gaussian Plume models are mitigated by estimating the emission as a series of puffs over a specific period. This allow the wind speed to be varied, in this method each puff behaves according to the Gaussian dispersion equation and the overall contribution of the source is calculated by integration of the individual puffs with respect to time and summation of the contribution puffs at the receptor position (Pasquill, 1961). Multiple sources of plumes are in most cases used to calculate the concentration of pollutants in urban environment. It is further noted that additional limitations of the Gaussian treatment is that the Gaussian models are not designed to model the dispersion under low wind conditions or where modelled sites are in close proximity to the source. In this regard the distance should not be less than 100m. Gaussian models have depicted over prediction of concentrations in low wind conditions

(Benson, 1984; Sokhi et al., 1998). Modelling of pollutants at low concentrations under low wind speed conditions is achieved by using hybrid models which use a combination of Gaussian plume and puff models (Sharan et al., 1996; Thomson and Manning, 2001). Further limitation results from the simplified treatment of turbulence and meteorology when pollutants concentrations are calculated over an hourly average. Gaussian plume equations assume a homogeneous wind field, in this regard it is not recommended to be used for far field modelling since the meteorology is expected to vary over large distances Caputo et al. (2003) noticed that four Gaussian models calculated non-zero concentrations for the downwind domain and suggested a limited distance of few kilometres from the source.

In New Zealand's South Island the community suffers from intolerable exceedances of particulate matters during Winter seasons. The air quality guideline for PM_{10} over a 24-Hour average of $50\mu m/m^3$ is exceeded 30 times in Winter seasons. The frequency of exceedances was noted during 1988 to 1999 period. The exceedances of PM_{10} resulted to several studies being conducted to establish the harmful effect of PM_{10} (Vedal, 1997). Particulate Matters with aerodynamic of 10µm is recognised as a public concern and aesthetic challenge due to its characteristic of decreasing visibility which create brown haze over the City. The study conducted in New Zealand demonstrated industrial and domestic heating usage of coal as fuel source is the main contributing factor to elevated emissions of PM_{10} (Schwartz et al., 1996). Studies conducted demonstrated that the total number of emissions recorded for industrial sources and motor vehicles was 13,400 kg per day. During the presence of temperature inversion Particulate Matters becomes trapped near the ground surface. Temperature inversion has been in existence and documented since 1930s (Sparrow, 1968; Moody, 1983). The study concluded that the City's air quality is poor and has deteriorated by 69% of the community, this require additional emission abatement controls to be implemented to existing boilers (Wilton and Ayrey, 2000). The implementation of additional abatement control technologies intends to reduce the number of exceedances of PM_{10} concentration. The study resulted to an introduction of a policy which its aim included banning the use of coal as dirty fuel. The impact of coal fired boiler require atmospheric impact assessment in terms of dispersion modelling. In the urban environment accurate prediction of boundary layer should form part of dispersion modelling. Data collected for modelling purposes in rural environment cannot be utilised for development of boundary layers for urban layers (Fisher et al., 2006). The modelling system used for the study area evaluated the transportation of and dispersion of particulate matters and predicted the effect of pollution reduction possibilities. The first episode of the study was conducted for a 6-day PM_{10} episode. The modelling was implemented during of July to August. The results depicted a maximum 1-hour and 24-hour PM_{10} concentration of 368 and $107\mu g/m^3$, respectively. It was noted that CO concentration depicted exceedances of standards. The modelling took into consideration meteorology of the study area. Precise simulation of PM_{10} dispersion required consideration of wind and temperature structure within the study area for the model to produce representative results. It was noted that during the period of calm, cold and clear conditions the surface level temperature inversion developed through radiational cooling (Tapper, 1990).

The most significant atmospheric conditions are wind direction, vertical temperature and wind speed structure of the immediate atmosphere. However, when heat drops with height at a frequency higher than the adiabatic lapse rate, the atmosphere is in unbalanced equipoise and vertical motions are improved. The concentration of an air contaminant at a specified position is a result of a number of variables, comprising of the atmospheric conditions, emission rate and the distance of the receptor from the source (Melli and Runca, 1979). Miller and Hively (1987) stated that this keeps concentration of pollutants weak or moderate at surface level. On the other hand, if temperature drops with height at a rate inferior than the adiabatic lapse rate or rises with height vertical motions are decreased. This will possibly lead to excessive contamination concentrations.

Atmospheric air quality dispersion models are frequently used to estimate the decrease that has happens throughout the transportation of contaminant from a manufacturing source, and subsequently to project the contaminant concentration at ground level. Diffusion models regularly combine terrain, physical, meteorological and chemical properties of the sewage and source design to simulate the development and transportation of contaminant plumes. Environmental regulations globally are behind the increasing distress about the legitimacy and consistency of air quality diffusion models (Benarie, 1987). Gaussian plume model practices a genuine explanation of diffusion, where it epitomises an analytic solution to the dispersion equation for unrealistic situations. The model assumes that the atmospheric turbulence is mutually standardised and stationary. Authentically nothing of these conditions is entirely contented. Nevertheless, Gaussian plume model has been used effectively for rural configurations huge justification has been executed on tracer experiments done in Kincaid and Prairie grass. Gaussian model has similarly been tested in contradiction of tracer experiments in metropolitan surroundings. The model is still the technique of preference for many, particularly for the estimation of annual averaged concentration. It is the utmost extensive used plume model (Hanna et al., 1996; Kumar, 1998). In the Gaussian plume diffusion model the concentration of contamination downwind from a source is preserved as accumulating outward from the centreline of the plume subsequent to a standard arithmetical distribution. The plume spreads in both the vertical and horizontal directions. In the model, establishing the contaminant concentrations at ground-level below an elevated plume comprises two major steps namely the elevation to which the plume rises at a specified downwind distance from the plume source is evaluated. The evaluated plume rise is added to the elevation of the plume's source point to achieve effective stack height. And the second step involves the ground-level contaminant concentration below the plume at the specified downwind distance is anticipated using the Gaussian dispersion equation (Beychok, 2005).

2.7.2. Performance evaluation of AERMOD and CULPUFF

In formulating a model testing procedure it is imperative to attempt and generate a programme comprising a comparatively limited number of dispersion calculations, but which is adequate to expose any critical variances between models. It is simple to carry out large numbers of calculations but to then be unable to understand the results easily unless these can be summarised to some simpler comprehensible arrangement. This is fundamentally the procedure implemented by Hanna et al. (1993), in studying model comparisons with experimental data, which are both numerous and scattered. The characteristics of dispersion model calculations that mostly affect modelling practices were identified and include the basic rates of plume emission dispersion in typical neutral, stable and unstable atmospheric conditions for low and high point sources, the plume elevation, large buoyant plume interaction with, and penetration of, the top of the boundary layer, the building downwash, the effects of terrain, surface roughness, ground level concentration, coastal effects and multiple sources of pollution (Olesen, 1995). It is probable to develop a fairly limited set of interconnecting calculations, which should readily expose any major variances in behaviour between these fundamental aspects of a model. This possibility lies with the number of test cases which can be assessed by direct comparison without further recourse to complex analysis. The test conditions used for flat terrain were:

The first being the four boundary layer states, neutral strong wind and neutral, stable and unstable light wind for single condition calculations. The weather constraints, based on examples from site data, were fixed for these cases. The low wind velocity which also use three boundary layer depths to assess the interaction of a large buoyant plume. Emissions discharges from high stacks at two heights, low which is 40m and 150m, each with a zero and a high buoyancy discharge. The two building heights attached to the lower point source of

25m and 35m, of cubical and of wide form (Hanna et al., 2001). The impact of topography was taken into consideration and studied using a single, neutrally buoyant emission release from a 40m stack, over terrain derived from a single real site. The general and vertical topography scale were varied to provide a range of surface slopes and comparative heights of stack and terrain. It was felt that a real topography depicted a more accurate test of the models than a simple, unrealistic form (Bennett et al., 1996).

2.7.2.1. Winter Validation Tracer Study

The Lagrangian puff model, AERMOD as well as CULPUFF are steady state models approved by United States Environmental Protection Agency (US EPA) regulatory purposes. AERMOD modelling software was invented by The American Meteorological Society and EPA (Cimorelli et al., 2004). The objective was to incorporate planetary boundary layer into compliance monitoring model. The model took into consideration the emission released from point sources for instance the stack, the area sources as well as the volume sources. The terrain is also taken into consideration whether simple or complex. The development of AERMOD intended to replace the Industrial Source Complex Version 3 (ISC3) model. The distance used near field is normally <50km and far field is >50 km respectively. AERMOD is the Environmental Protection Agency's (EPA) chosen model for near field determination of regulatory compliance model (<50 km). The studies conducted indicated that CULPUF has also been used for non-regulatory purposes (Rood et al., 2008). Examples of retrospective assessment includes the demonstration of regulatory compliance as well as incidence analysis whereas the example of epidemiological studies includes dose reconstruction. Demonstration of regulatory compliance and accident consequence analysis are generally prospective assessments, whereas dose reconstruction and epidemiological studies are generally retrospective in nature. The assessment questions for the prospective and retrospective analyses are fundamentally different and require different model performance objectives (Grogan et al., 2007). The assessment questions for prospective analysis were totally different from retrospective assessment**.** The questions on prospective analysis tried to established whether emissions would exceed the ambient air quality standard or result in significant impact. It was noted that for retrospective assessment the questions were an unbiased approximation of the temporal and spatial distribution of emission concentration and deposition. For the prospective analysis, the assessment question is whether air emissions will exceed ambient air quality standards, or result in impacts that are unacceptable. This assessment question can initially be addressed using conservative assumptions and simple models. It may not be critical to accurately estimate temporal and spatial variations in concentration, as long as the estimated impacts do not exceed the standards within a safety margin of error. More detailed model applications may be required if simple models cannot demonstrate that regulatory standards are achieved. For a retrospective assessment, the assessment question is an unbiased estimate of the temporal and spatial distribution of concentration and deposition. Examples of a retrospective analysis include the dose reconstructions performed at U.S. Department of Energy Facilities (Fox et al., 2009).

2.7.2.2. Modelling Point Source Plume

Emissions form industrial usage of coal adversely effects the environment, human health, damages plants, reduces visibility and negatively impact on economic development and growth. It’s further noted that it devalues properties and quality of life throughout the world.

Point source emissions are released at high altitudes as a result emission contribute to regional air pollution. The regulators require emission data to evaluate whether emission releases from stacks has adverse health to the community or environment. Modelling of emissions is a legal requirement to quantify emission emanating from coal fired fuel boilers (Kingsland et al., 1998). Regulation of industrial emission protect human health and the environment. Industries are legally required to obtain emission permits to demonstrate compliance with regulations. Prior to obtain atmospheric emission permit industrial facilities require to conduct dispersion modelling to assess the impact of emission to the environment.

Dispersion of plume emission depends on atmospheric conditions which is a driving force in the transportation of emissions. Meteorological data is the requirement when conducting dispersion modelling.

2.7.3. Modelling of Pollutants dispersion

Pollutants are defined as man-made non-natural substances resulting to adverse effect to health and environment as a result of concentration higher than expected from natural cause. The main pollutants released from burning of fossils fuels are carbon monoxide, nitrogen dioxide, particulate matter whether PM_{10} or $PM_{2.5}$ and sulphur dioxide. These pollutants have the possibility to further interact with the environment and thereafter generate secondary pollutants and effect to the environment. Secondary effect which results from interaction with environment include the greenhouse effect, acid rain and smog (Radovic and Schobert, 1997). Sulphur dioxide is released from combustion of sulphur containing fossil fuels. This refers to sulphur content of above 6%. The exposure to high concentration of sulphur result to respiratory problem. Sulphur is also a major cause of acid rain which is formed when sulphur dioxide combines with water droplets in the atmosphere to form sulphuric acid (H_2SO_4). Once inhaled into the human body sulphuric acid will be binding in the lungs and results to respiratory diseases. The impact caused by (H_2SO_4) to the environmental include corrosion of materials and building and degradation of the quality of water. Radiation balance of the atmosphere is also affected by the presence of SO_2 and other tropospheric aerosols containing sulphur (Matthias et al., 2006).

The dispersion modelling system specifically AERMOD takes into consideration local effects that influence emission dispersion. The factors considered include the influence of building and obstacles, the local terrain, building downwash, buoyancy-induces emission dispersion, chemical reaction and deposition (Zannetti, 2013). Accuracy of the results depends on the number of factors which include source emission data, the quality of meteorological data for the study area.

Africa as a continent is currently facing rapidly growing population growth, predictions depicts major growth between 2010 and 2050 (UN, 2012; Desa, 2013). It’s noted that as population grow rapidly so as the pollution as a result of industrialisation, urbanisation, growing usage of various mode of transports and continued industrial and domestic use of coal and biomass as fuel sources(Economic and Division, 2012; Heilig, 2012; Desa, 2014). Industrialisation has been identified as a contributing factor for global demographic changes, characterised by elevated upper respiratory illnesses. (Omran, 1971; Boutayeb, 2006), confirmed that developing countries like South Africa demonstrate double burden of communicable disease which results from poor environmental conditions, living conditions, infrastructure. Communities especially near industrial areas are experiencing poor indoor and outdoor air quality (Bailis et al., 2005; Barnes et al., 2010). According to the World Health Organisation (WHO) African countries face most of the death owing to increased cardiovascular diseases, cancer and respiratory disease (Aikins et al., 2010b, 2010a). Exposure to industrial emissions has the possibility to aggravate upper respiratory conditions. Particulate Matter whether PM_{10} or $PM_{2.5}$ emission has been identified as the health indicator for air quality, as such it’s currently used by regulator worldwide in setting air quality guidelines. The particulate matter guideline that has been developed includes total suspended particulate matter and particulate matter with aerodynamic between 1 and 100µm. Inhalable fine particulate matters with aerodynamic of less than 10 µm with diameter less than 2.5 has become the matter of concern, this included ultrafine particles with aerodynamic less than 1 µm. Studies emanating from developing countries indicate that particulate matter cause a wide range of long- and short-term health effects. The two major studies were conducted by Havard Six Cities (Dockery et al., 1993)and the American Cancer Society Study (Pope et al., 1995). These results produced by these studies demonstrated major association between long-term exposure to particulate matter and pre-mature death as a result of cardiopulmonary diseases (Krewski et al., 2004). Another study conducted by American Cancer Foundation between 1982 and 2008 further demonstrated elevated lung cancer mortality rate for cardiovascular illnesses as a result of exposure to $PM_{2.5}$ (Turner et al., 2011). Air quality guideline for annual exposure as set by WHO for $PM_{2.5}$ and PM_{10} are 10 and 20 µg/m^3 respectively. It's further noted that the 24-hour mean exposure values for $PM_{2.5}$ and PM_{10} are 25 and 50µg/m^3, respectively (World Health Organization, 2006). These are interim standards for each country to achieve through setting its own stringent emission control practices. In countries where no standards exist, WHO guideline are utilised as point of reference for analysing PM compliance status. African countries have various climatic conditions, the Northern Africa dominated by Sahara has arid climate. Below the Sahara, semiarid transition which separates the desert rom the savanna and tropical rainforest exists. The area around the equator is noticeably the Intertropical Convergence Zone. It's where northern and subtropical winds meets (Giannini et al., 2008). Diverse climate conditions for African countries significantly influence dispersion of pollutants specifically PM. Noticeably, in countries that experience rain more often, elevated particulate matter emissions are experienced during winter season. Undoubtedly, North Africa is amongst the world's dust-emitting regions (Engelbrecht et al., 2001). The areas surrounding these regions are mostly affected by dust emissions specifically $PM_{2.5}$, emanating from soil particles due to mining activities. It's noted that the studies were conducted away from industrial activities and thus provides no true reflection of dust emissions emanating from boiler sources (Sinha et al., 2003).

2.7.3.1. Western Africa PM compliance status.

In noted that in Nigeria and Burkina Faso including population of lower socio-economic status in Ghana reported exceedances of PM standard. Nigeria with high population is dominated by high traffic congestion which results to elevated PM emissions (Baumbach et al., 1995). According to Baumbach et al. (1995), the daily TSP levels due to vehicular emissions increased up to tenfold to approximately 800µg/m^3. Adeleke et al. (2011) conducted 5 months of health impact assessment which encompasses dispersion modelling and reported elevated levels of 272.8, 217.4 and 117.7µg/m^3 for PM2.5, PM10 and TSP, respectively. Dust emissions monitoring was conducted by two different samplers from USA and UK with assistance from the World Bank. Both dust monitoring utilised gravimetric sampling methodology and light scattering, the results were 123.5 to 55.6 and 240 to 600µg/m^3, respectively (Ukpebor et al., 2006)

2.7.3.2. Southern Africa.

Comprehensive and operating PM monitoring network exists in South Africa, specifically in Cape Town and Johannesburg. Particulate Matter monitoring for $PM_{2.5}$ and PM_{10} was conducted in Qalakabotjha area to evaluate air quality improvement in the community resulting from upgrading the source of fuel usage from D-grade coal to low-smoke fuels (Engelbrecht et al., 2001). The results of the study demonstrated a reduction in PM emissions levels emanating from the low-smoke fuel source. The 24-hour urban concentration for PM 2.5 were 71 to 93 µg/m^3 over a 30-day period. In 2011, the study that was conducted by Worobiec et al. (2011) reported 24-hour average $PM_{2.5}$ of 65 µg/m^3 in Bethlehem, South Africa. This study concluded that PM_{10} was had significant contribution to PM_{20} owing to biomass burning specifically during the evening.

CHAPTER THREE

3. Stack Emissions

The methodology used during the stack emission testing including the emissions inventory is discussed in this chapter. Further discussions of the data which was obtained during the stack emissions testing are provided here.

3.1. Determination of the Boiler Capacity

The coal fired boilers considered in this research had a design rating which was greater than 10 MW net heat input (NHI), but less than 50 MW net heat input. Therefore, they were classified as a Controlled Emitters in terms of the national legislation known as the Declaration of a Small Boiler as a Controlled Emitter.

The calculations were based on the energy in the fuel being burnt in the boiler, and were therefore a reflection of the amount of energy in the fuel and not the amount of energy in the steam (which is known as the evaporative rating). Boilers are usually referred to by their size, which is measured in "Tonnes per Hour (TPH) and at 100 °C. Equations (3-1) and (3-2) were used in converting the industry standard of "Tonnes per Hour" to MW.

$$\mathrm{NCV} = \mathrm{GCV} - 2442 \times (\mathrm{H_2O\ in\ fuel} + 9 \times \mathrm{H_2\ in\ fuel}) \tag{3-1}$$

Where NCV is the net calorific value (kJ/kg), GCV is the Gross Calorific value (kJ/kg), H_2O is the total moisture in the fuel and H_2 is the total hydrogen in the fuel including hydrocarbons.

$$\mathrm{NHI} = \frac{\mathrm{M_f} \times \mathrm{NCV}}{3.6 \times 10^6} \tag{3-2}$$

Where NHI is the net heat input (MW), M_f is the mass flow rate (kg/hour).

The boilers were thus required to comply with emissions limits of 250 mg/Nm^3 for particulate matter (PM) and 2500 mg/Nm^3 for sulphur dioxide (SO_2) from November 2018.

3.2. Equipment Selection

3.2.1. Isokinetic Sampling Train

The sampling train consist of various components which include, a sampling nozzle, a heated probe, a filter, four impinger, a gas pump, a dry gas meter and a metering orifice. An S-Type pitot tube is attached on top of the sampling probe. A manometer is then connected across the metering orifice, this is used to indicate the flow rate.

The purpose of ensuring isokinetic conditions is to ascertain that sampling is executed at such a rate that the velocity and the direction of the gas entering the sampling nozzle is the same as that of the gas in the duct/stack at the same sampling point. This is achieved by ensuring that the duct is divided into equal areas:

- Need to sample at the minimum number of sampling points set out by the standard in order to get a proper representative sample due to uneven distribution of particles in gas stream
- Number of points depends on size of duct

The components of the sampling train are demonstrated in Figure 3-1.

The nozzle is sharp edged with smooth interior walls. Its shape provides minimum resistance when inserted into the sampling port.

The probe is either stainless steel or glass with sharp tapered (30° angle) leading to the edge. The probe is inserted into the stack together with the nozzle to draw the actual sample. Probe liner: Borosilicate or quartz-glass tubing with a heating system capable of maintaining a gas temperature between 480 and 900 °C.

S-Type Pitot tube measure differential pressure (stack velocity). As the air flows up from the stack the bottom of the S-type Pitot measures high pressure (Impact Pressure). The top of the S-type Pitot measures low pressure (wake). As the air passes through the probe then run through the filter assembly. The filter assembly is a glass leak-free assembly where particulate is deposited on a filter. Differential pressure gauge, this utilises an inclined manometer for velocity head reading.

Filter holder; Borosilicate glass with a glass frit filter support and a sealing gasket. The sealing gasket should be made of material that will not cause contamination of organic material into the gas stream. In this regard the gasket should be made of Teflon. The filter is designed to withstand high temperatures of at least two hundred degrees above the temperature of the sampled gas. The filter should be 99.7% efficient for particles of 0.3µ, The Impinger condenses the moisture in the stack gas, condenses liquid particulate matter and grab most of solid particulate which has passed through the filter. The glassware temperature is maintained at 4°C where water is at its most dense state and will be pulled out of the gas. The first and second impingers contain quantities of water or an appropriate trapping solution. The first impinger traps any material which would clog the nozzle of the second impinger. The first impinger removes 90% of the moisture in the gas. The second impinger removes 10% remaining moisture. The third is left empty or sometimes charged with caustic solution. The caustic solution is used as a contingency measure should the stack gas contain hydrochloric acid (HCl. The forth impinger is filled with silica gel which is a drying agent. The drying gel ascertain that the gas is completely dry when it reaches the dry gas meter.

The Umbilical Cord carries the sample gas line, the pitot tube tubing, the electrical heating control wiring. It is the flexible arrangement of the cable and lines wrapped in expandable durable nylon. Rotary vane pump which draws air from the source.

The Control console is composed of:

The pump, the console is equipped with a bypass for the pump which can recirculate part of the flow through the pump. The pump is also equipped with a valve in the bypass which is used to control the flow through the train.

Dry Gas Meter which is equipped with a dial type readout and inlet and outlet dial type thermometer which is used to measure the volume of the dry gas.

Temperature Controllers which control the temperature in the probe and hotbox.

Two flow control valves these are coarse valve and fine control valve.

Incline limb Manometer which measure the differential pressure created by the velocity of the stack and the velocity of the gas in the sample.

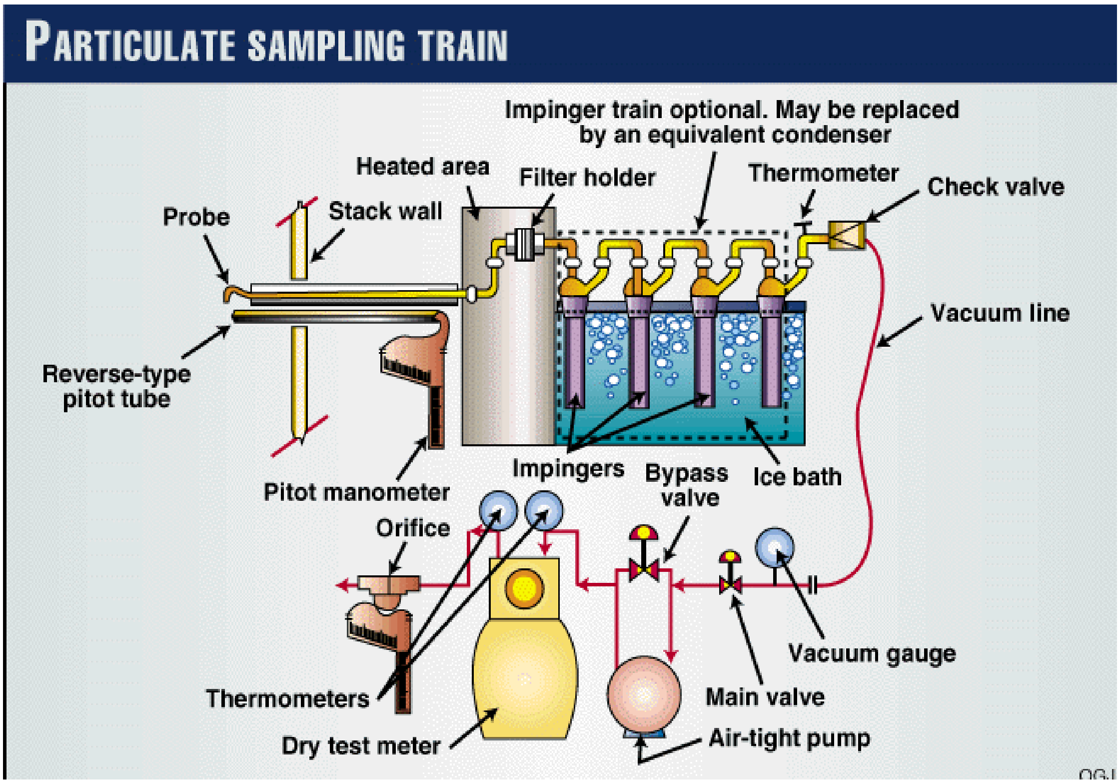


Figure 3-1: Particulate sampling train

Isokinetic sampling is required when the pollutants in a solid or liquid form is entrained in a gas stream. In order to achieve representative sample, it is important that sample should be conducted at the correct location on the stack sampled. The stack is divided into equal cross-sectional areas. The sample is collected at the centre of each area. The number of sampling ports is determined by the number of disturbances to flow. Points for consideration during sampling port location include the stack height, stack diameter, strength of the stack, work platform, port dimension. The sampling port are located at least two diameters downstream from an existing disturbance to flow, at least half a diameter upstream of a disturbance to flow. During sampling all port are utilised equally, and sampling should not be conducted through only one port. As indicated in Figure 3-2 the first sampling port is installed in the same plane as the ducting that joins the stack. The second sampling port is installed 90° to the first port. The diameters for both sampling port are 100mm. The sampling ports which are at the same height are installed >2diameters downstream of the nearest disturbance to flow.

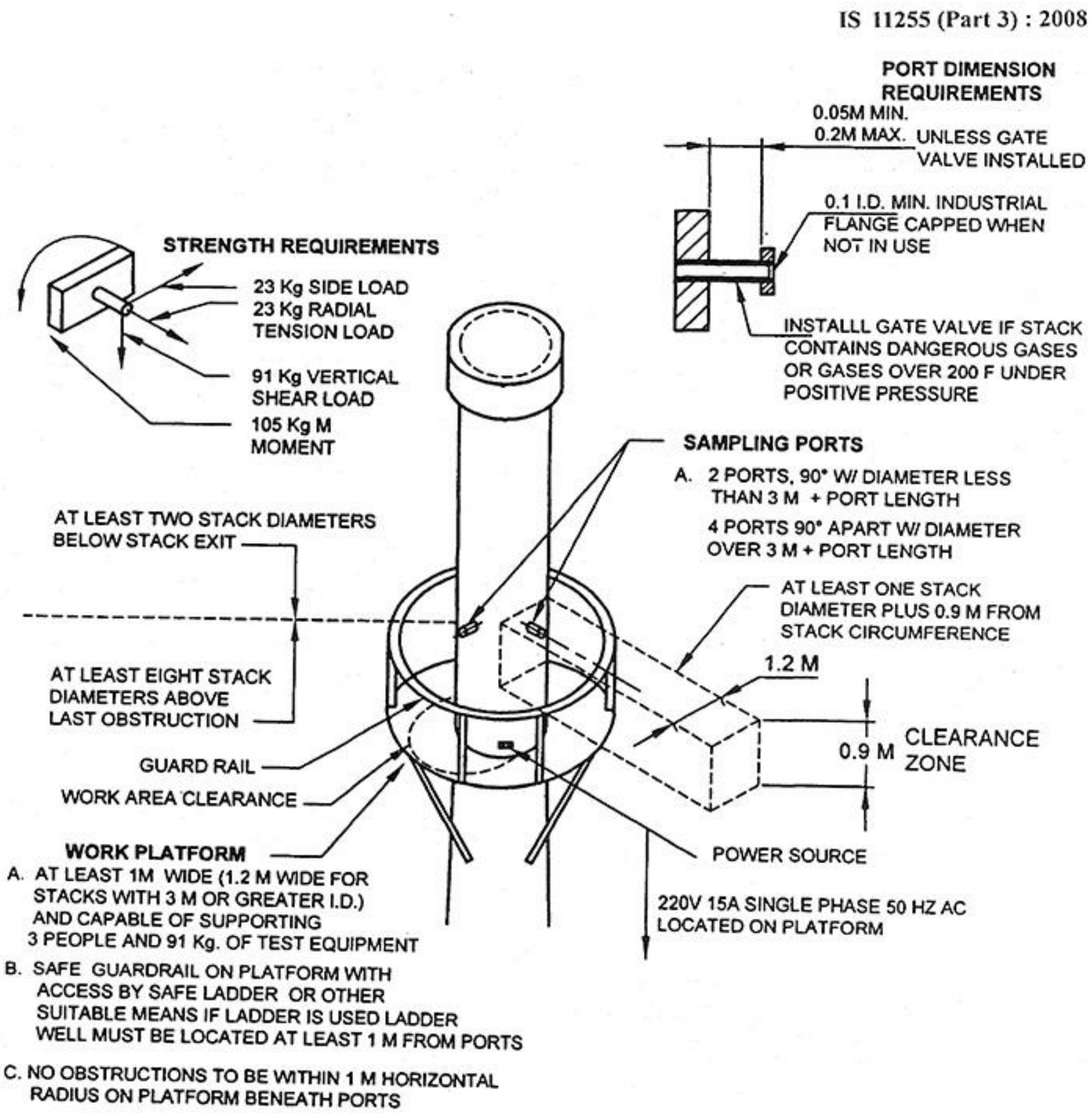


Figure 3-2: Sampling port location

3.3. General requirements for sampling points

ISO 9096:2003 requires that the following must be taken into consideration:

- The angle of gas flow should be less than 15° with regard to the duct axis;
- The local positive flow should be present
- The minimum velocity should be higher than the detection limit of the method used for the flow rate measurement (for pitot tube, a differential pressure larger than 5 Pa)
- The ratio of the highest to the lowest local gas velocity should be less than 3:1.

3.4. Sampling Procedures

The US EPA methods 1, 2, 3, 4, 6c and 7e were used as the procedures by which the stacks were sampled. Three tests were conducted on each stack in accordance with South African legislation. Each test involved one hour of sampling. The testing of particulate matter consisted of 24 sampling points across the diameter of the stack through two sampling ports situated at 90^{o} to each other. The gas concentrations were logged every 30 seconds.

In order to ensure that the methodology for testing conforms to South African legislation, the inclusion of international standards, sampling and analysis was undertaken in accordance to the sampling and analysis methods presented in Figure 3-3.

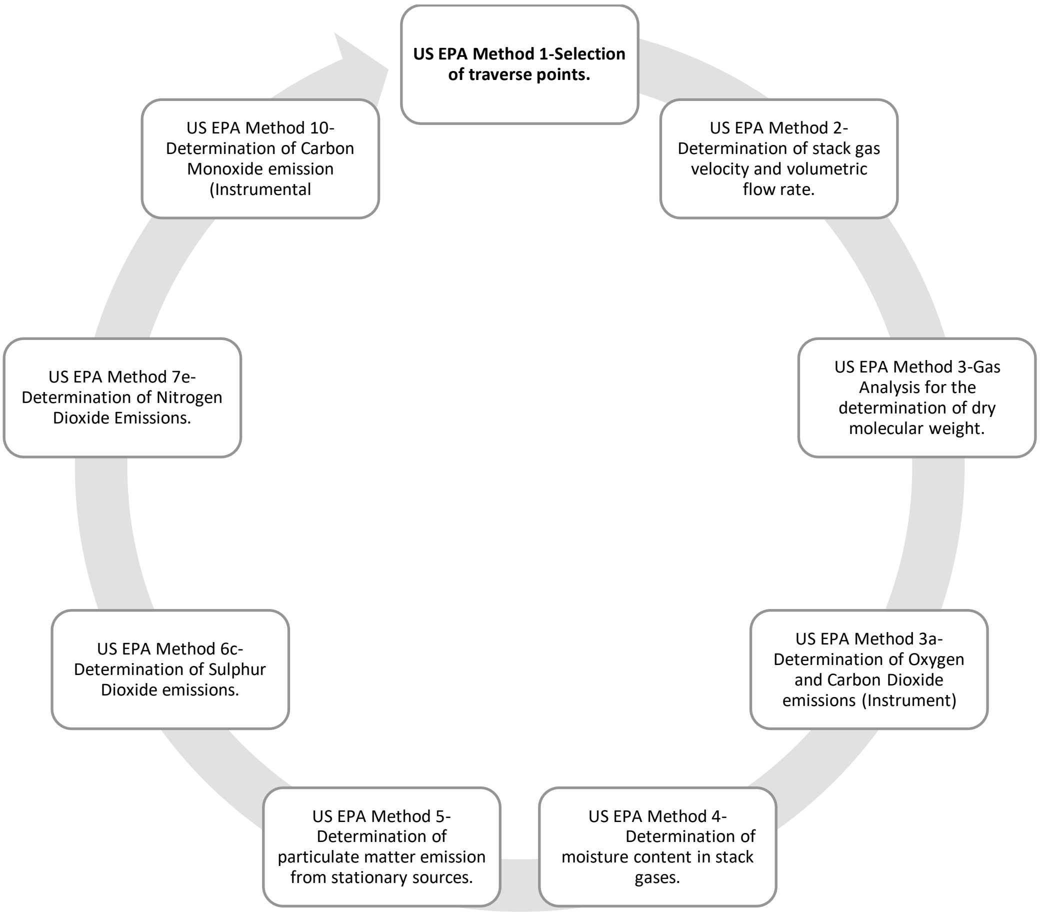


Figure 3-3: US EPA methods for sampling and analysis (United States Environmental Protection Agency, 2018c, 2018b, 2018a)

3.4.1. Good Practice Engineering Stack Height

Good Engineering Practice (GEP) stack height is the height necessary to ensure that emissions from stack do not result in excessive concentration of any air pollution in the immediate vicinity of the source as a result of atmospheric downwash, eddies or wakes which may be created by the source itself, nearby structure or nearby terrain obstacle. It is important to take note that GEP does not limit the physical height of the stack, but limits the credit that can be given for that portion of the stack that exceed GEP.

The GEP stack height can be determined using the following formula:

$$H_g = H + 1.5\ L \qquad \textbf{(3-3)}$$

Where:

H_g = good engineering practice stack height, measured from the ground-level elevation at the base of the stack

H = height of nearby structure (s) measured from the ground-level elevation at the base of the stack.

L = lessor dimension, height or projected building width of nearby structure (s).

3.4.2. Particulate Matter Sampling Procedure

The Particulate Matter samples were drawn isokinetically from within the stack in accordance to US EPA Method 5. The sampling train consisted of a stainless steel nozzle, probe liner and impingers, a metering console containing a calibrated dry gas meter, and a rotary vane pump. The heated probes and filter holders, as well as pitot tubes conformed to US EPA design specifications. The impingers were immersed in an ice bath and the forth impinger contained silica gel which facilitates complete condensation of water vapour from the stack gas stream.

High purity pre-weighted glass fibre thimble and a disc filter were used to collect the particulate matter in the sampled flue gas. The filters were capable of operating at temperatures of up to 500 °C without any filter loss, and had a retention of 99.9 % of particles greater than 0.3 µm. No deviation was encountered during the sampling.

3.4.3. Gas Emission Sampling Procedure

Gas sampling was performed isokinetically in order to take a representative sample of the gas, liquid phase mists and solid phase material. Isokinetic sampling is achieved when the gas enters the sampling nozzle at the same velocity and direction as the gas travelling in the duct. In addition, to allow for non-uniformity of distribution, the samples were obtained from multiple sampling points across the sampling plane in order to give an overall average of the emissions. The sampling included different impinger solutions which reacted with targeted gas species. The solutions were analysed in a laboratory to determine the species concentrations.

The samples for gases (CO, SO_2, NO_x, CO_2 & O_2) were drawn from within the stack according to the US EPA Methods 3, 6C, and 7E using an ECOM CN gas Analyser and Testo 325-I SO_2 Analyser. The Summary of the US EPA methods, parameters, impinger solutions, description of methods as well the laboratory analysis is shown in Table 3-1.

Table 3-1: Typical US EPA Methods and determinants for sampling

US EPA Method	Parameter	Impinger solution(s)	Method description	Laboratory analysis
1	Site/port selection		Sample and velocity traverses for stationary sources	
2	Flow		Determination of stack gas velocity and volumetric flow rate	
3	O_2, CO, CO_2		Gas analysis for carbon dioxide, oxygen, excess air, and dry molecular weight	
4	Moister	Deionised water	Determination of moisture content in stack gases	
5	Particulate matter (PM)	Deionised water	Determination of particulate matter emissions from stationary sources	Filter drying, desiccation and weighing.
6C	SO_2		Determination of sulphur dioxide emissions from stationary sources (instrumental analyser procedure)	
7E	NO, NO_2, NOx		Determination of nitrogen oxides emissions from	

			stationary sources (instrumental analyser procedure)	

The sampling ports were located along the boiler stack. The port conformed to US EPA Method 1 and was able to acquire a representative sample from the allocated location. The scaffold platform was provided, thereby facilitating the access to the sampling ports. This provision enabled the samples to be taken from multiple points across the sampling plane, which ensured a representative average of the emissions from the stack. The sampling procedure went on without any deviation. The sampling procedure consisted of three runs, with the duration of each run being 60 mins as per the legislated sampling requirements.

Emission Limit Values and reported results are expressed on an hourly average basis in mg/Nm^3 under conditions of 10 % O_2, 273 K and 101.3 kPa as per the category for "Solid fuel-fired small boiler", published in Government Notice Number 831, Government Gazette Number 36973 of 1 November 2013.

There was no limit applicable to NO_2 emissions from boilers in the Declaration of a Small Boiler as a Controlled Emitter. However, the limit of 1100 mg/Nm^3, which is applicable to large combustion installations larger than 50 MW was used, as a guideline for acceptable NO_2 emissions. The results obtained are the indicative of the conditions that prevailed during the sampling periods.

3.5. Determination of Pollutant Concentrations

The pollutant concentrations are reported in mg/Nm^3 and referenced to a specific concentration of oxygen. The concentrations are converted to absolute emissions. In this process, the initial step is to reverse the oxygen normalisation so that the concentration is reported in mg/Nm^3 without oxygen normalisation.

Equation (3-4) presents the formula which demonstrates an oxygen normalisation process.

$$\frac{21 - O_{2\text{reference}}}{21 - O_{2\text{measured}}} \tag{3-4}$$

In order to un-normalise the emissions, the inverse of Equation (3-4) is used. This yields Equation (3-5).

$$\frac{21 - O_{2\text{Measured}}}{21 - O_{2\text{referenced}}} \tag{3-5}$$

Equation (3-6) shows the calculation of the concentration with no oxygen normalisation, where the pollutant concentration is 100 mg/Nm^3 at 10 % oxygen. In this case, the measured stack emission concentration is 20 %. The calculation in equation (3-6) is based on Equation (3-5).

$$100\,\frac{\text{mg}}{\text{Nm}^3} \times \frac{21 - 20}{21 - 10} = 9.1\ \frac{\text{mg}}{\text{Nm}^3} \tag{3-6}$$

The absolute hourly emissions is calculated according to Equation (3-7), and this is done by incorporating the concentration obtained in Equation (3-6). For example, if the average flow rate obtained during stack emission testing at both actual and normal conditions is 21079 Nm^3/h, then the absolute hourly emissions becomes:

$$9.1\,\frac{\text{mg}}{\text{Nm}^3} \times 21079\,\frac{\text{Nm}^3}{\text{h}} = 191819\,\frac{\text{mg}}{\text{h}} = 0.19\,\frac{\text{kg}}{\text{h}} \tag{3-7}$$

The longer the operation period of the emission unit, the higher the quantity of emissions released. Based on this principle, for the emission unit that operates for 8 hours per day and 344 days per annum, Equation (3-8) can be used.

$$0.19\,\frac{\text{kg}}{\text{h}} \times 8\,\frac{\text{h}}{\text{day}} \times 344\ \frac{\text{days}}{\text{yr}} = 523\ \frac{\text{kg}}{\text{yr}} \tag{3-8}$$

When the flow rate at actual conditions is provided, the ideal gas law is used to convert the flow rate at actual conditions to normal conditions i.e. 273 K (0 °C) and 101.3 kPa. Equation (3-9) is therefore used.

$$V_{\text{STP}} = V_{\text{actual}} \times \left(\frac{273}{273\ + \text{T}}\right) \times \ \left(\frac{\text{P}}{101.3}\right) \tag{3-9}$$

Equation (3-10) demonstrates the calculation of the flow rate at actual conditions of 28800 m^3/h and the stack temperate and pressure of 100 °C and 101.3 kPa respectively.

$$V_{STP} = 28800\,\frac{m^3}{h} \times \left(\frac{273}{273\ +100}\right) \times \ \left(\frac{101.3}{101.3}\right) = 21079\,\frac{Nm^3}{h} \tag{3-10}$$

In the cases where the gas flow is not provided, the gas velocity and the stack diameter can be used to calculate the flow rate. The area is first calculated using Equation (3-11), taking into consideration that the stack diameter is 1 m.

$$\text{Area} = \frac{\pi D^2}{4} = \frac{\pi(1^2)}{4} = 0.8\ m^2 \tag{3-11}$$

Assuming that the gas velocity is 10 m/s, Equation (3-12) can be used to determine the flow rate by incorporating the area obtained in Equation (3-11).

$$10\ \frac{m}{s} \times 0.8\ m^2 = 8\ \frac{m^3}{s} \tag{3-12}$$

Equation (3-13) shows the conversion of the flow rate obtained in Equation (3-12) into hourly flow rate.

$$8\ \frac{m^3}{s} \times 3600\ \frac{s}{h} = 28800\ \frac{m^3}{h} \tag{3-13}$$

3.5.1. Conversion of atmospheric pollutant concentration from mg/Nm^3 to ppm.

When demonstrating emission concentration, it is important to understand that the concentration format which is weight per volume i.e. µm/m^3. Measurements are presented in this format in parts per million (ppm)

When units of measurement are presented in a different format and require conversion the following Table 3-2 is used. This table demonstrates the conversions of different masses to those typically used.

Table 3-2: Conversion of Units

Units		Conversion		
Name	Symbol	g	mg	µg
grams	g	-	10^3	10^6

milligrams	mg	10^{-3}	-	10^3
micrograms	µg	10^{-6}	10^{-3}	-
kilograms	kg	10^3	10^6	10^9
pounds	lb	453.59	453.59×10^3	453.59×10^6

The ppm measurement is independent of temperature or pressure. When dealing with a liquid which dissolved in another liquid material within another solid material, then 1 ppm is one millionth of the overall mixture mass. If dealing with vapours or gasses, 1ppm is one millionth of the volume of the gas.

The assumption is that the ambient pressure is at 1 atmosphere and temperature at
25°C (273.15+25) as recommended by the WHO.

SO$_{2}$: mg/Nm^3 Conversion to ppm for boiler 1

mg/Nm^3 = ppm

$$\mathrm{ppm} = \frac{\mathrm{mg}}{\mathrm{Nm}^3} \times \frac{22.4}{\mathrm{M_W}} = 1036.25 \times \frac{22.4}{64} = 363\ \mathrm{ppm} \tag{3-14}$$

SO$_{2}$: mg/Nm^3 Conversion to ppm for boiler 3

$$\mathrm{ppm} = \frac{\mathrm{mg}}{\mathrm{Nm}^3} \times \frac{22.4}{\mathrm{M_W}} = 9.39 \times \frac{22.4}{64} = 3.28\ \mathrm{ppm} \tag{3-15}$$

SO$_{2}$: mg/Nm^3 Conversion to ppm for boiler 4

$$\mathrm{ppm} = \frac{\mathrm{mg}}{\mathrm{Nm}^3} \times \frac{22.4}{\mathrm{M_W}} = 73.6 \times \frac{22.4}{64} = 26\ \mathrm{ppm} \tag{3-16}$$

NO$_{2}$: mg/Nm^3 Conversion to ppm for boiler 1

$$\mathrm{ppm} = \frac{\mathrm{mg}}{\mathrm{Nm}^3} \times \frac{22.4}{\mathrm{M_W}} = 200.57 \times \frac{22.4}{46} = 98\ \mathrm{ppm} \tag{3-17}$$

NO_2: mg/Nm^3 Conversion to ppm for boiler 3

$$\text{ppm} = \frac{\text{mg}}{\text{Nm}^3} \times \frac{22.4}{M_W} = 181.1 \times \frac{22.4}{46} = 88.1\ \text{ppm} \tag{3-18}$$

NO_2: mg/Nm^3 Conversion to ppm for boiler 4

$$\text{ppm} = \frac{\text{mg}}{\text{Nm}^3} \times \frac{22.4}{M_W} = 215.18 \times \frac{22.4}{46} = 105\ \text{ppm} \tag{3-19}$$

3.6. Emissions Inventory

The key emissions characteristics associated with combustion sources or other discharge arrangements which affect dispersion of emissions include:

- Stack dimensions (m): Effective stack height, effective width and the vertical profile of the atmosphere can significantly affect dispersion of pollutants;
- Exit gas velocity (m/s): Gas velocity (correlated to stack diameter) provides plume momentum, influencing vertical (and horizontal) dispersion;
- Exit gas temperature (K): Affects the buoyancy of the combustion gas and thus the vertical dispersion of pollutants; and,
- Emission rate (g/s): Proportional to the associated ground level concentration (GLC) of a particular pollutant (assuming conservation of mass within the dispersing plume).

3.7. Applicable emission limits for coal-fired boilers

Table 3-3 shows the comparison of the emission limits for the existing and new plant standards for controlled emitters (DEA government Notice No. 831, 01 November 2013, Government Gazette No. 36973. “Declaration of a Small Boiler as a Controlled Emitter and Establishment of Emissions Standards”). The results presented in Table 3-3 are for Small boilers, fuelled with solid fuels. In addition, they are specifically for small boilers fuelled with hydrocarbon based solid fuel, excluding biomass.

Table 3-3: Emission limits for the new and existing plants

Substance or mixture of substances		Plant status	Limit value dry (mg/Nm^3 at 273K, 101.3 kPa and 10 % O_2)
Common name	Chemical/commonly used name		
Particulate matter	PM	New	120
		Existing	250
Sulphur dioxide	SO_2	New	2800
		Existing	2800

3.8. Results and discussion

Table 3-4 shows the point source emissions parameters. The concentration of emissions from the combustion of coal fired boilers were isokinetically measured from the three-point sources linked to boiler 1, boiler 3 and boiler 4. It is important to note that there is no link to boiler 2 as it was not in operation during the stack emission testing. The point sources imply a single identifiable source at a fixed location from where pollutants may be discharged to atmosphere. The stack emission measurements consisted of three types of pollutants namely sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter. The measurement of emissions distribution required the physical stack parameters such as the location of each stack depicted using x and y coordinates, base elevation, the release height, emission rate, gas exist temperature, gas velocity that emitted from stack and the diameter of stack.

Table 3-4: Point source emissions testing results

Parameters	Units	Boiler		
Source:	-	**Boiler1 (Main Stack)**	**Boiler 3**	**Boiler 4**
Source ID:	-	SV1	SV2	SV3
UTM Coordinates:	E	304756.90	304704.00	304704.00
	N	6689723	6689723	6689723
Stack Height:	m	47.5	27.5	30.5
Stack Diameter:	m	2.6	0.8	1.2
Height above nearby building		55	55	55
Stack Area:	m^2	5.31	0.50	1.13
Exhaust Temperature:	C	177.2	47	231
Stack Temperature:	K	450.2	320	504

Normal Exhaust Flow Rate:	Nm^3/s	39.42	3.05	21.49
Actual Exhaust Flow Rate:	m^3/s	65	3.58	39.67
Velocity:	m/s	12.2	7.1	17.5
Exhaust Concentrations:				
S02	mg/Nm^3	1036.25	9.39	73.6
NOx:	mg/Nm^3	200.57	181.1	215.18
PM:	mg/Nm^3	465.32	311.99	342.71
Emission Rates:				
NOx:	kg/h	28.47	8.15	52.21
NOx:	g/s	7.91	2.26	14.50
SO_2:	kg/h	147.11	0.414	19.93
SO_2:	g/s	40.86	0.12	5.54
PM:	kg/h	66.06	13.83	94.43
PM:	g/s	18.35	3.84	26.23

It can be noted from Table 3-4 that for boiler 1, during the emission testing, the rate at which NO_2, SO_2 and PM were released varied. Nitrogen Oxide was released at 7.91 g/s whereas sulphur dioxide and particulate matter were released at 40.86 and 18.35 g/s respectively. However, the temperatures at which these gases were released were all the same (450.20 K). The distance at which the plume rises is determined by the rate at which pollutants are emitted and whether it has a higher temperature than the surrounding air. The height of the stack was 47.5m with a diameter of 2.60m.

Boilers 3 and 4 shared a stack i.e. emission emanating from both boilers are emitted through a single point source. The stack diameters for boilers 3 and 4 (0.8 m and 1.2 m respectively) were lower than that of boiler 1 (2.6 m). Similarly, boilers 3 and 4 had less stack heights (27.5 m and 30.5 m respectively) in comparison with boiler 1 (47.5 m). For boiler 3, the rates at which nitrogen dioxide, sulphur dioxide and particulate matter were released were 2.26, 0.12 and 3.84 g/s respectively. On the hand, for boiler 4, nitrogen oxide was released at 14.5 g/s whereas sulphur dioxide and particulate matter were released at 5.54 and 26.23 g/s respectively. The exit velocities for boilers 1, 3 and 4 were 12.2, 7.1 and 17.5 m/s respectively. These velocities were achieved at temperatures of 450.2, 320 and 504 K respectively.

Based on stack emission results, for boiler 1, the average emission concentration of particulate matter (PM) released to the atmosphere was 465.32 mg/Nm^3 which reflected emission above the reference emission limit of 250 mg/Nm^3. The concentration of Sulphur Dioxide (SO_2) was 1036.25 mg/Nm^3, corrected to 10% O_2. This was below the emission limit of 2800 mg/Nm^3. The concentration of NO_2 was 200.57 mg/Nm^3, corrected to 10% O_2. This value could not be compared with any emission limit as no limit exist in terms of the regulations.

As seen in Table 3-4, the stack concentrations of particulate matter, sulphur dioxide and nitrogen dioxide were higher than those of boilers 3 and 4. It can be noted that the concentration of sulphur dioxide in boiler 1 was higher than the concentrations of particulate and nitrogen dioxide. However, for boilers 3 and 4, the concentrations of sulphur dioxide was the lowest. This could be attributed to the fact that boiler 1 had a highest capacity in terms of net heat input.

3.9. Conclusion

The study examined emissions of sulphur dioxide, particulate matter and nitrogen dioxide emitted from three existing boilers identified as boiler1, boiler 3 and boiler 4. The emission assessment was conducted from the point sources to determine the concentrations at which the gases are released to the atmosphere. The sampling of gases was undertaken in accordance to US EPA methods for sampling and analysis as per annexure A (methods for sampling and analysis) of the air quality act. The approved methods state that gas sampling should be performed isokinetically in order to take representative sample of gas and solid particles from stacks. The regulation relating to ‘declaration of a small boiler as a controlled emitter and establishment of emission standards’ requires all users of boilers with design capacity of greater than 10 MW NHI to conduct annual stack emission testing to ascertain compliance with emission limits. The samples collected were taken to the laboratory for analysis and a comparison was made with the emission limits. The results obtained for boiler 1 for sulphur dioxide and particulate matter demonstrated that the concentration levels exceeded the emission limits of 1000 mg/Nm^3 and 120 mg/Nm^3 respectively. Boilers 3 and 4 demonstrated elevated concentration of particulate matter, but complied with emission limit for sulphur dioxide. Overall, emissions of particulate matter from boilers 1, 3 and 4 were substantially high and created an impact on the ambient air quality. The results obtained during the stack emission testing were incorporated into a dispersion model for atmospheric impact assessment. The details of dispersion modelling are presented in chapter four.

CHAPTER FOUR

4. Dispersion modelling

In this chapter, the methods for dispersion modelling are first presented. This is followed by a detailed description of the modelling of emissions such as model selection, settings and domain. Lastly, the results of obtained from the modelling of emissions are presented.

4.1. Air pollution dispersion

Dispersion modelling utilizes mathematical formulations to characterize the emission process that disperses a pollutant emitted by a source (Yuwono and Wulandani). Utilizing observations and simulated meteorological fields, dispersion modelling can predict concentration at various points downwind receptor locations (Matthias et al., 2006). Equation (4-1) shows the Gaussian Dispersion Equation, which is a mathematical approximation that simulates the steady-state dispersion of emissions from emission sources.

$$C_{(x,y,z,H)} = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}} \times \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \times \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \quad \textbf{(4-1)}$$

Where:

C is the concentration at the receptor measure in µm/m^3;

x, y and z is the ground level coordinate of the receptor relative to the source of emission and wind direction (m);

H = effective release height of emissions (m);

Q is the mass flow of a pollutant measured from the source located at the origin in g/s;

$\bar{u}$ = speed of wind (m/s);

σ_y and σ_z is the standard of the plume concentration distribution in y and z plane (m);

This assessment was conducted in accordance with the Regulations Regarding Air Dispersion Modelling (Government Gazette, 2014). AERMORD was used as the modelling system to calculate air pollutant concentrations at the key receptor points and to generate plume isopleths for comparison with the relevant National Ambient Air Quality Standards. The Meteorological dataset for the year 2015 to 2017 was used to accurately represent meteorological conditions at South Durban Industrial

Basin covering the domain of 50 km x 50 km. This meteorological data was then input to the model. Furthermore, hourly averaged meteorological data from eThekwini Municipality Meteorological Stations were used.

4.2. Description of receptors

Sensitive receptors are sites where there is potential health impact of emissions as a result of emission sources. The receptors include schools, residential areas, hospitals, office establishments and shopping centres. For the purpose of this research, sensitive receptors were selected on the basis of population exposure. Table 4-1 provides the locations and names of sensitive receptors.

Table 4-1: Locations and names of sensitive receptors

Sensitive Receptor	UTM Coordinates mE	UTM Coordinates mS	Distance from Emission source	Direction from site
		Hospitals		
King Edward VIII Hospital	305313.71	6692115.19	2.46km	15.77 °
Addington Hospital	310825.61	6694608.87	7.81km	50.66 °
Wentworth Hospital	305778.89	6686867.26	3.04km	159.49 °
Life Entabeni Hospital	305547.96	6695437.95	5.83km	8.70 °
Inkosi Albert Luthuli Hospital	302811.56	6693456.18	4.24km	334.49 °
Netcare St Augustine Hospital	305963.76	6695287.50	5.69km	13.21 °
Durdoc Hospital	308438.73	6694908.58	6.37km	36.43 °
Clairwood Hospital	302828.62	6686542.40	3.73km	211.73 °
		Educational facilities		
Glenwood High School	306165.34	6694611.96	5.11km	17.30 °
UKZN Medical School	305662.94	6692628.99	3.04km	15.44 °
Glenwood Junior Primary	306369.90	6694349.05	4.86km	19.89 °
Durban Institute of Technology	306572.37	6696018.95	6.59km	24.71 °
Durban Primary School	305621.44	6692612.50	3.03	17.91 °
Phambili High School	304438.84	6690351.75	0.69km	0.57 °
Woodland Primary School	302705.18	6687495.00	3.04 km	302.44 °
		Old Age homes		

Natal Settlers Memorial Homes	304737.11	6692718.34	3.10km	359.69 °
Flame Lily Park Retirement Village	297631.55	6692042.19	7.47km	290.10 °
Residential Areas				
Sea View	303700.22	6690344.82	1.25km	45.59 °
Mont Clair	303802.48	6688571.82	1.50km	217.86 °
Wentworth	306578.78	6687704.34	2.74km	138.93 °
Bluff	307294.01	6687911.06	3.13km	12.75 °
Grosvenor	307800.31	6689129.18	3.10km	102.32°
Glenwood	305915.65	6693864.52	4.29km	16.56°
Berea	306040.72	6695755.07	6.24 km	10.84°
Lamontville	301070.34	6685913.44	5.31km	224.57°
Woodlands	302195.71	6687172.92	3.62km	225.56°
Umbilo	304846.38	6692371.49	2.66km	3.37 °
Jacobs	305104.64	6685895.91	3.87km	176.35°

4.3. Topography

Local topography can have several influences on plume transport. Diffusion upwind terrain can alter the wind flow and turbulence characteristics from those measured at the nearest meteorological station. Hills or rough terrain can also change wind speeds, directions and turbulence characteristics. Nearby water bodies can considerably dampen turbulence levels. Significant valleys can restrict horizontal movement and dispersion which can encourage the development and persistence of drainage flows. Sloping terrain may help to provide katabatic (drainage of air down hillside) or anabatic (drainage of air up hillside) flows in response to changing vertical temperature profiles (Katestone Scientific, 1998).

The South Durban Industrial Basin is bound to the South – East by the 100 m high Bluff Ridge and to the North- West by the 110m high Berea Ridge. This creates a flat, basin-like area defined by the harbor in the north and UMbogintwini in the South. The plant is located on flat land adjacent to the harbor and at an altitude of 3 m above the sea level. The land rises to the west of the site up to a height of 148 m over the distance of 3 km to the top of the Berea Ridge. The topography to the east is defined by the flatness of the harbor water until the west facing slopes of the Bluff ridge area encounters. The topography then rises steeply to the top of the Bluff Ridge to an average height of 60 m above mean sea level (AMSL) over an approximate distance of 310 m. This steep topography surrounding the study site prevents the lateral dispersion of pollutants, especially during winter when stable condition and temperature inversions (Coastal Inversion) are prevalent. This potentially limits the vertical dispersion of pollutants (Simpson and McGee, 1996).

4.4. Climate

The day to day climate of Durban forms Macroscale Climate mainly due to the control of sub-tropical high pressure, with temporary disruptions by low pressure cell or fronts. This high pressure zone is located along an approximately latitude of 30° South and is associated with strong divergence at the surface and convergence in the upper atmosphere

Based on historic average temperature and total monthly rainfall experienced over Durban, it is clear that the seasonal variation in the recorded temperature and rainfall is prevalent. Durban typically receives high levels of rainfall during the summer months since the South Indian High is located close along the east of South Africa. This high pressure cell transports warm moist air over Durban resulting in elevated rainfall during summer. During winter, however, the South Indian High migrates further away from the coast of South Africa; hence reducing its ability to advect moisture onto the coast resulting in low rainfall. The rainfall removes dust and gases from the atmosphere via a process called wet precipitation (Simpson and McGee, 1996)

The prevailing winds in Durban region are north-easterly and south-westerly (Tyson and Preston-Whyte, 2000). The north-easterly winds are associated with high atmospheric pressure and fine weather system whilst the south-westerly winds are associated with the passage of coastal low pressure system and cold front. (Guastella and Knudsen, 2007).

4.5. Modelling of emissions

Dispersion modeling was developed to calculate the concentration as a function of source configurations, emission factors and meteorological characteristics. This provides a useful tool to ascertain the spatial and temporal patterns in the ground level concentrations arising from the emissions of various sources. An increasing amount of reliance was placed on the concentration estimates derived from the model. For the purpose of this study, AERMOD was used as prescribed in the Regulations regarding Air Dispersion Modelling (Government Gazette, 2014). This advanced model output provides valuable data, depicting ambient concentrations of pollutants surrounding the sources (Shell Canada Energy, 2013). AERMOD is a 'near-field, steady-state' guideline model. It uses boundary-layer similarity theory to define turbulence and dispersion coefficients as a continuum, rather than as a discrete set of stability classes. The variation of turbulence with height allows a better treatment of dispersion from different release heights.

4.5.1. Background concentration

Dispersion Modelling code of practice requires that the highest background concentration of emissions, as measured by a suitable monitoring station, used to represent the background concentration of that particular pollutant for the region throughout the period assessed. It is necessary to integrate the background concentrations of air pollutants as they provide a baseline level to which the predicted impact of the development can be added, thus producing a cumulative air quality impact that is suitable for comparison against regulatory criteria.

The Ambient air quality data used in this research was obtained from the eThekwini Municipality Air Quality stations (eThekwini Health and Norwegian Institute for Air Research, 2007). As part of the Air Quality Management Plan report, city-wide dispersion modelling was undertaken for NO_2, SO_2 and PM_{10} emissions. The annual background concentrations for these pollutants were predicted to be as follows:

- NO_2 annual average background (8 µg/m^3)
- SO_2 annual average background (10 µg/m^3)
- PM_{10} annual average background (17.5 µg/m^3)

The concentrations of ambient air quality monitoring data of NO_2, SO_2 and PM_{10} were considered for the cumulative assessment purposes and are presented in Table 4-2. The pollutants levels measured at the monitoring stations were evaluated against the current NAAQS. The annual average concentrations which were obtained from the monitoring station were NO_2, SO_2 and PM_{10}.Whereas the hourly average in terms of NAAQS were applicable to NO_2 and SO_2. The 24-hour average concentrations were applicable to SO_2 and PM_{10}. It is noted that background concentrations measured for all three pollutants were significantly low and below the NAAQS.

4.5.2. Interpretation of Criteria Pollutants in Terms of the NAAQS

Modelled ground level concentration for the criteria pollutants, PM_{10}, NO_2 and SO_2 were interpreted in terms of the National Ambient Air Quality Standards. The NAAQS provides an averaging period, a concentration threshold, a number of allowable exceedances of the threshold and a compliance date for each pollutant as per Table 4-2.

Table 4-2: National Ambient Air Quality Standards

South Africa Ambient Air Quality Standards				
Pollutant	Averaging Period	Concentration (µg/m^3)	Frequency of Exceedance	Compliance Timeframe

Particulate Matter (PM_{10})	24 - hour	75	4	01 January 2015
	1 year	40	0	01 January 2015
Sulphur Dioxide (SO_2)	10 Minutes	500	526	Immediate
	1 – hour	350	88	Immediate
	24 – hour	125	4	Immediate
	1 year	50	0	Immediate
Nitrogen Dioxide (NO_2)	1 – hour	200	88	Immediate
	1 – year	40	0	Immediate

The allowable frequency of exceedance provides an allowance to exceed for instance, the 24-hour average limit of PM_{10} (75 µg/m^3) for 24-hour period in a year (Table 4-2). This is not high when one considers that there are 365 × 24-hour periods in a year. To put this into perspective, if we were to consider the NAAQS of PM_{10} for a period of 24-hours, it is specified that the daily ground concentration for PM10 may not exceed the regulatory threshold of 75 µg/m^3 no more than 4 times. Should a model output show an exceedance of say a 100 over an area, it would mean that the regulatory threshold of 75 µg/m^3 was exceeded up to 100 time in 365 days. The model accounts for even the smallest exceedance of 75 µg/m^3 for instance 75.001 µg/m^3 and these 100 exceedance may have taken place sequentially or intermittently throughout the year.

4.5.3. The effect of Building Downwash

Buildings can have a significant effect on the dispersion of pollutants from sources. The main effect is the entrainment of pollutants into the cavity region in the immediate leeward side of the building. This results in an increase in the concentration of the pollutants close to the building. Building downwash was taken into account for all point source model runs. Sources situated within 5 times the lesser of the height or width dimension of Building but not greater than 0.8km downwash from the trailing edge of the building are presumed nearby enough to be of concern in determining downwash potential.

Building downwash effects are only considered for point source emission releases. Downwash effects for fugitive emissions releases such as volume and area sources are not considered.

4.5.4. Model Selection

In order to estimate the ground level concentrations for each pollutant, the atmospheric dispersion modelling was undertaken using AERMOD (Version 9.6.1), which is recommended in the Code of Practice for Air Dispersion Modelling (ADM). AERMOD is a straight-line, steady-state Gaussian plume model that can model the dispersion of pollutants over rural and urban areas as well as over flat and complex terrain. AERMOD considers surface and elevated releases, and multiple sources (including point, area and volume sources) to determine the ground level pollutant concentrations at specified receptor points.

AERMOD is a new generation air quality modelling system, developed by the US EPA in collaboration with the American Meteorological Society (AMS). It contains improved algorithms for convective and stable boundary layers, for computing vertical profiles of wind, turbulence and temperature, and for the treatment of all types of terrain. One of the major improvements that AERMOD brings to applied dispersion modelling is its ability to construct vertical profiles of required meteorological variables, allowing improved modelling of the dispersion of pollutants (particularly of vertical dispersion).

4.5.5. Model Settings

For the purpose of atmospheric impact assessment, AERMOD, which is one of the tier two Gaussian-plume dispersion models was used. AERMOD is the recommended tier two model in the regulations regarding air dispersion modelling as published in Government Gazette (GG) 37804, Government Notice (GN) 533, dated 11 July 2014.

AERMOD is a model developed with the support of the AMS/US EPA Regulatory Model Improvement Committee (AERMIC), whose objective has been to include state-of the-art science in regulatory models**.** AERMOD makes use of a terrain pre-processor (AERMAP) and a meteorological pre-processor (AERMET).

The pollutants were modelled for an area covering 10 km by 10 km and plotted on a Cartesian receptor grid matrix with a resolution of 100 m by 100 m, with the study facility located towards the centre of the receptor area.

The surface roughness was taken into consideration during the dispersion modelling process. The surface roughness length is not a physical height, but a theoretical one based on the wind profile. It is the height at which the mean horizontal wind speed approaches zero. For many modelling applications, the surface roughness length is typically about an order of magnitude smaller than the average heights of the roughness elements**.**

The surface roughness file was developed using the Google earth and spatial information obtained from the South African National Biodiversity Institute (SANBI) GIS website. The Universal Transverse Mercator (UTM) coordinate system (horizontal datum: World Geodetic System 84, WGS-84 system) was used for the model domain base map. Table 4-3 depicts the settings which were selected for modelling.

Table 4-3: Modelling options

Model Settings	US EPA AERMOD Model 18018
Terrain Data	Shuttle radar topography mission (SRTM) 1 Global 30 m data
Land characteristics	AERMET Default Bowen ratio, surface albedo and surface roughness as per meteorological file
Buildings	Building Profile Input Program Enabled

4.5.6. Model Domain

Initial model runs were undertaken to determine the geographical extent of plume dispersion. This subsequently allowed the selected modelling domain to be refined accordingly. The model domain, in accordance with the Code of Practice for ADM consists of the receptor spacing and resolution as specified in Table 4-4. The modelling domain is presented in Figure 4-1.

Table 4-4: Recommended Grid Spacing for receptor Grids

Model Domain	Resolution (m)
Large Grid (20 km x 20 km)	1000
Medium Grid (10 km x 10 km)	250
Small Grid (5 km x 5 km)	100
Fine Grid (2.5 km x 2.5 km)	50
Boundary Receptors	50

Sensitive receptors are sites that could be potentially impacted and include selected points in the surrounding areas. The potentially sensitive receptors selected in this study are illustrated Figure 4-1 and their relative direction and distance from each nearby source of emission. Figure 4-1 depicts the sensitive receptors that have been considered in the study. The Sensitive Receptors included hospitals, schools/universities and old age homes situated within a 10 km radius of the Project site

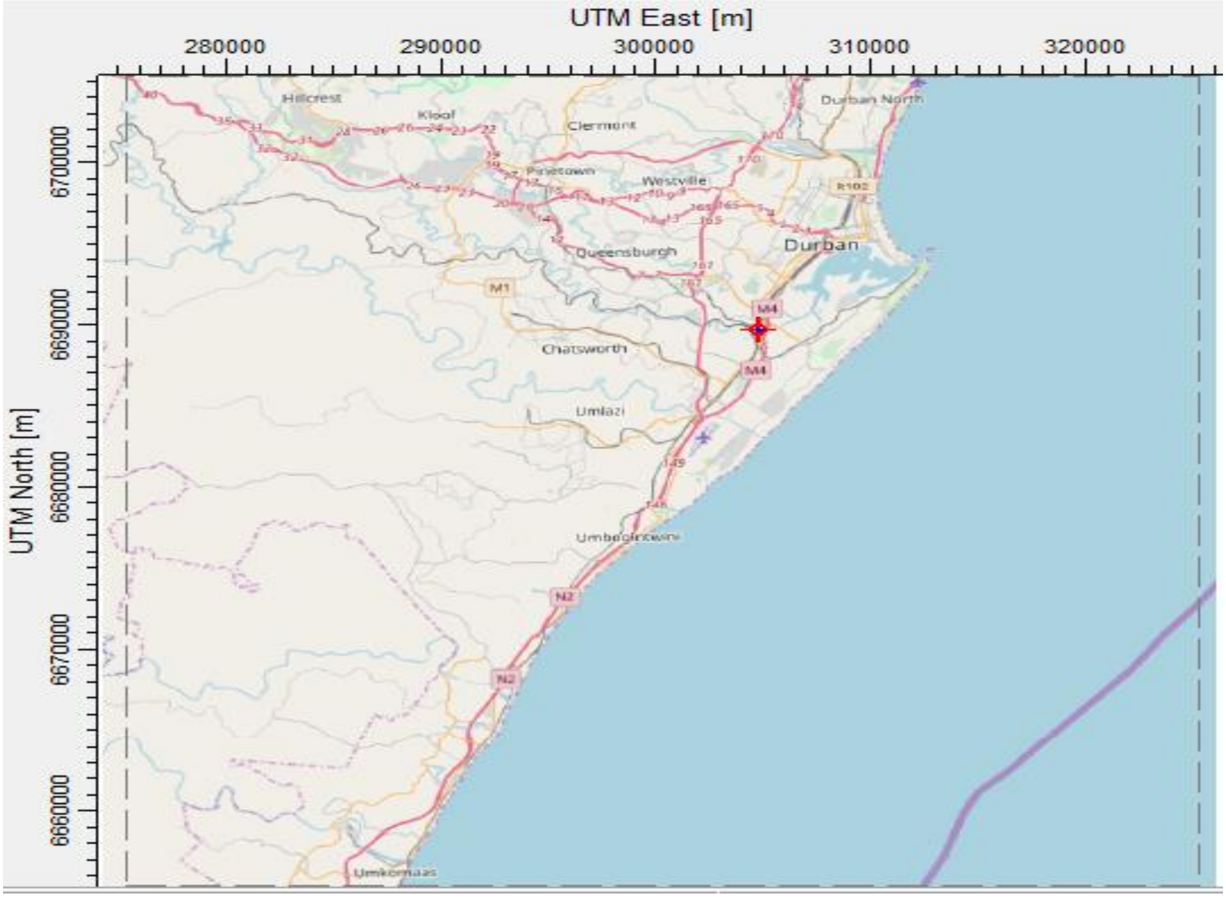


Figure 4-1: Sensitive receptors within the modelling domain

4.5.7. Model Input for the Terrain and Land Use

As defined in the Modelling Regulations (2014), ambient air quality objectives are applied to areas outside the facility fenceline (i.e. beyond the facility boundary). Within the facility boundary, environmental conditions are prescribed by occupational health and safety criteria. The facility boundary is defined on these criteria:

- The facility fenceline or the perimeter where public access is restricted;
- If the facility is located within another larger facility boundary, the facility boundary is the boundary of the encompassing facility; and
- If a public access road passes through the facility, the facility boundary is the perimeter along the road allowance.

A 10 km by 10 km modelling domain was defined for this assessment. The Modelling Regulations recommend a specific spatial resolution grid, however, due to the size of the modelling domain and the limitations of CALPUFF, this grid resolution could not be achieved. Instead a nested grid was utilised with a resolution of 250 m x 250 m within 5 km of the site, 500 m x 500 m within 5 to 10 km of the site, and a 1000 m x 1000 m within 10 to 50 km of the site.

The surrounding project area is characterised by a gently undulating coastal plain with low hills, steepening inland towards the west. Terrain influences dispersion of pollutants, especially during periods of stable conditions. For the land use categorization, an AERSURFACE output was created from the Global Land Cover Characterization Global Coverage – Version 2 (1 km x 1 km resolution over a domain of 10 km x 10 km).

For the purpose of this study, ArcGIS 24 was used as a mapping interface. ArcGIS includes a suite of integrated applications that provides multiple GIS functions, from simple to complex, including mapping, geographic analysis, data editing and compilation, data management, visualization and geo-processing. The fundamental tools in ArcGIS allow the performance of several tasks including:

- Map compilation;
- Geo-processing;
- Editing and data compilation

4.5.8. Meteorological Input

AERMOD utilises hourly sequential upper atmospheric meteorological data for the calculation of vertical profiles of wind turbulence and temperature. There is a preference to use meteorological data for dispersion modelling that has been collected as close as possible to the project site. However, the meteorological measurements should be inclusive of the various parameters necessary for incorporation into the model and suitably quality-assured.

The nearest meteorological station in the vicinity of the project site is the old Durban Airport station. However, this station was decommissioned in 2009. In order to make use of more recent meteorological data, and in accordance with the Code of Practice, site specific MM5 data for the years 2015-2017 was used for assessment purposes.

Prevailing meteorology of the boundary layer is a dominant influence on atmospheric dispersion. Important parameters for the characterisation of dispersion potential include wind speed, wind direction, extent of atmospheric turbulence, ambient air temperature and mixing depth. To accurately represent meteorological conditions in the study area, MM5 data was purchased from Lakes Environmental. A 4 km resolution AERMET-ready MM5 dataset for the years 2015 to 2017 cantered at 406244 mE and 6816279 mS and covering a domain of 10 km x 10 km was utilised. The AERMET meteorological model contains a diagnostic wind field module that includes parameterized treatments of terrain effects. In addition, local surface meteorological data was sourced from the SAWS meteorological monitoring.

4.5.8.1. Beaufort wind scale

Wind speeds are defined using Beaufort Wind Scale. Beaufort numbers ranges from 0 which is classified as calm to >12 which is a Hurricane. Wind speed less than 0.5 m/s is defined as calm, and at this condition the air pollution smoke rises vertically. Wind speed ranging between 0.5 - 1.5 m/s is defined as light wind, and at this condition the direction of smoke drifts but not by wind vanes. Light breeze ranges between 1.6 - 3.3 m/s, and at this speed, the wind is felt on the face. This causes the leaves to rustle and the wind vanes are moved. Gentle breeze ranges between 3.4 - 5.5 m/s, and at this wind speed, tree leaves and small twigs are in constant motion. Moderate breeze which is number four in Beaufort scale ranges between 5.5 – 7.9 m/s, and at this condition dust is raised. Fresh breeze is at number 5 on Beaufort Wind Scale and the wind speed in this case ranges between 8 – 10.7 m/s, and at this speed, small trees begin to sway. Strong breeze range between 10.8 – 13.8 m/s, and this causes large branches to sway and umbrellas are used with difficulty. High wind, moderate gale and near gale are at number seven on Beaufort scale, and the speed ranges between 13.9 – 17.1 m/s. in this condition the entire tree is in motion and walking becomes difficult. Gale wind ranges between 17.2 – 20.7 m/s, and at this condition twigs breaks off and generally impede walking. Strong gale ranges between 20.8 – 24.4 m/s, and this condition results in structural damages.

4.5.9. Modelling Assumptions

The following assumptions were made for the dispersion modelling assessment, and wherever possible, a conservative approach was adopted:

- Co-ordinates have been based on best approximation of the source locations from the Plot Plans;
- The assessment considers environmental receptors (impacts beyond the plant boundary);
- The maximum values corresponding to the relevant standards / guidelines are based on a three-year data set and are considered conservative;
- As a conservative approach, $PM_{2.5}$ is assumed to be equivalent to 100 % of PM_{10};
- As per the Code of Practice for ADM, the NO_2 to NO_x ratio has conservatively been assumed to be 80%.

4.5.10. Model Uncertainty

Air quality models attempt to predict concentrations at a specific point and time based on “known” or measured values of various parameters input into the model, such as wind speed, temperature profiles, solar radiation. There are however, variations in the “unknown” parameters that are not measured as well as unresolved details of atmospheric turbulent flow. Variations in these “unknown” parameters can result in deviations of the predicted concentrations of the same event, even though the “known” parameters are fixed. As a result of the deviations of the “unknown” parameters, a “perfect” model may be able to predict an average of identical events well, while each repetition of that event will provide somewhat different results. The statistics of these concentration residuals are termed ‘‘inherent’’ uncertainty of a model.

In addition, there are “reducible” uncertainties due to inaccuracies in the model, errors in input values and errors in the measured concentrations. “Reducible” uncertainties include inaccuracies in the input values of the known conditions (for example, poor quality or unrepresentative meteorological, geophysical and source emission data); errors in the measured concentrations that are used to compare with model predictions and inadequate model physics and formulation used to predict the concentrations. As the term indicates, “reducible” uncertainties can be controlled or minimised by collecting accurate input data, preparing the input files correctly, checking and re-checking for errors, correcting for odd model behavior, insuring that the errors in the measured data are minimised and applying better model physics.

In terms of this modelling assessment, a number of factors have contributed to uncertainty in the model results with emphasis on reducible errors. The highest degree of reducible error exists in establishing emissions from sources for which emission rates cannot be measured. In these instances, emission rates are conservatively based on regulatory emission limits.

There will always be some error in any geophysical model. However, notwithstanding the limitations regarding the cumulative assessment (and emission rate determination mentioned above), the structure of the modelling approach has been prepared in such a way to minimise the total error, whilst the conservative approach adopted allows for increased confidence in the model results.

4.6. Results and discussion

In this section the results and discussion of prevailing winds and wind roses are first presented. This is followed by the presentation of both actual and modelled results.

4.6.1. Interpretation of prevailing winds using wind roses

4.6.1.1. Surface wind roses depicting dominant wind flow sectors at the study area

Wind roses (Figures 4-2 to 4-13) summarise the occurrence of winds at location, representing their strength, direction and frequency. In the wind roses graphs, wind speeds were classified according to Beaufort scale categories.

As in Figures 4-2 to 4-13 the winds were predominantly easterly varying from light to moderate winds, with frequency of occurrence of 80 %. There was 0.0 % of occurrence of calm conditions. However, data capture was greater than 60 % for both wind speed and wind direction. The surface wind roses are the representative of the dataset used in the model for the years 2015, 2016 and 2017 and are presented in Figures 4-2 to 4-13.

The fate of suspended emissions is determined by the prevailing winds which occurs in the troposphere. However, meteorological processes that are important to air pollution are at the lowest layer of the atmosphere close to earth's surface. Close to the surface, the vertical mixing is strong but fluctuates on a daily basis as well as seasonally. This variation is due to heating and cooling of the earth surface. It can be concluded that the conditions were calm as depicted in Figures 4-2 to 4-13. As a result of calm conditions, the atmospheric emissions reach high levels due to limited dispersion. High levels of emissions are more frequent during low to moderate winds, low temperature, low precipitation and wet deposition.

The surface wind conditions as per 4-2 shows North Easterly light breeze of 17% during the period of September, October and November (Spring Season) in 2015, However during Summer season light breeze were experienced at an increased percentage of 19% as compared during the spring season (Figure 4-3). During autumn it is noted that wind direction changed to south easterly and light breeze at 13.9 % were experienced as per Figure 4-4. In 2016 during September, October and November of 2016 season light breeze were predominant both in north easterly and south westerly directions. It can be concluded that there were no gale winds or moderate gale wind experienced during 2015, 2016 and 2017.

Wind speed, atmospheric stability and mixing depth determine the dispersion of and dilution of pollutants. Wind speed transport air pollution away from the source causing them to disperse at diluted level. This means the higher the wind speed the more emissions are dispersed and the lower the level of emission concentration. However, the disadvantage of high wind speed is generation of dust which result in elevated PM_{10} and $PM_{2.5}$. In addition to wind speed the study area experienced atmospheric stability which is the heating of ground during the middle of the day resulting in turbulent air. Air turbulence compels polluted air to disperse as drifting away from the source. However, it is further noted during the period of June, July and August (JJA) as per Figure 4-13 air cools with increasing height in the atmosphere however the upper air layer becomes warmer than a lower layer as such, the inversion layer is formed, this is the result of calm nights when grounds cools rapidly.

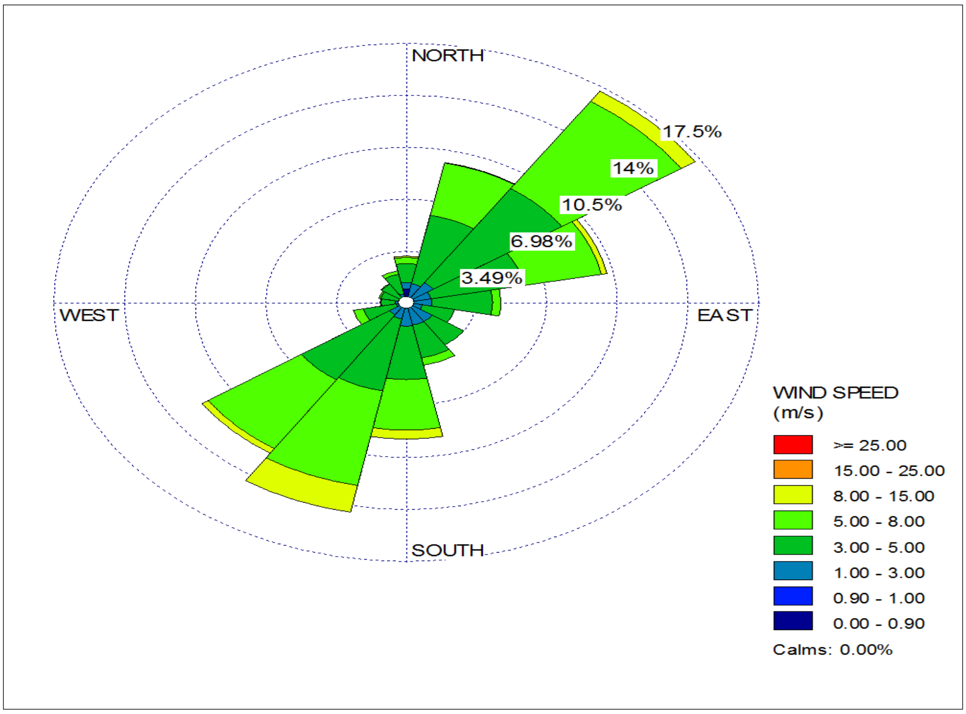


Figure 4-2: Surface Spring wind rose for 2015 (SON)

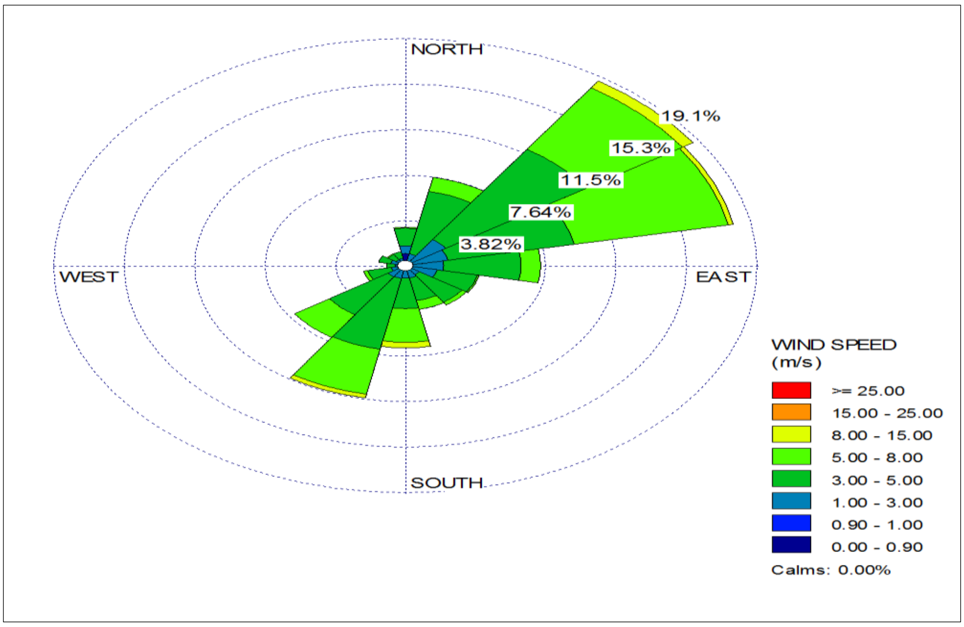


Figure 4-3: Surface summer wind rose for 2015 (DJF)

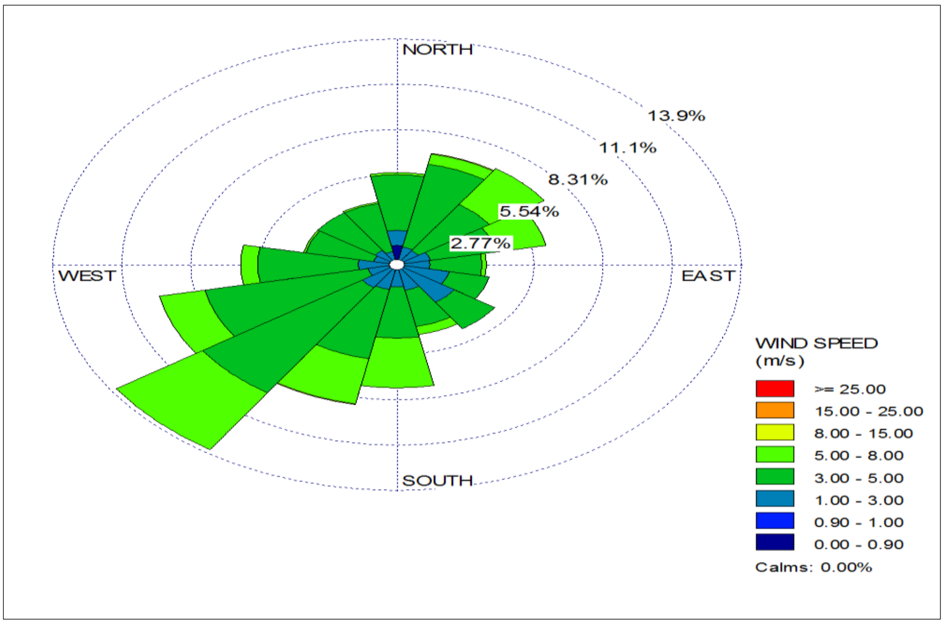


Figure 4-4: Surface autumn wind rose for 2015 (MAM)

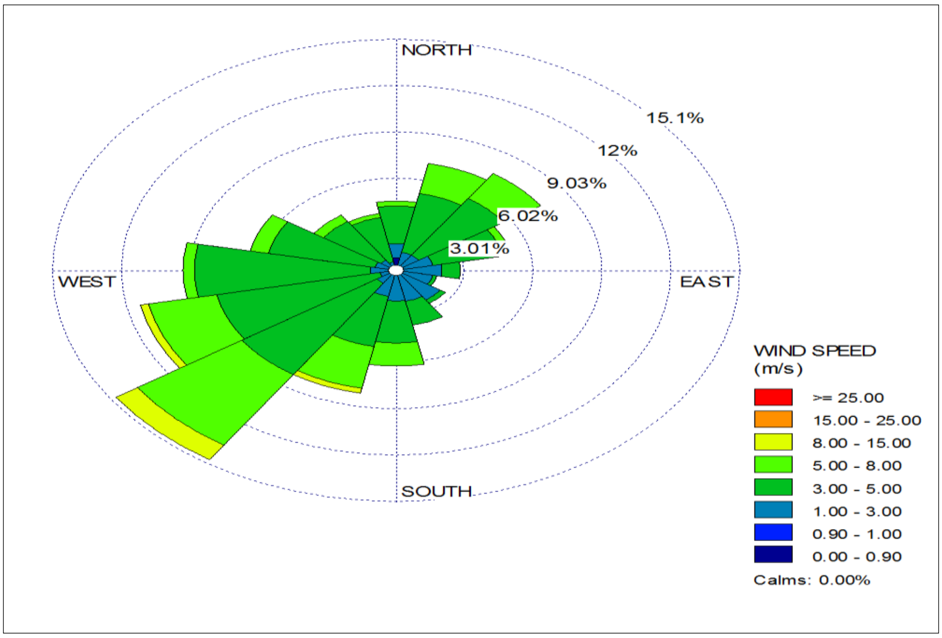


Figure 4-5: Surface winter wind rose for 2015 (JJA)

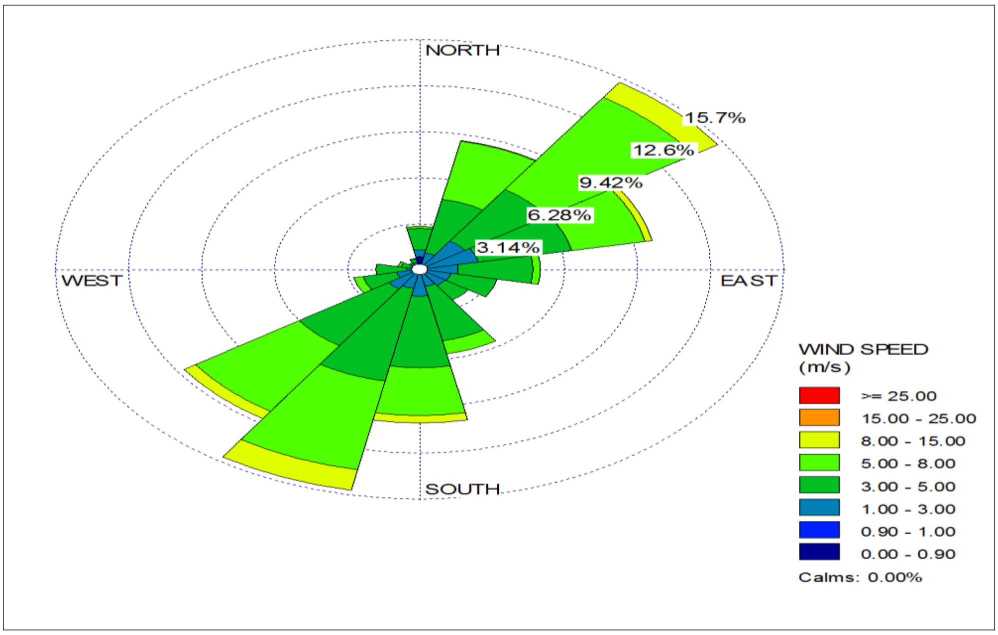


Figure 4-6: Surface Spring wind rose for 2016 (SON)

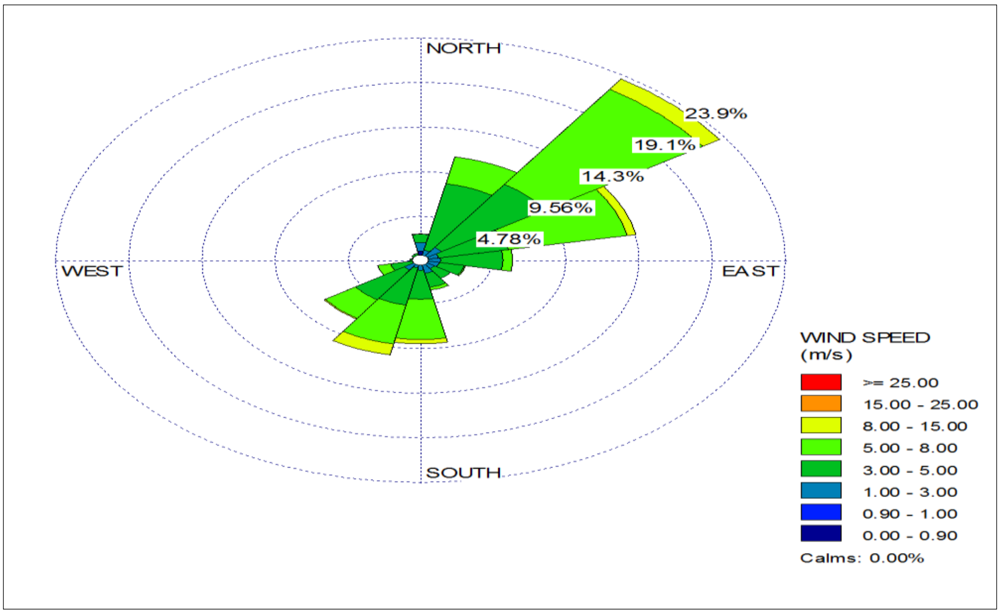


Figure 4-7: Surface summer wind rose for 2016 (DJF)

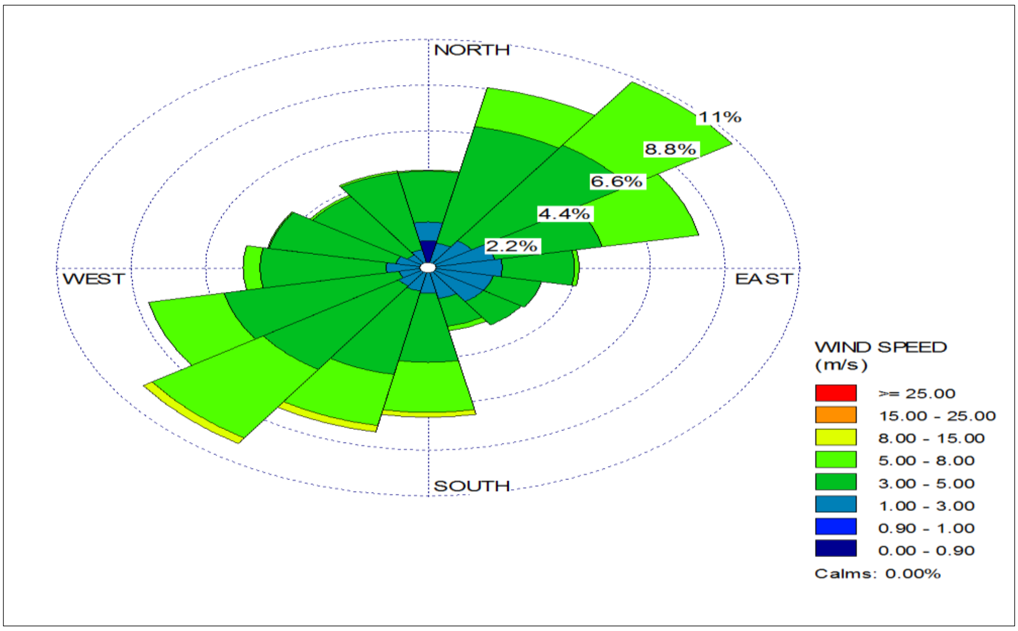


Figure 4-8: Surface autumn wind rose for 2016 (MAM)

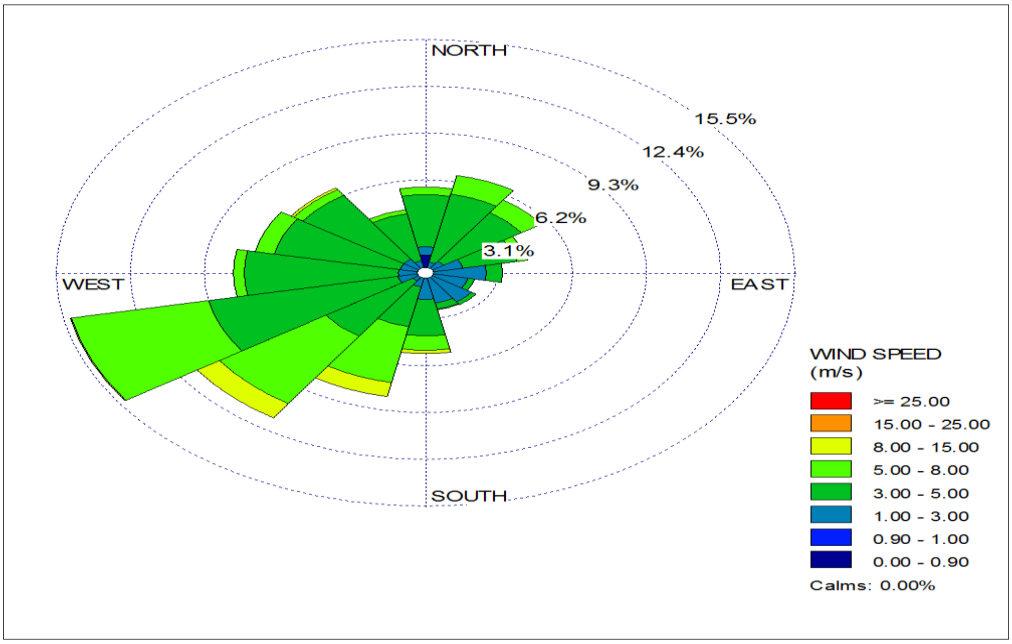


Figure 4-9: Surface winter wind rose for 2016 (JJA)

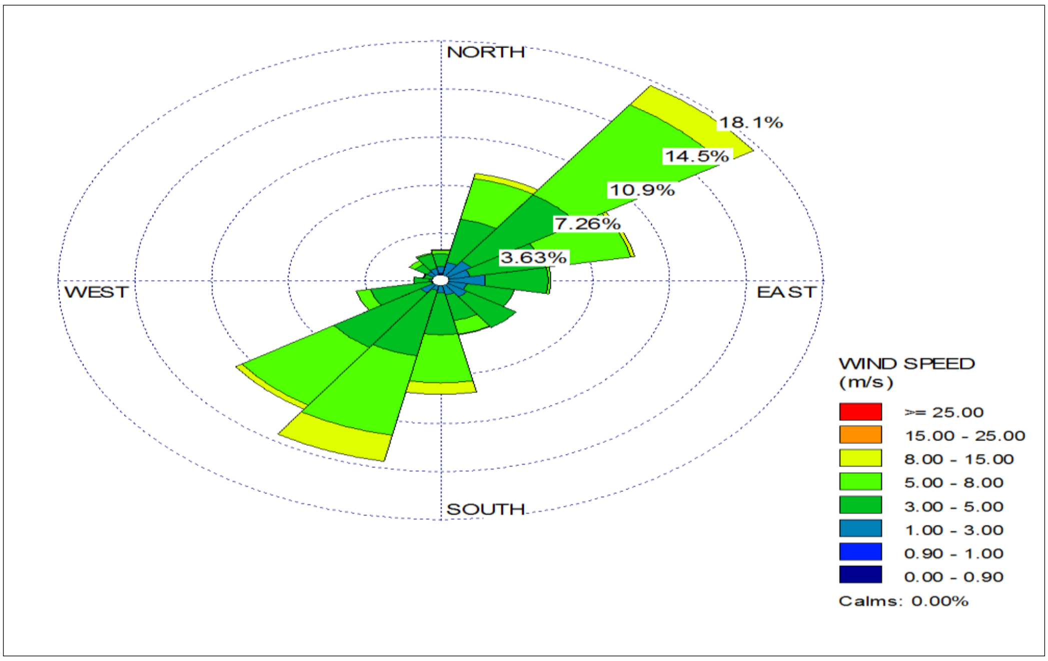


Figure 4-10: Surface Spring wind rose for 2017 (SON)

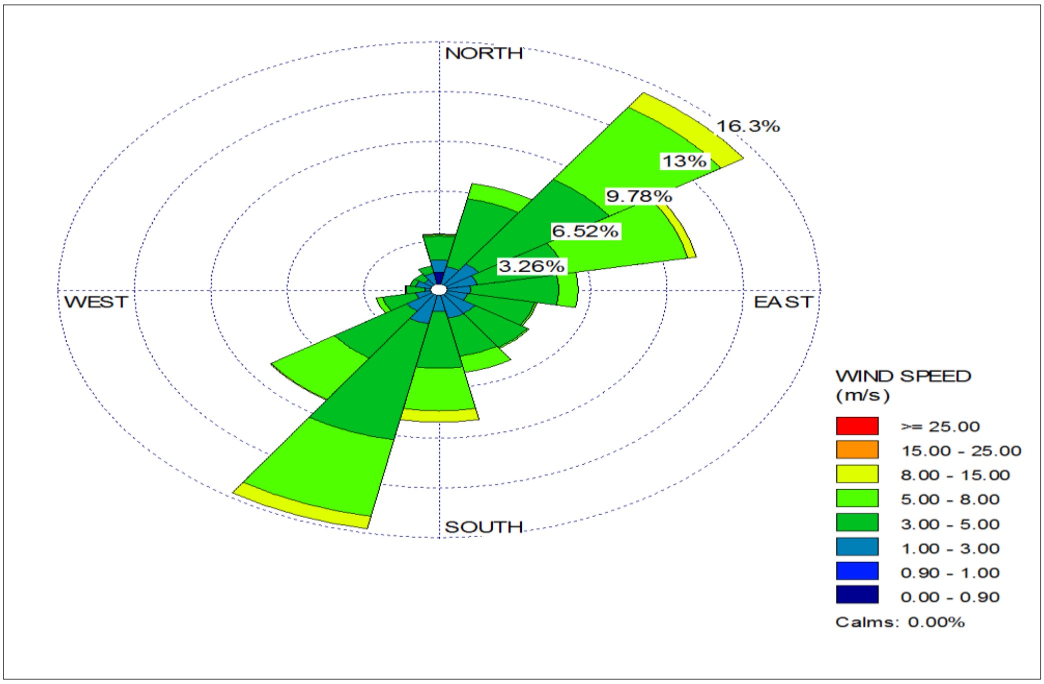


Figure 4-11: Surface summer wind rose for 2017 (DJF)

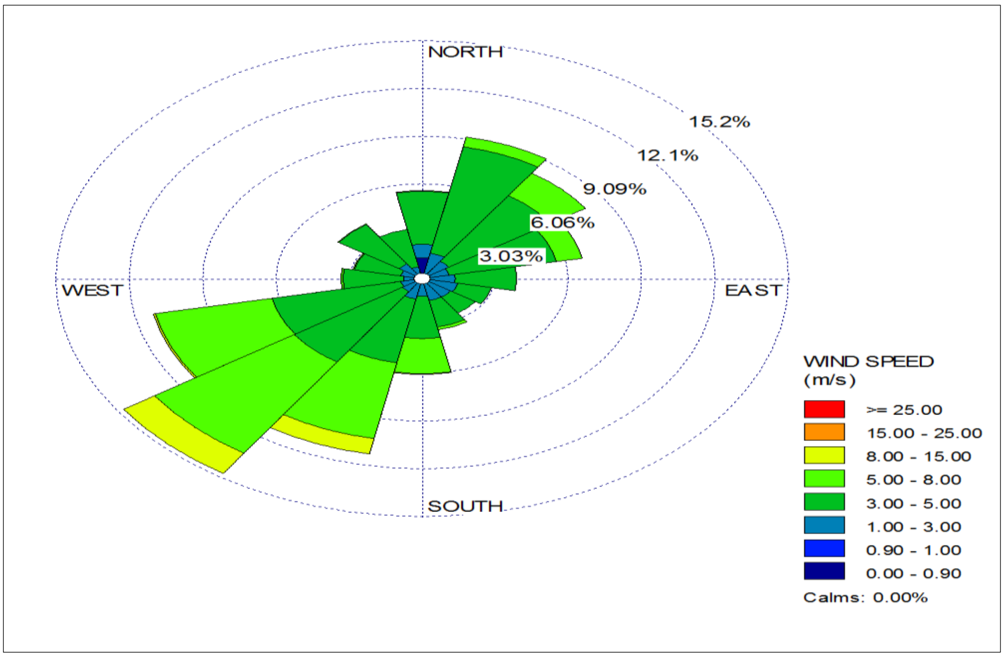


Figure 4-12: Surface autumn wind rose for 2017 (MAM)

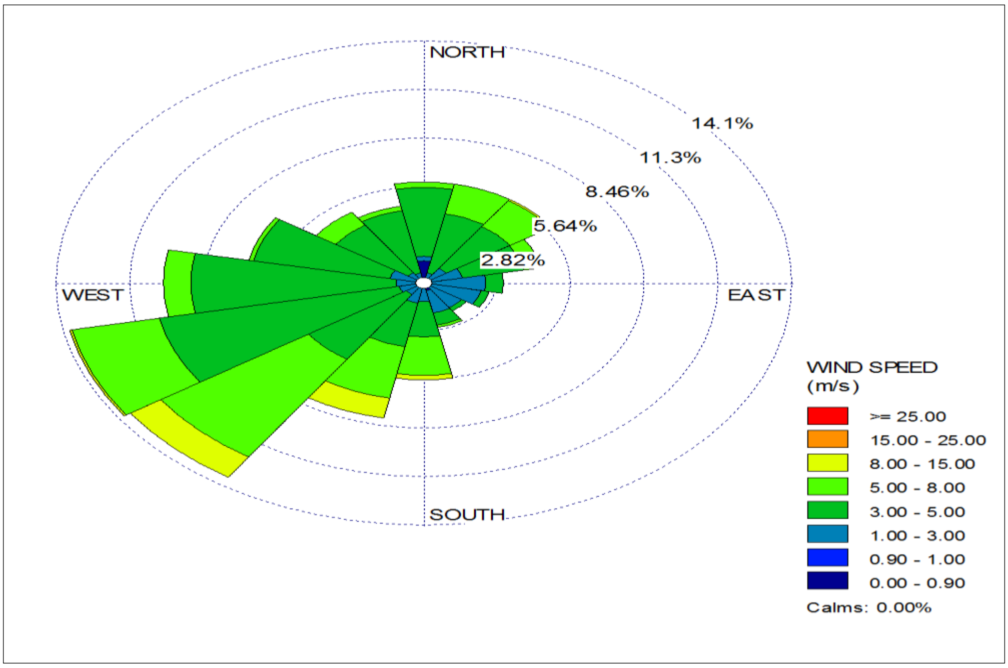


Figure 4-13: Surface winter wind rose for 2017 (JJA)

4.6.1.2. Upper air wind roses depicting dominant wind flow sectors at the study area

Upper air winds are defined as the jet stream winds at the top of the troposphere. These winds are generally poleward and westerly in direction. Air flow in this region is intensified by strong temperature and pressure gradient that develops when cold air from the poles warm air from the tropics.

Figures 4-13 to Figure 4-25 show the upper air wind roses. The wind roses demonstrate that prevailing winds are North-Easterly and South-Westerly. The North-Easterly winds are associated with high atmospheric pressure and fine weather systems whilst the south-westerly winds are associated with the passage of coastal low-pressure system and cold fronts. Winds affect the horizontal and vertical dispersion of air pollutants away from the source.

The general wind direction that prevails over Durban is north-easterly as it has the highest total frequency (~1300 hours per year). These winds range from the gentlest (1.5 m/s) to the strongest (>8.2 m/s) with the largest portion of wind speed ranging between 3.1m/s and 8.2 m/s. The highest total frequency of strong wind (8.2 m/s) emanates from the south westerly direction. These are associated with passage of cold fronts that pass over the east coast South Africa during winter month. The third most prevalent wing direction is from a northerly direction and has a gentle wind (< 3.1 m/s) the strong north-easterly and south-westerly wind favour the dispersion of air pollutants within the South Durban Industrial Basin is greater during summer as compared to winter.

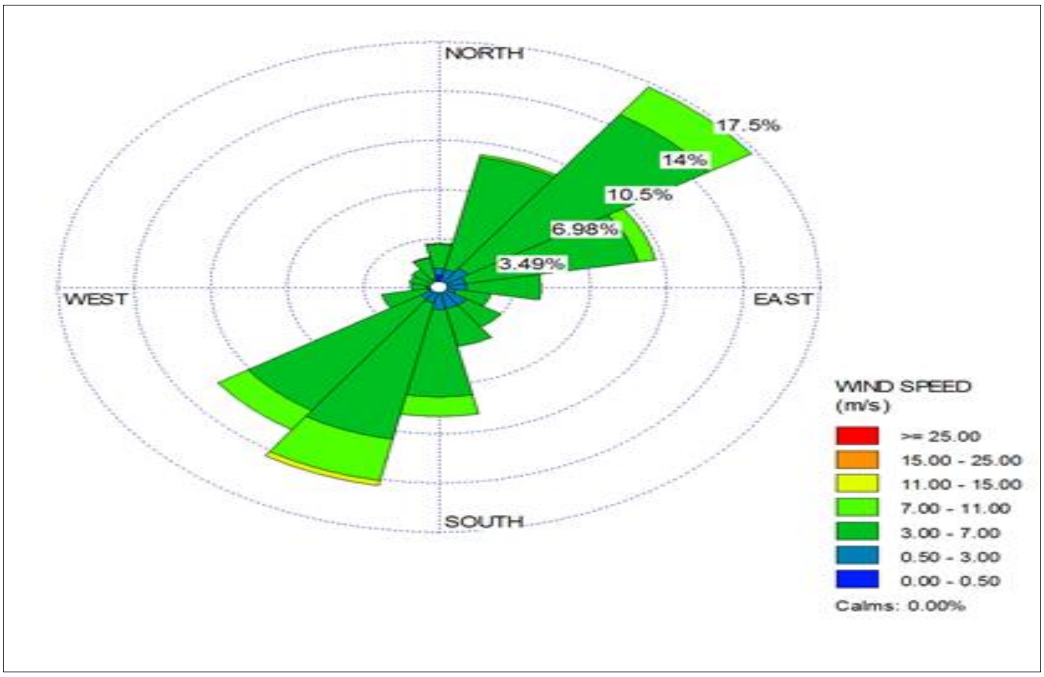


Figure 4-14: Upper air Spring wind rose for 2015 (SON)

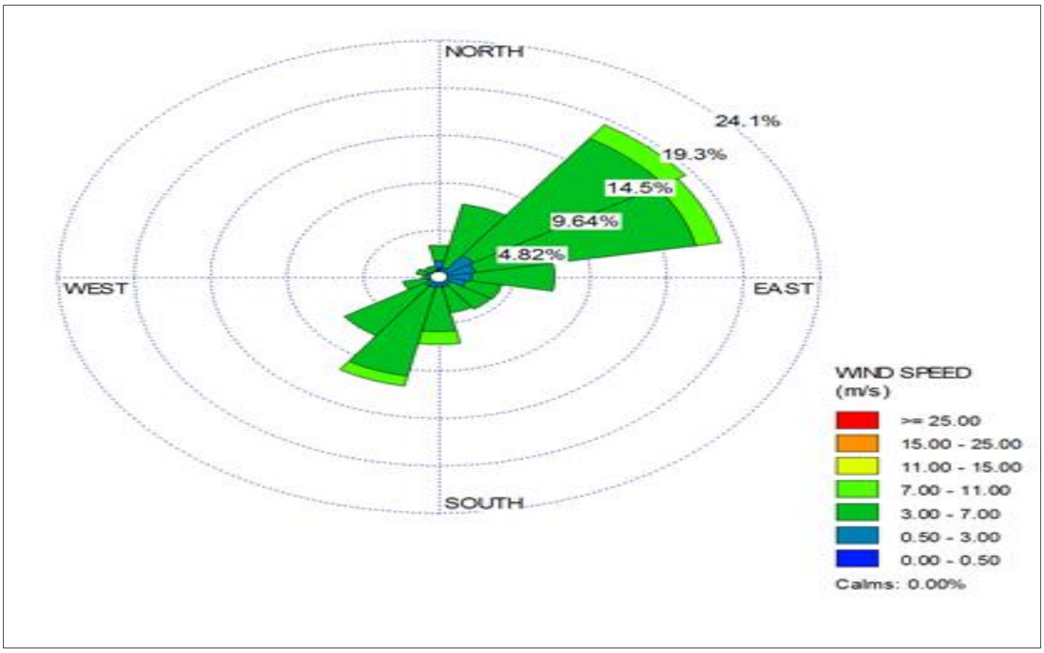


Figure 4-15: Upper air summer wind rose for 2015 (DJF)

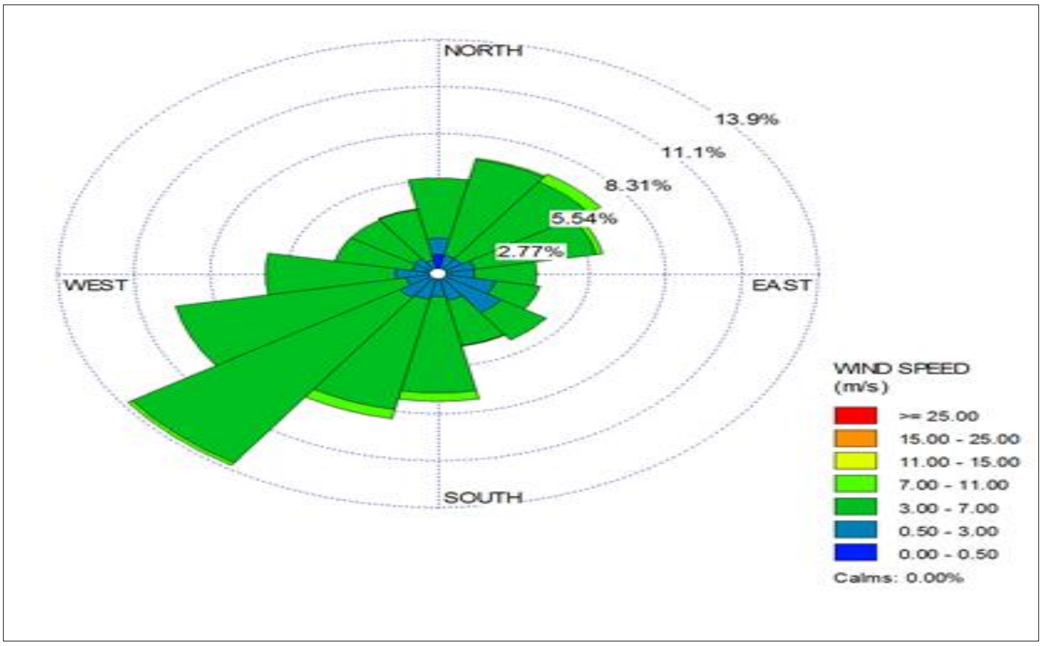


Figure 4-16: Upper air autumn wind rose for 2015 (MAM)

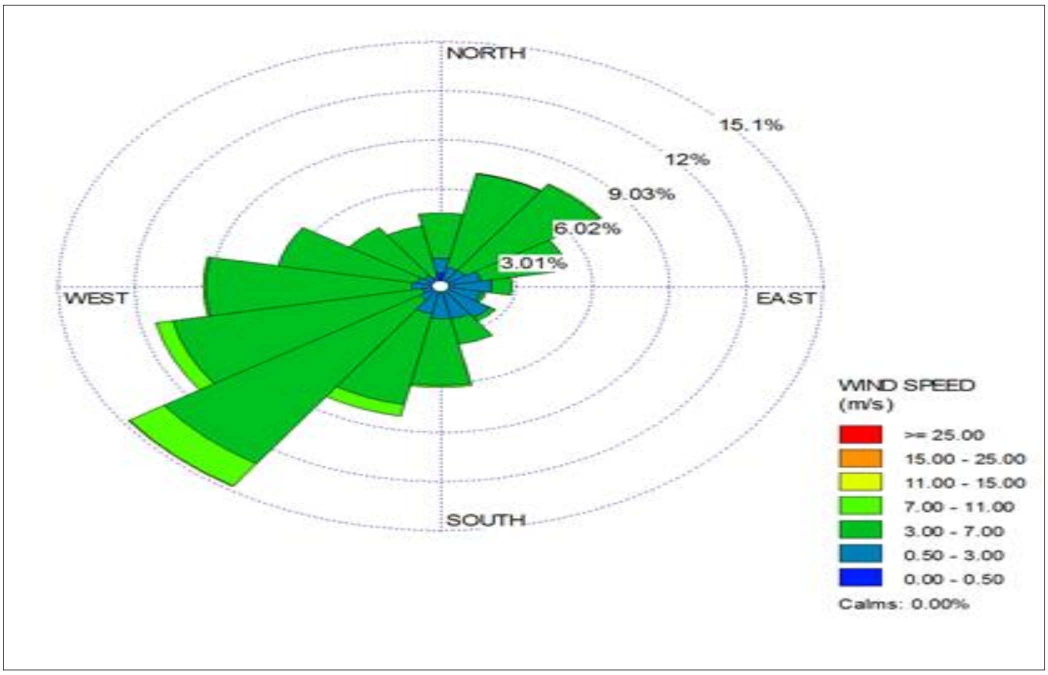


Figure 4-17: Upper air winter wind rose for 2015 (JJA)

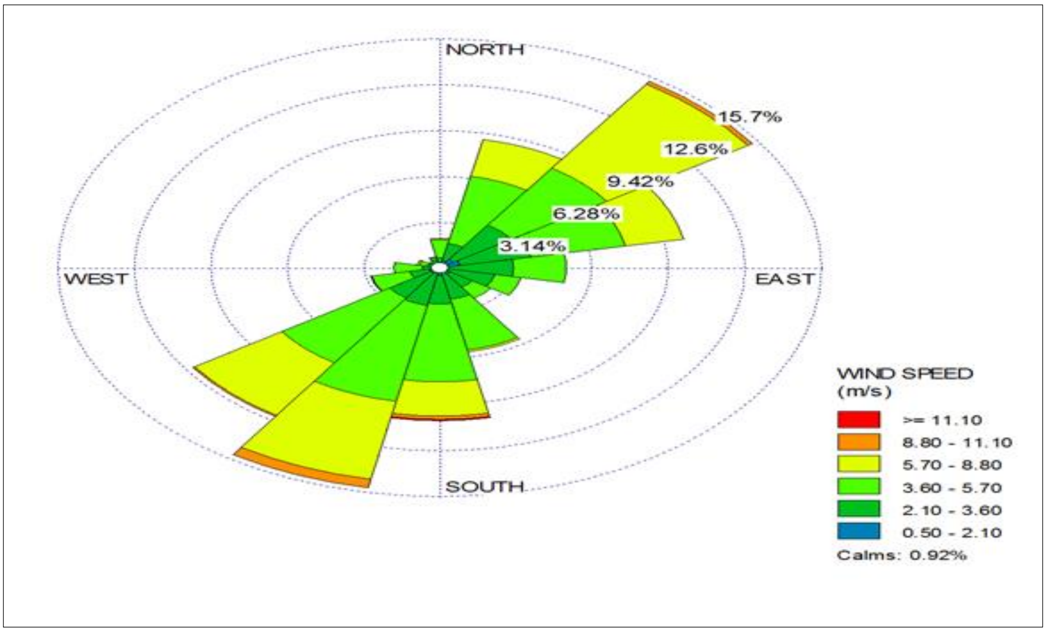


Figure 4-18: Upper air Spring wind rose for 2016 (SON)

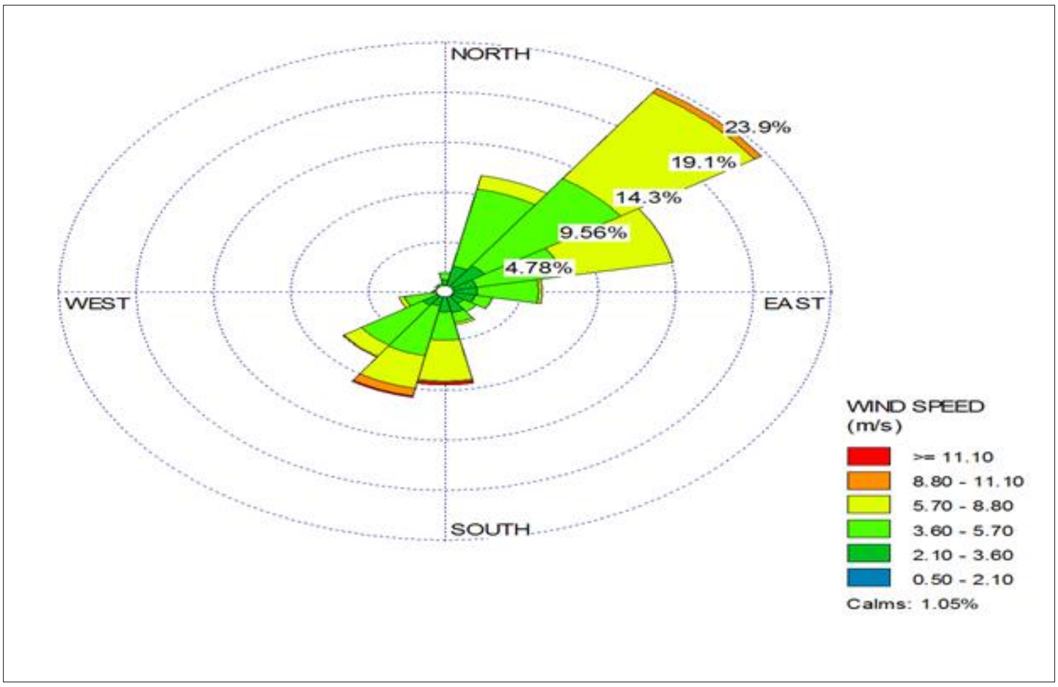


Figure 4-19: Upper air summer wind rose for 2016 (DJF)

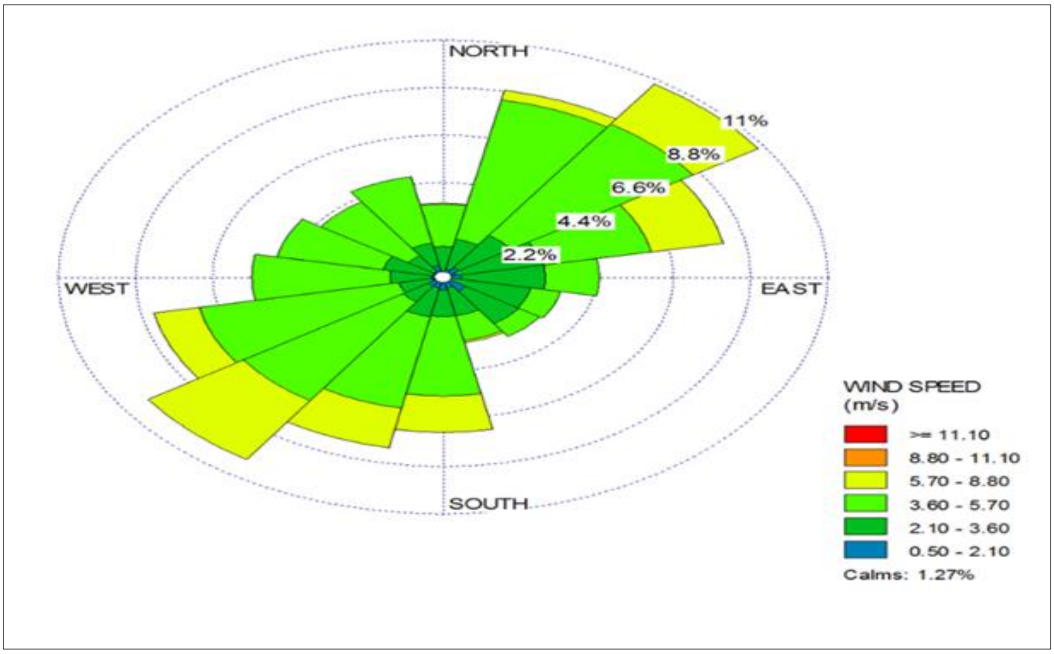


Figure 4-20: Upper air autumn wind rose for 2016 (MAM)

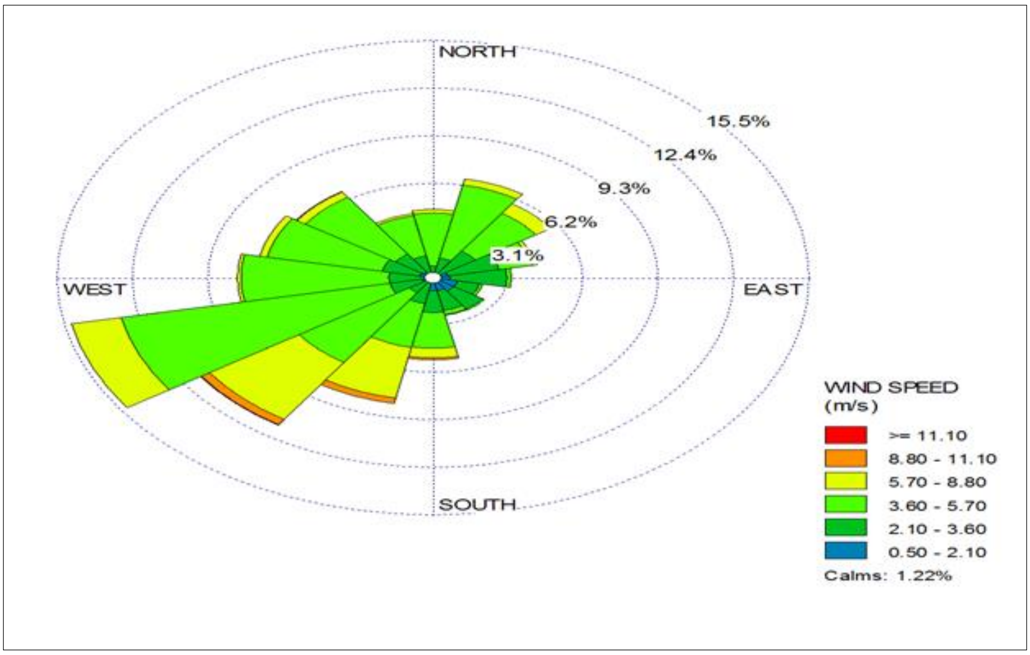


Figure 4-21: Upper air winter wind rose for 2016 (JJA)

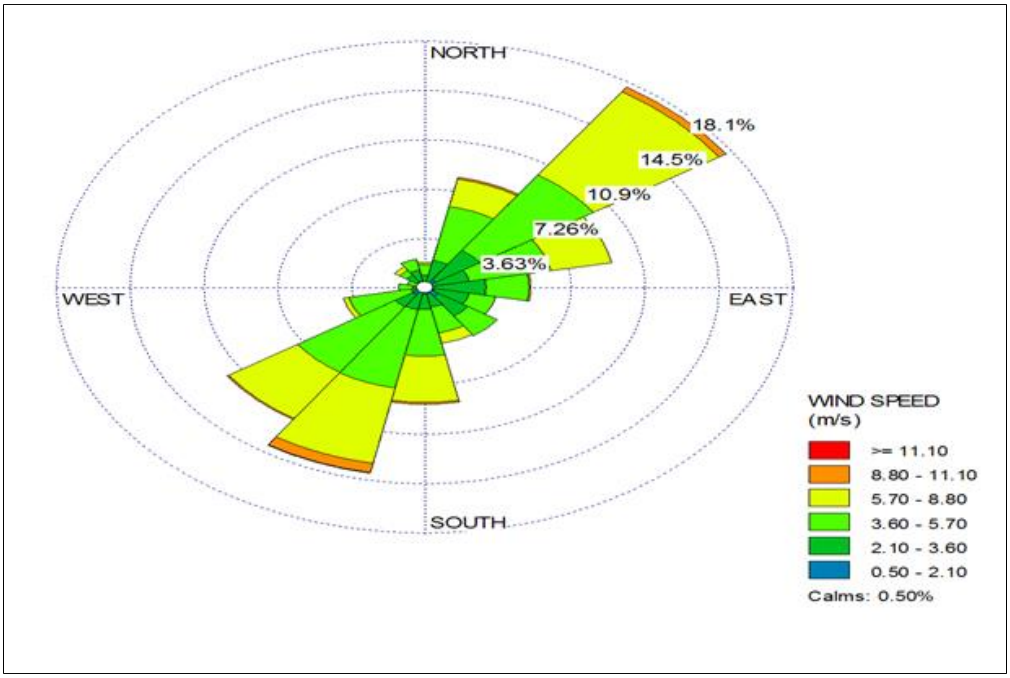


Figure 4-22: Upper air Spring wind rose for 2017 (SON)

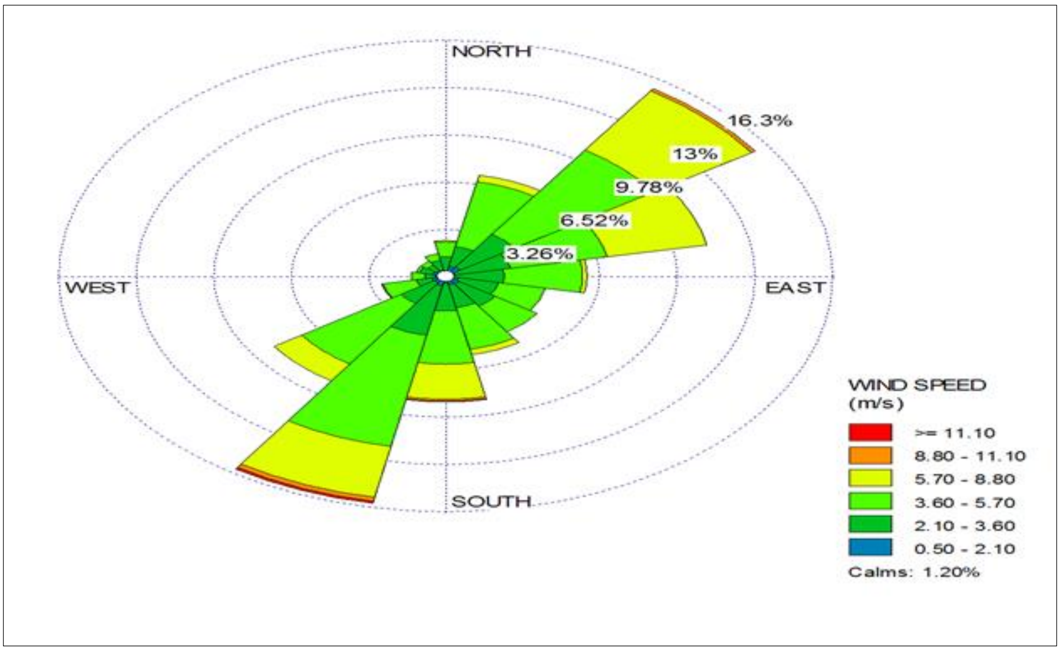


Figure 4-23: Upper air summer wind rose for 2017 (DJF)

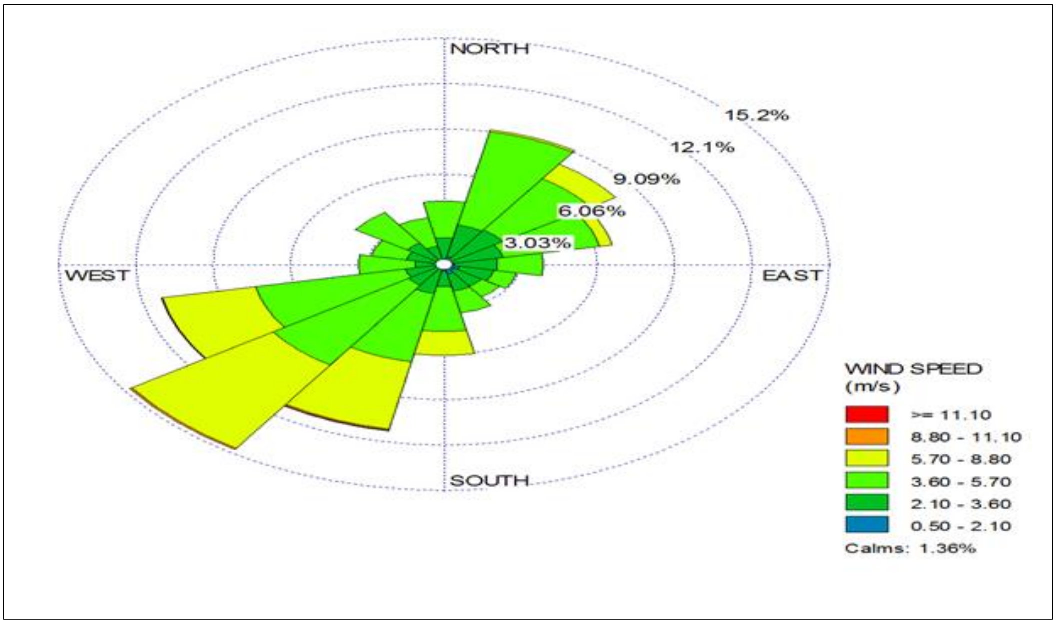


Figure 4-24: Upper air autumn wind rose for 2017 (MAM)

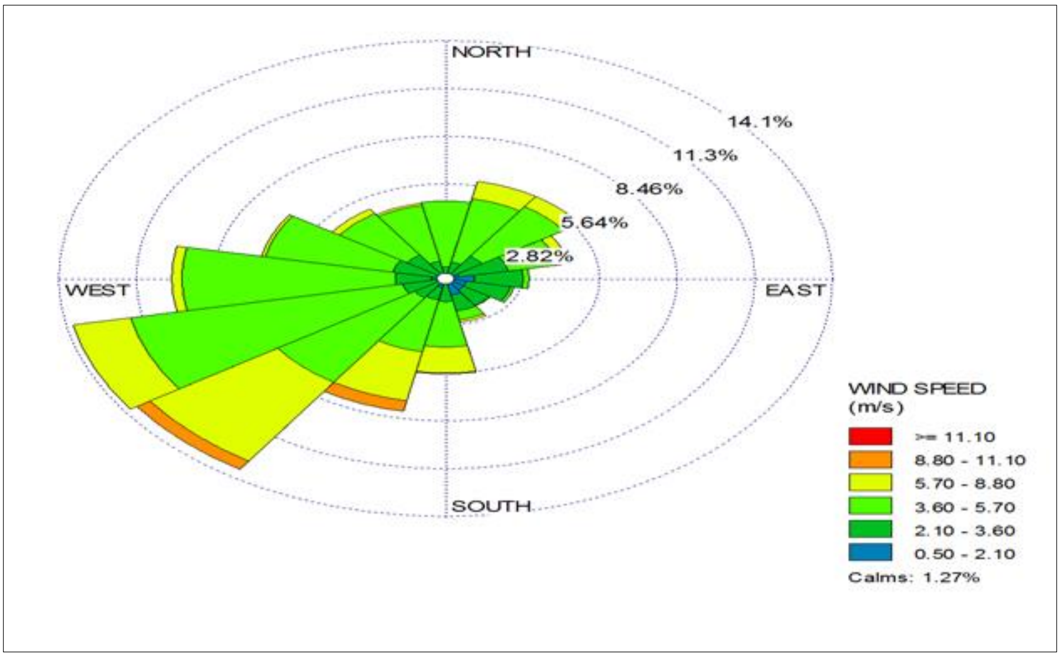


Figure 4-25: Upper air winter wind rose for 2017 (JJA)

4.6.1.3. Summary of prevailing winds

From Table 4-5, it can be seen that there is no seasonal variation in direction between the surface and upper air wind roses in the study area.

Table 4-5: Seasonal variation between surface and upper air wind roses

Surface Air		Upper Air	
Direction	Period	Direction	Period
North easterly	SON (Spring)	North easterly	SON (Spring)
North easterly	DJF (Summer)	North easterly	DJF (Summer)
South Westerly	MAM (Autumn)	South Westerly	MAM (Autumn)
South Westerly	JJA (Winter)	South Westerly	JJA (Winter)

During autumn and winter, three main wind direction prevail namely, north-east, south-west and northerly. Winds are relatively calmer, with the majority of winds occurring between 3.1–5.1 m/s. with respect to the dispersion of air pollution, during winter months, conditions are calmer therefore more stable conditions will be experienced over the South Durban Industrial Basin. The dispersion of pollutants in these conditions is low, which can potentially lead to a greater impact of emissions across a wider area. The calm conditions can also potentially lead to the creation of inversion layer, which further inhibits the dispersion of emissions within the basin. The break-up of an inversion can result in fumigation of trapped pollutants to ground level, and is easily recognized as peak on diurnal pollution graph (Simpson and McGee, 1996).

Nocturnal drainage winds are replaced above the crest line of individual valley by the seaward movement of cool air. This seaward movement of air is termed a land breeze and integrates with the mountain plan circulation that is formed due to the pressure gradients between the mountain and coastal areas of KwaZulu Natal. Mountain plain winds occur under conditions of stable equilibrium resulting in fanning plumes that are capable of travelling larger distances towards and beyond the Durban coastline.

During winter month, from late afternoon through the night, cool air drains from inland, down-valley towards the study site. The cools air dams up against the coastal dune (Bluff) and slowly moves in a northerly direction towards the Durban harbor. This results in pollution being released in the catchment area of the South Durban Industrial Basin. Contributing to background air pollution concentration around the harbor site. These topographically induced katabatic flows are probably the most adverse conditions for dispersion of pollutants from the study site and largely determined when peak pollution episode will be experienced to the east of the study site (Ricardo Energy and Environment, 2017). The katabatic wind become more pronounced with the addition of regional scale mountain-plan winds, which show a diurnal reversal. However, in this coastal environment the gentle daily winds (Anabatic Flow) are often overridden by stronger sea breezes and synoptic conditions which favour the study site for dispersion (Josipovic et al., 2010).

Previous research work has proven that atmospheric stability characteristics influence the diffusion of airborne pollutants in the atmosphere (Piotr et al., 2012). Unstable conditions occur most frequently during the day and in summer month favouring dispersion, whilst stable conditions experienced mainly at night during winter inhibits this dispersion, especially when laterally confined by the valley topography (Levis, 2004). Surface temperature inversions can dramatically increase ground-level pollution concentration, especially as the inversion breaks up in the mid-morning. Figure 4-26 shows the wind class frequency distribution.

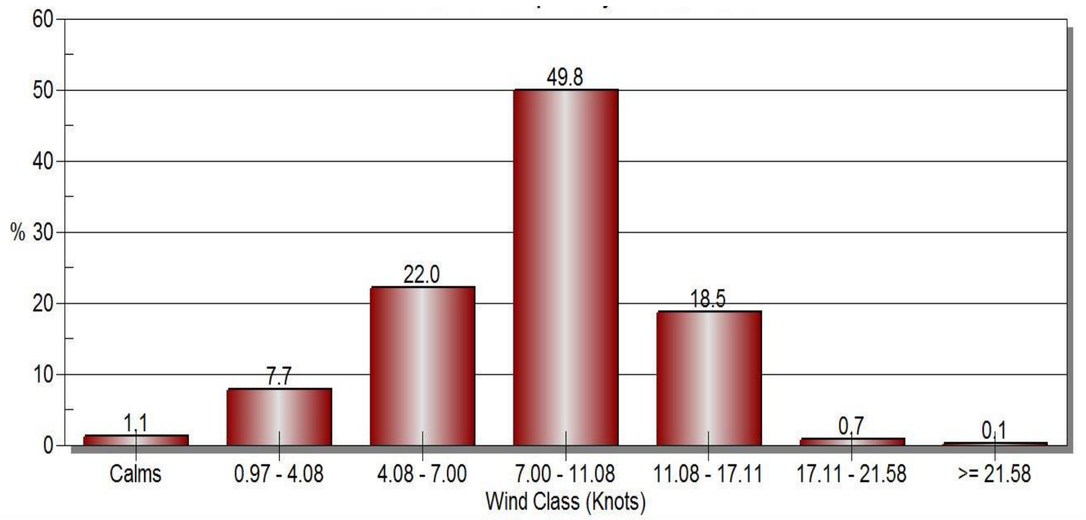


Figure 4-26: Wind class frequency distribution

4.6.2. Background concentrations and comparison with NAAQS

The background concentrations for PM_{10}, NO_2 and SO_2 emissions were interpreted in terms of the NAAQS. The NAAQS provide an averaging period, a concentration threshold and a number of allowable exceedances.

The allowable frequency of exceedance means you are allowed to exceed. For instance, the 24-hour average limit of PM_{10} is 75 µg/m^3. However, the 24-hour averaging period should not exceed four times (4 x 24-hour) per year. This is not high when one considers that there are 365 x 24-hour periods in a year. To put this into perspective, if we were to consider the NAAQS of PM_{10} for a period of 24 hours, it is specified that the daily ground level concentration for PM_{10} may exceed the regulatory threshold of 75µg/m^3 no more than 4 times. Should a model output show an exceedance of say a 100 over an area, it would mean that the regulatory threshold of 75 µg/m^3 was exceeded up to 100 times in 365 days. The model accounts for even the smallest exceedance of 75 µg/m^3, for example, 75.001 µg/m^3. The comparison of background concentrations with NAAQS values is presented in Table 4-6.

Table 4-6: Comparison of NAAQS with actual background concentrations for pollutants

Pollutant	Averaging Period	NAAQS (µg/m^3)	Permitted Frequency of Exceedance	Background Concentration (µg/m^3)
NO_2	1 Hour	**200**	88	16.0
	Annual	40	0	18.0

SO_2	1 Hour	**350**	88	20.0
	24 Hours	125	4	20.0
	Annual	50	0	10.0
PM_{10}	24 Hours	**75**	4	35.0
	Annual	40	0	17.5

4.6.3. Modelled output results

The following statistical outputs were calculated:

- Long-term (period) average is calculated by averaging all hourly concentrations over the modelled period (three years in this study). The calculation is conducted for each grid point within the modelling domain and at each discrete receptor for every line of meteorological data;
- Annual average is calculated by averaging all hourly concentrations over one calendar year. Values were compared with the annual NAAQS to assess likely health impacts across the model domain. The calculation is conducted for each grid point within the modelling domain and at each discrete receptor for every line of meteorological data;

4.6.3.1. Ambient and modelled PM_{10} Concentrations

Figure 4-27 shows daily mean PM_{10} concentrations measured at Southern Works during 2018 monitoring period. There were two exceedances of the daily PM_{10} which were experienced at Southern Works Monitoring station. The exceedances occurred on 22nd November 2018 (77 µg/m^3) and 28th November 2018 (256 µg/m^3). These exceedances could be attributed to the construction activities which occurred 3 metres away from the monitoring station.

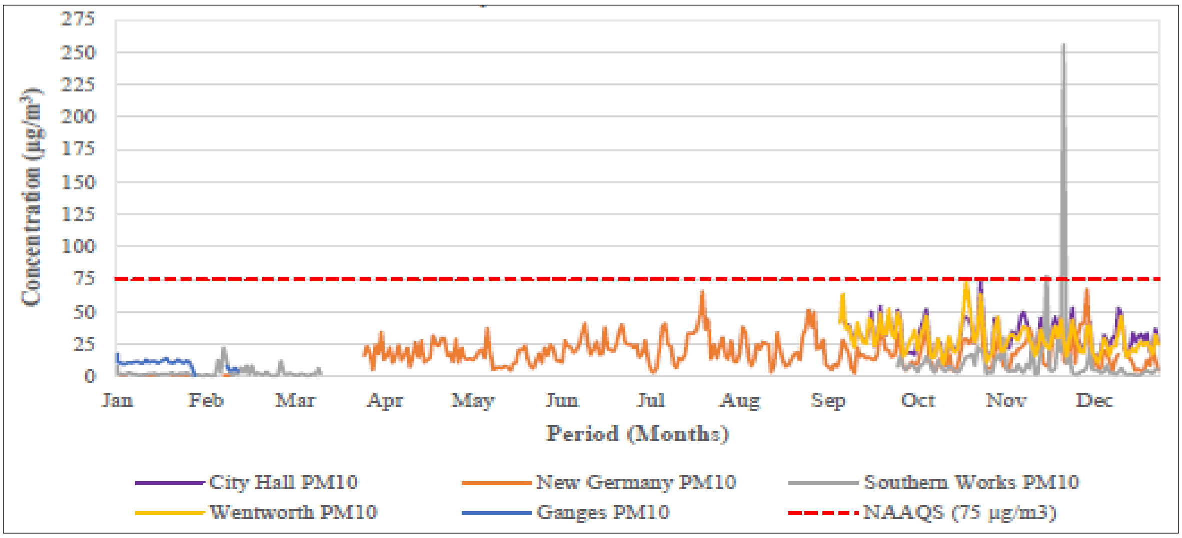
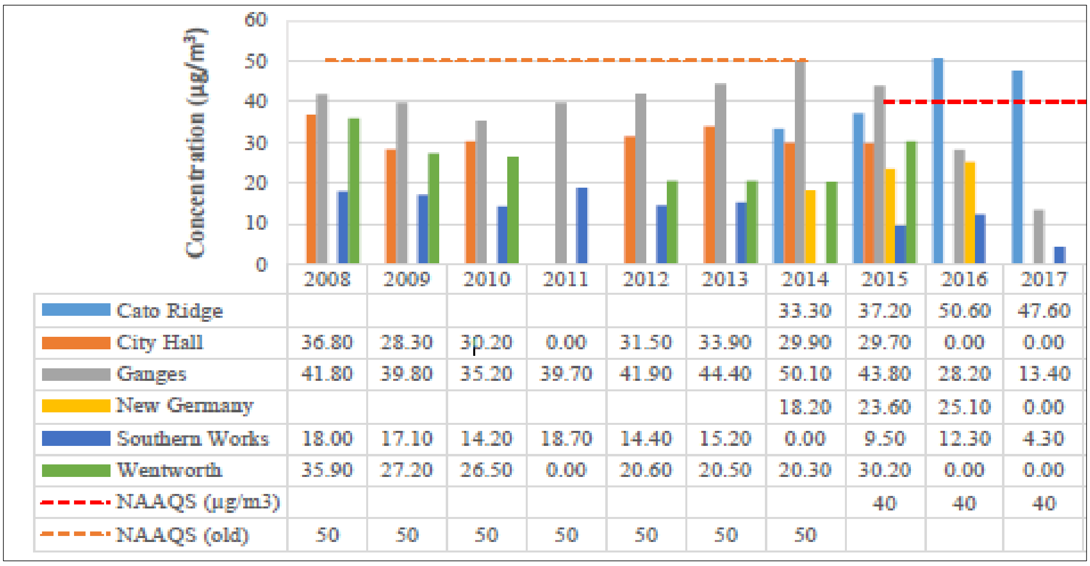


Figure 4-27: Daily mean PM_{10} Concentrations at eThekwini AQMN 01 January-31 December 2018 (eThekwini Municipality, 2018)

The annual PM_{10} concentrations are presented in Figure 4-28. The Figure presents data for six monitoring stations within eThekwini Municipality. The monitoring stations presented include Cato Ridge, City Hall, Ganges, New Germany, South Works and Wentworth. However, it is important to note that this research focused on the Southern Works Monitoring station.

It is noted from Figure 4-28 that from the year 2008 to 2013 there was no data presented for Cato Ridge and New Germany stations. The two stations were commissioned in the year 2014 and started reporting to air quality monitoring network monitoring. A year subsequent to commissioning of these two stations, the Department of Environmental Affairs (DEA) reviewed the NAAQS and set stricter ambient air quality standards. The old NAAQS for PM_{10}, which was 50 µg/m^3 was tightened to 40 µg/m^3 from the year 2015. As a result of this new PM_{10} NAAQS, two exceedances were experienced at Ganges Monitoring station in the year 2015 as well at Cato Ridge monitoring station in 2016 and 2017.

The Southern Works monitoring station which is located within the research area did not experience any exceedances of PM_{10} during the years 2015, 2016 and 2017. However, it is evident from Figure 4-28 that Ganges monitoring station experienced elevated PM_{10} concentration and exceeded both the old and new NAAQS for two consecutive years (2014 and 2015). For two subsequent years (2016 and 2017), Cato Ridge monitoring stations experienced exceedances of PM_{10}.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Cato Ridge							33.30	37.20	50.60	47.60
City Hall	36.80	28.30	30.20	0.00	31.50	33.90	29.90	29.70	0.00	0.00
Ganges	41.80	39.80	35.20	39.70	41.90	44.40	50.10	43.80	28.20	13.40
New Germany							18.20	23.60	25.10	0.00
Southern Works	18.00	17.10	14.20	18.70	14.40	15.20	0.00	9.50	12.30	4.30
Wentworth	35.90	27.20	26.50	0.00	20.60	20.50	20.30	30.20	0.00	0.00
NAAQS (µg/m3)								40	40	40
NAAQS (old)	50	50	50	50	50	50	50			

Figure 4-28: Annual PM_{10} concentrations long term trend at eThekwini AQMN (2008 - 2017) (eThekwini Municipality, 2018)

The predicted ambient PM_{10} concentrations associated with the coal fired boilers operations at each discrete receptor are presented in Table 4-7. The concentrations presented are for two averaging periods i.e. annual and daily. Long-term (annual) and short-term (P_{99} 24-hour average) PM_{10} concentrations were compared with the NAAQS.

The modelled annual average concentration was 18.3 µg/m^3. This concentration was experience at the receptor located at 304437.06 mE, 6689526.36 mS. The NAAQS for PM_{10} is 40 µg /m^3 which was set to protect the receiving environment and these standard should not be exceeded. It's therefore noted the annual PM_{10} concentration of 18.3 µg/m^3 was below the set NAAQS (40 µg /m^3). In this case, the receiving environment located in south easterly direction from the source of emission was not impacted by PM_{10} emissions. Figure 4-29 shows the isopleths that demostrates the annual average dispersion of PM_{10} plume from the source of generation. It is noted that the maximum concentration of 18.3 µg/m^3 was experienced at the fenceline of the source. The PM_{10} concentration decreases as the distance from the source of generation increases. This was proven by PM_{10} concentration which was 18.3 µg/m^3 at the source but 0.2 µg/m^3 few kilometres away from the source.

The predicted ambient PM_{10} concentrations associated with the coal fired boilers operations at each discrete receptor are presented in Table 4-7. The concentrations presented are for two averaging periods i.e. annual and daily. Long-term (annual) and short-term (P_{99} 24-hour average) PM_{10} concentrations were compared with the NAAQS.

The modelled 24-Hours average concentration was 105µg/m^3. This concentration was experience at the receptor located at 304983.90 mE, 6689967.92 mS. The NAAQS for PM_{10} is 75 µg /m^3 which was set to protect the receiving environment and this standard should not be exceeded. It's therefore noted the 24-Hours average PM_{10} concentration of 105µg/m^3 was above the set NAAQS (75 µg /m^3). In this case, the receiving environment located in south easterly direction from the source of emission was impacted by PM_{10} emissions. However, the permitted frequency of exceedance was not exceedance. As such, no adverse health effect was experienced by the community.

Figure 4-29 and Figure 4-30 show the isopleths that demostrate the annual and 24-Hours average dispersion of PM_{10} plume from the source of emission generation respectively. It is noted that the maximum concentrations of 18.3 µg/m^3 and 105 µg/m^3 were experienced at the fenceline of the source for annual and 24-Hours average respectively. The PM_{10} concentration decreases as the distance from the source of generation increases. For instance, for the 24-Hours average, the concentration was 105 µg/m^3 at the source but 1 µg/m^3 few kilometres away from the source. The same was observed for annual average concentration where the concentration at the source was 18.3 µg/m^3 while the concentration few kilometres away was 0.2 µg/m^3.

Table 4-7: Maximum Modelled Ground Level Concentrations

Pollutant	Averaging Period	Modelled Results (µg/m^3)	**NAAQS**	Receptor's location in UTM Coordinates	
				mE	mS
Particulate Matter (PM_{10})	Annual	18.3 µg/m^3	40	304437.06	6689526.36
	24-HR	105 µg/m^3	75	304983.90	6689967.92

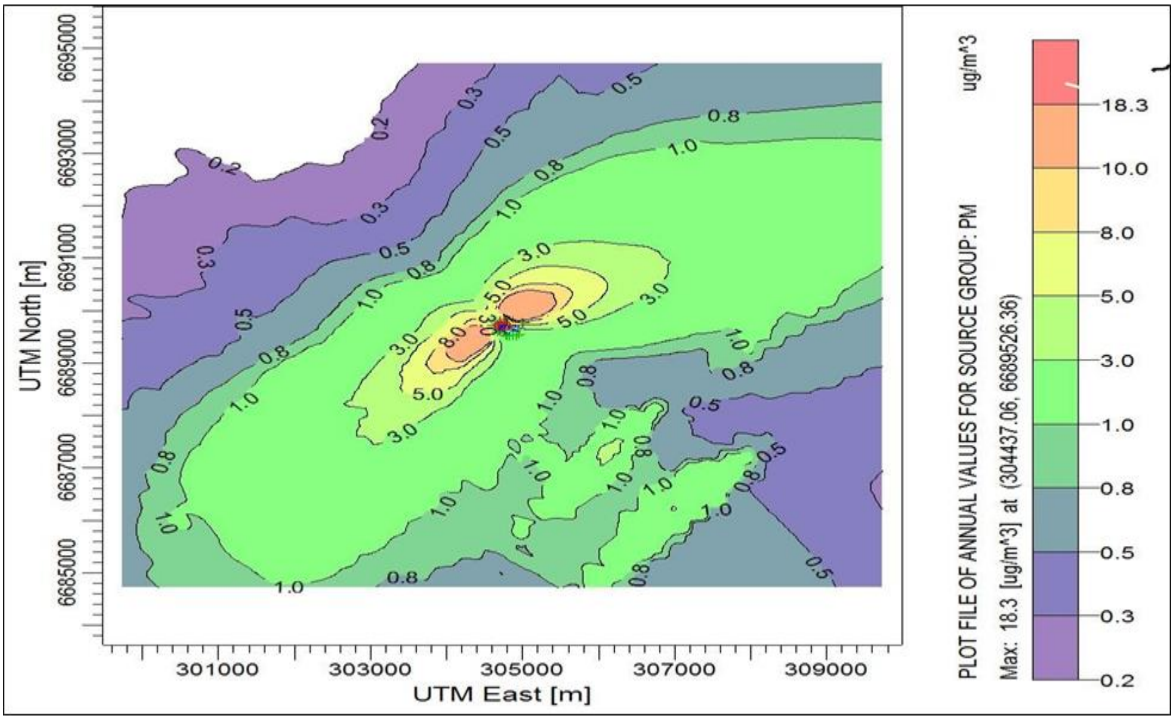


Figure 4-29: Isopleths depicting annual PM dispersion

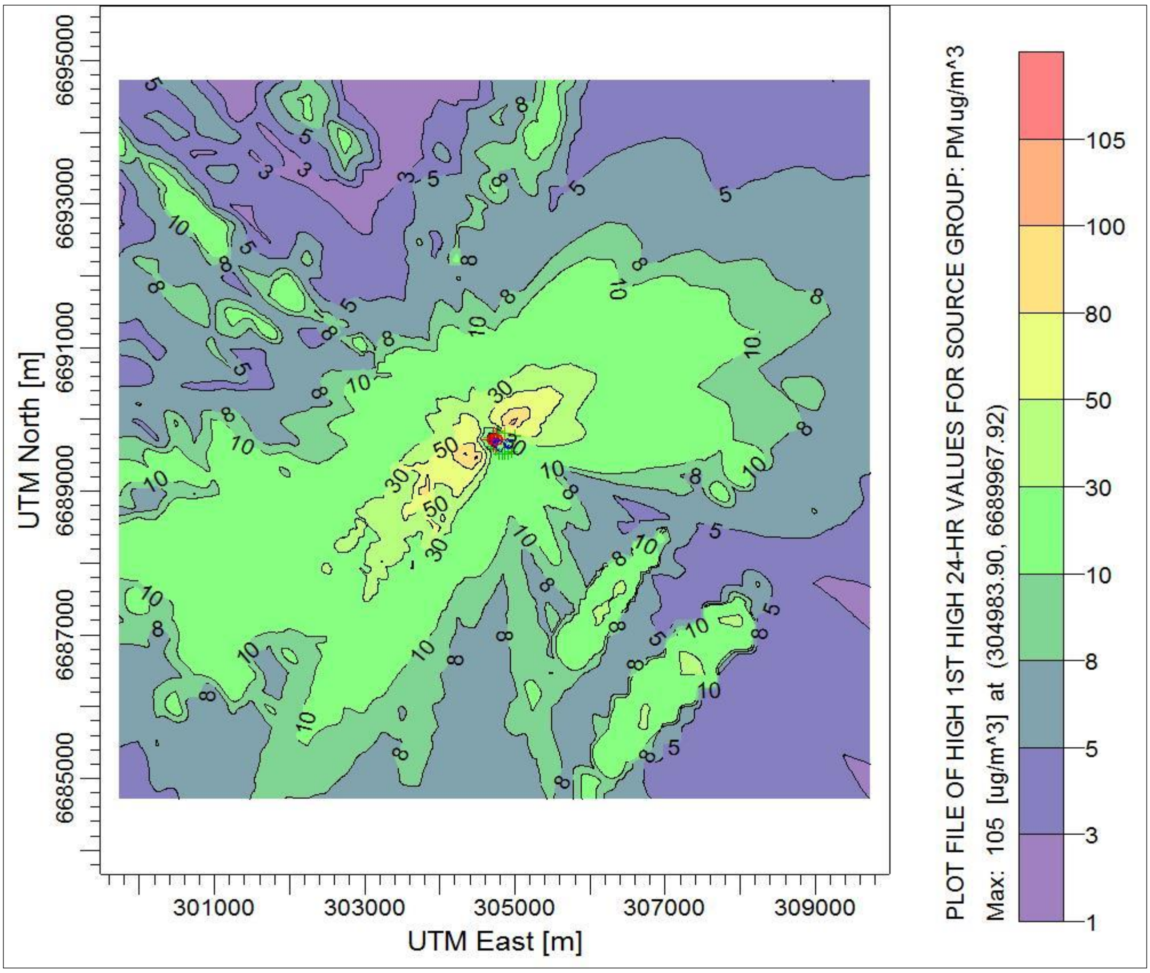


Figure 4-30: Isopleths depicting PM dispersion for 24 hour period

4.6.3.2. Ambient and modelled NO_2 Concentrations

The predicted modelled ambient NO_2 concentrations associated with the coal fired boilers operations at each discrete receptor are presented in Table 4-8. The concentrations presented are for the annual (long term) and 1-HR (short-term) averaging periods. These concentrations were subsequently compared with the NAAQS to determine the exposure levels.

Figure 4-31 shows the isopleths that demostrates the annual average dispersion of NO_2 plume from the source of generation. The highest modelled annual (long term) average concentration was 10.1µg/m^3, whereas the minimum concentration was 0.1µg/m^3. The highest concentration which was experienced within the modelling domain at the receptor location was at 304437.06mE, 6689526.36mS.

The NAAQS, relating to annual (long term) average concentration NO_2 is 40 µg /m^3. This standard should not be exceeded as it was set to protect human being and the receiving environment. The concentration NO_2 is 40 µg /m^3 when compared with NAAQS was found not to have exceeded the standard. In this case, the receiving environment and human beings located in south easterly direction from the source of emission was not impacted by NO_2 emissions.

Figure 4-32 shows the isopleths that demostrates the NO_2 concentration dispersion for 1-HR averaging period from the source of generation. On the other hand, the highest modelled NO_2 for 1-HR averaging was 492.8 µg/m^3. When comparing this value with NAAQS (200 µg /m^3), it is evident that the exposure exceeded the NAAQS and the concentration was significantly high. The elevated NO_2 1-HR concentration of 492.8 µg/m^3 was experienced within the modelling domain located at the 303837.06mE, 6689326.36mS. The concentration recorded during typical operations exceeded the NAAQS (200 µg /m^3), however it was in within the permitted frequency of exceedance for NO_2, 1-HR which is 88.

Table 4-8: Maximum Modelled Ground Level Concentrations

Pollutant	Averaging Period	Modelled Results (µg/m^3)	**NAAQS**	Receptor's location in UTM Coordinates	
				mE	mS
Nitrogen Oxide (NO_2)	Annual	10.1 µg/m^3	40	304437.06	6689526.36
	1-HR	492.8 µg/m^3	200	304483.90	6689467.92

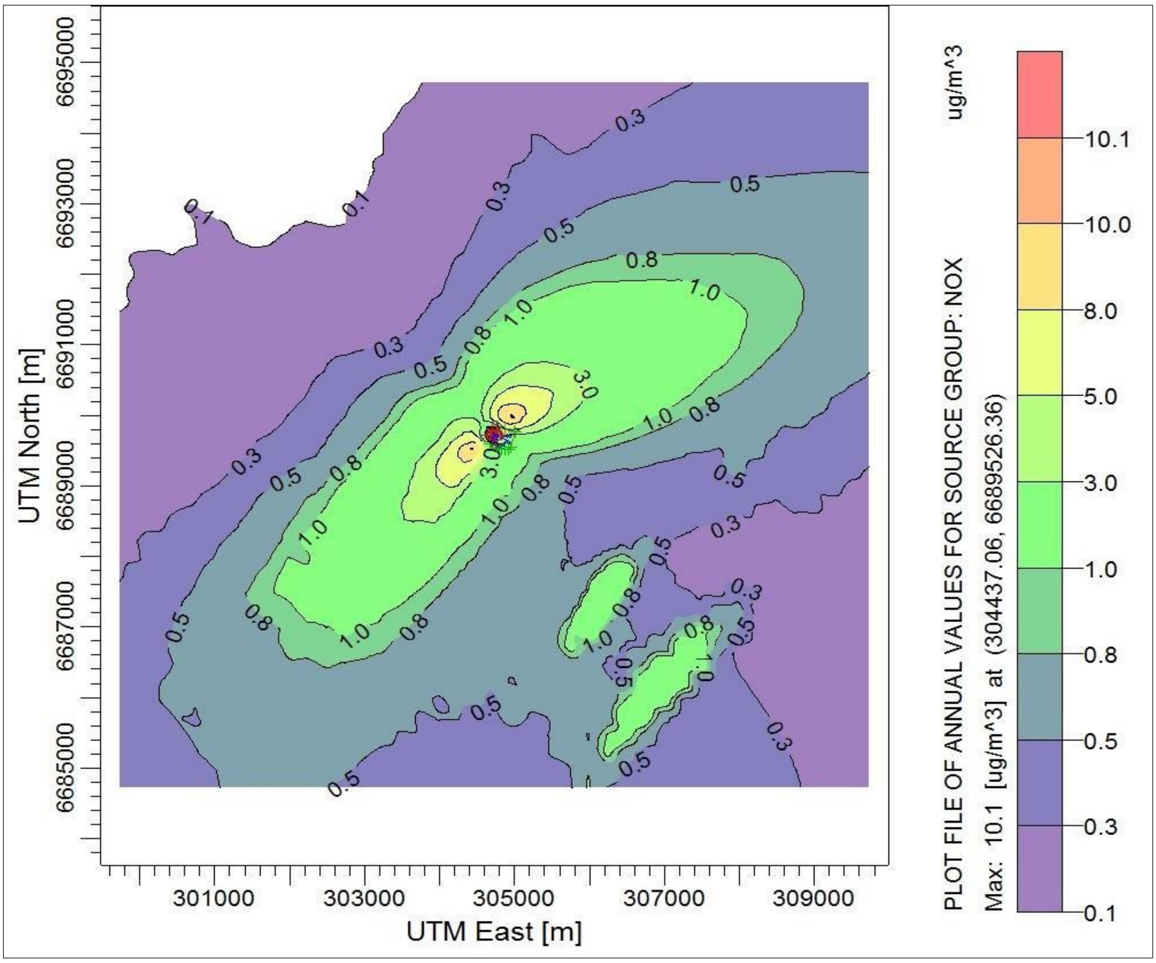


Figure 4-31: Isopleths depicting annual NO_2 dispersion

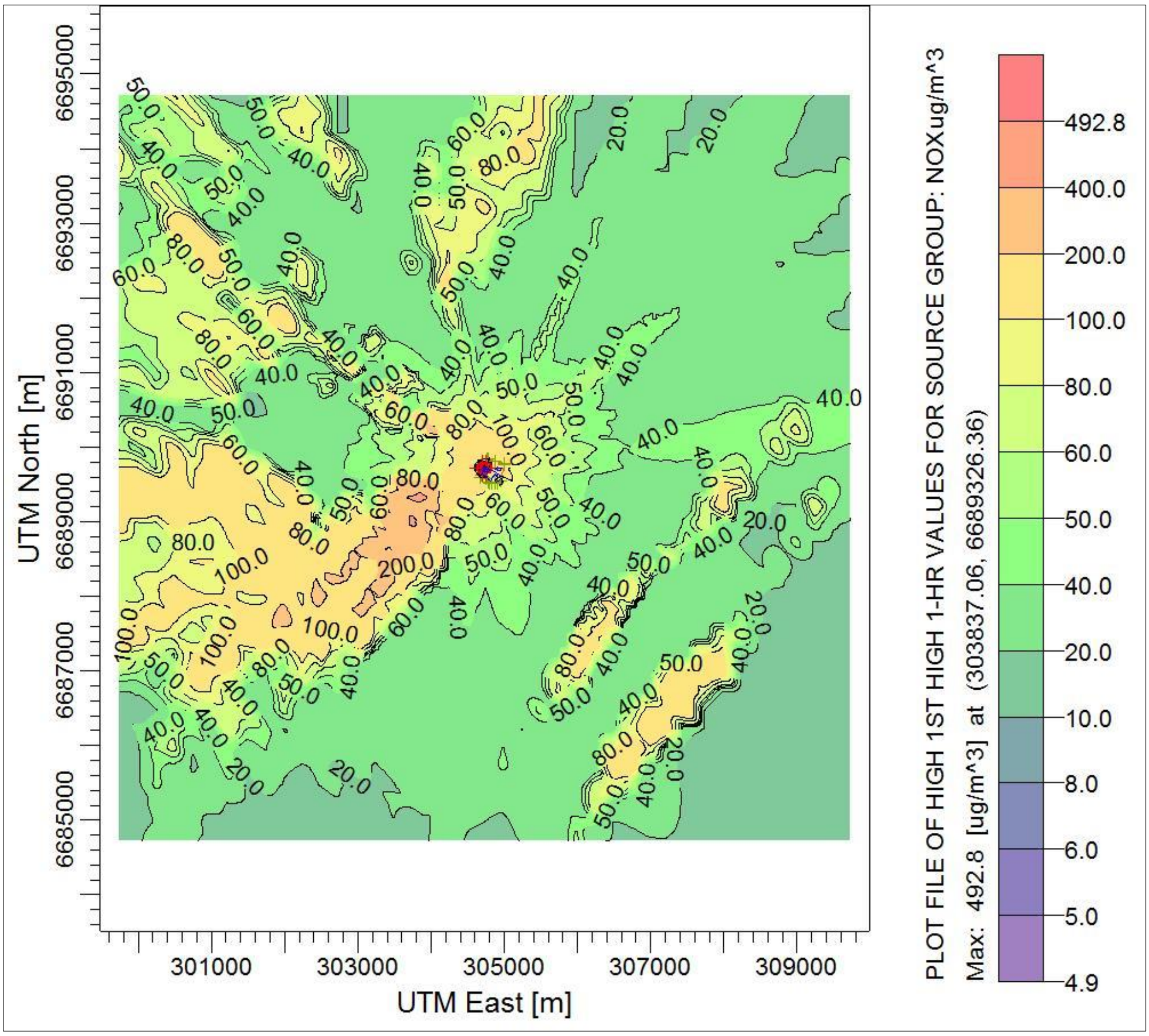


Figure 4-32: Isopleths depicting NO_2 dispersion for a 1 hour period

4.6.3.3. Ambient and modelled SO_2 Concentrations

Figure 4-33 shows SO_2 monthly mean for Southern Works air quality monitoring stations during the 2018 monitoring period. There was an exceedance of the daily mean NAAQS for SO_2 at Southern Works on the 21 November 2018 with the highest concentration of 49.96 ppb. Elevated SO_2 concentrations at Southern Works are observed in November and December which coincide with the commencement of the construction building adjacent to the monitoring station. Overall daily mean SO_2 concentrations were general below the NAAQS of 48 ppb.

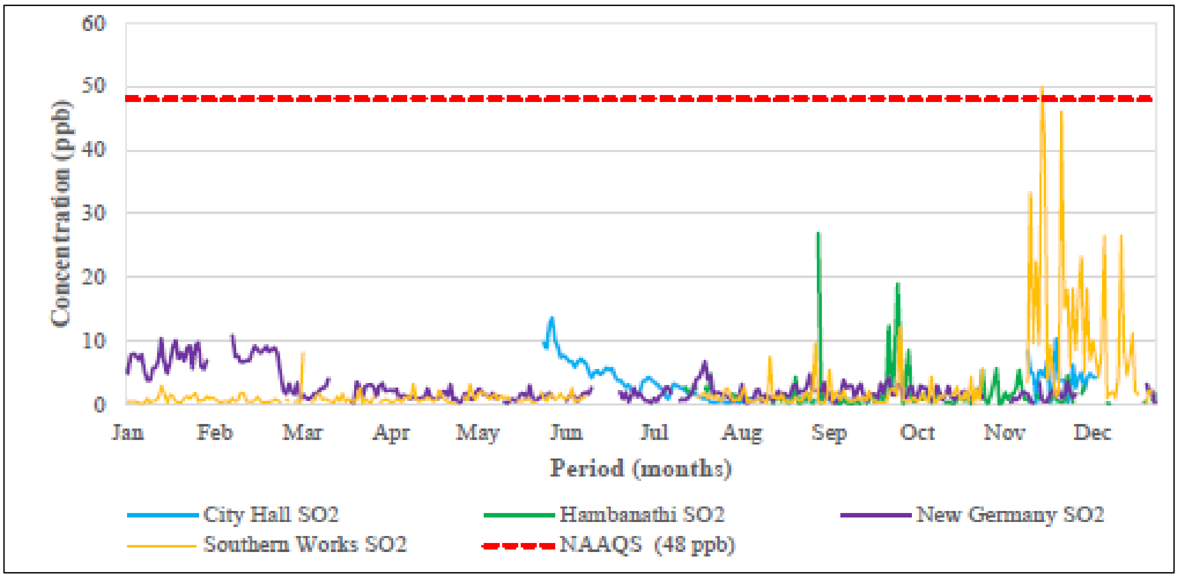
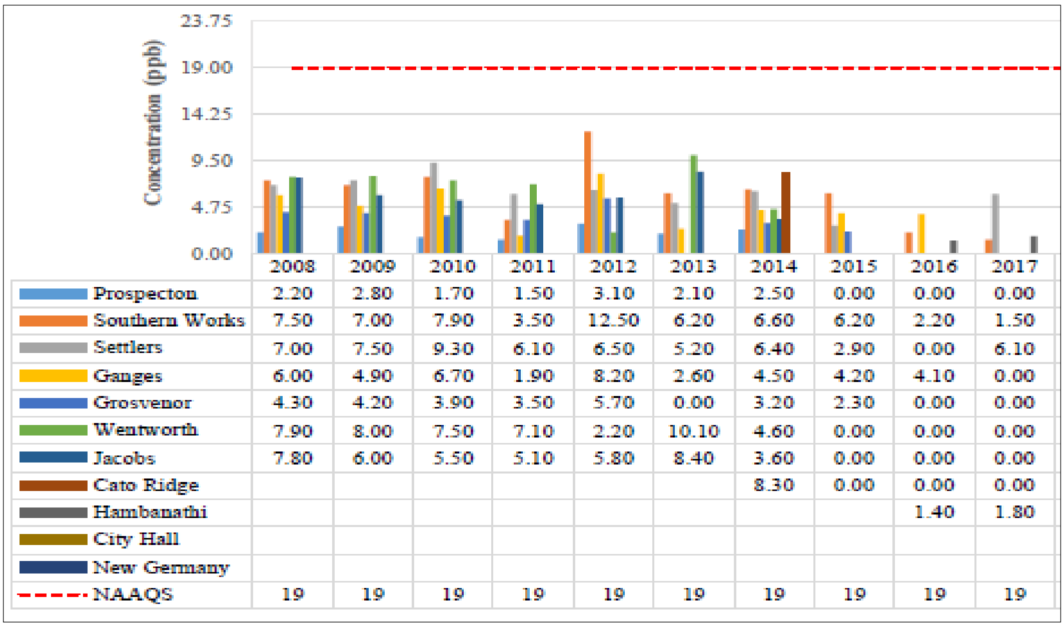


Figure 4-33: Monthly mean SO_2 concentrations at eThekwini AQMN 01 January-31 December 2018 (eThekwini Municipality, 2018)

Figure 4-34 presents the SO_2 concentrations across the eThekwini Air Quality Monitoring stations. There were nine monitoring stations which were equipped with SO_2 analysers. These monitoring stations are named after the area of location, namely Prospecton, Southern Works, Settlers, Ganges, Grosvenor, Wentworth, Jacobs, Cato Ridge, Hambanathi, City Hall and New Germany. The SO_2 concentrations across the eThekwini Air Quality Monitoring stations below the annual SO_2 NAAQS The highest annual average ever recorded was in 2012 with a concentration of 12.5 ppb at Southern Works. There is a discernible downward trend; however data capture has been poor over the recent years due to power failure and ageing monitoring stations. As a result monitoring stations like New Germany and City Hall were offline during data collection.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Prospecton	2.20	2.80	1.70	1.50	3.10	2.10	2.50	0.00	0.00	0.00
Southern Works	7.50	7.00	7.90	3.50	12.50	6.20	6.60	6.20	2.20	1.50
Settlers	7.00	7.50	9.30	6.10	6.50	5.20	6.40	2.90	0.00	6.10
Ganges	6.00	4.90	6.70	1.90	8.20	2.60	4.50	4.20	4.10	0.00
Grosvenor	4.30	4.20	3.90	3.50	5.70	0.00	3.20	2.30	0.00	0.00
Wentworth	7.90	8.00	7.50	7.10	2.20	10.10	4.60	0.00	0.00	0.00
Jacobs	7.80	6.00	5.50	5.10	5.80	8.40	3.60	0.00	0.00	0.00
Cato Ridge							8.30	0.00	0.00	0.00
Hambanathi									1.40	1.80
City Hall										
New Germany										
NAAQS	19	19	19	19	19	19	19	19	19	19

Figure 4-34: Annual SO_2 concentrations long term trend at eThekwini AQMN (2008 – 2017) (eThekwini Municipality, 2018)

The predicted modelled ambient SO_2 concentrations associated with the coal fired boilers operations at each discrete receptor are presented in Table 4-9. The SO_2 concentrations presented are for the annual (long term) and 1-HR (short-term) and daily averaging periods. These concentrations were subsequently compared with the NAAQS to determine the exposure levels.

Figure 4-35 shows the isopleths that demostrates the annual average dispersion of SO_2 plume from the source of generation. The highest modelled annual (long term) average concentration was 8.91 µg/m^3, whereas the minimum concentration was 0.09 µg/m^3. The highest concentration which was experienced within the modelling domain at the receptor location was at 304337.06mE, 6689426.36mS. The NAAQS, relating to annual (long term) average concentration for SO_2 is 50 µg /m^3. This standard should not be exceeded as it was set to protect human being and the receiving environment. The concentration SO_2 is 8.91µg/m^3 when compared with NAAQS was found not to be in compliance with the standard. In this case, the receiving environment and human beings located in south easterly direction from the source of emission was not impacted by SO_2 emissions.

Figure 4-36 shows the isopleths that demostrates the daily average dispersion of SO_2 plume from the source of generation. The highest modelled SO_2 24-Hours average concentration was 74.7µg/m^3. When comparing this value with NAAQS (125µg /m^3), it was found to be compliant. The maximum 74.7µg/m^3 concentration of 24-Hours $SO_2$was experienced within the modelling domain located at the 303637.06mE, 6688926.36mS. The concentration recorded during typical operations was below the NAAQS of 200 µg /m^3.

Figure 4-37 shows the isopleths that demostrates the hourly average dispersion of SO_2 plume from the source of generation. The highest modelled SO_2 1-HR average concentration was 632.6µg/m^3. When comparing this value with NAAQS (350 µg /m^3), it is evident that the exposure exceeded the NAAQS and the concentration was significantly high. The elevated SO_2 1-HR concentration of 632.6µg/m^3 was experienced within the modelling domain located at the 304483.90mE, 6689467.92mS. The concentration recorded during typical operations exceeded the NAAQS (200 µg /m^3). The permitted frequency of exceedance for 1-HR SO_2 averaging period was 88. The elevated SO_2 1-HR concentration of 632.6µg/m^3 was exceeded once as a result it was within the permitted frequency of exceedance for SO_2, 1-HR.

Table 4-9: Maximum Modelled Ground Level Concentrations

Pollutant	Averaging Period	Modelled Results (µg/m^3)	NAAQS	Receptor's location in UTM Coordinates	
				mE	mS
Sulphur Dioxide (SO_2)	Annual	8.9 µg/m^3	50	304437.06	6689526.36
	24-HR	74.7 µg/m^3	125	304337.06	6689526.36
	1-HR	632.6 µg/m^3	350	304483.90	6689467.92

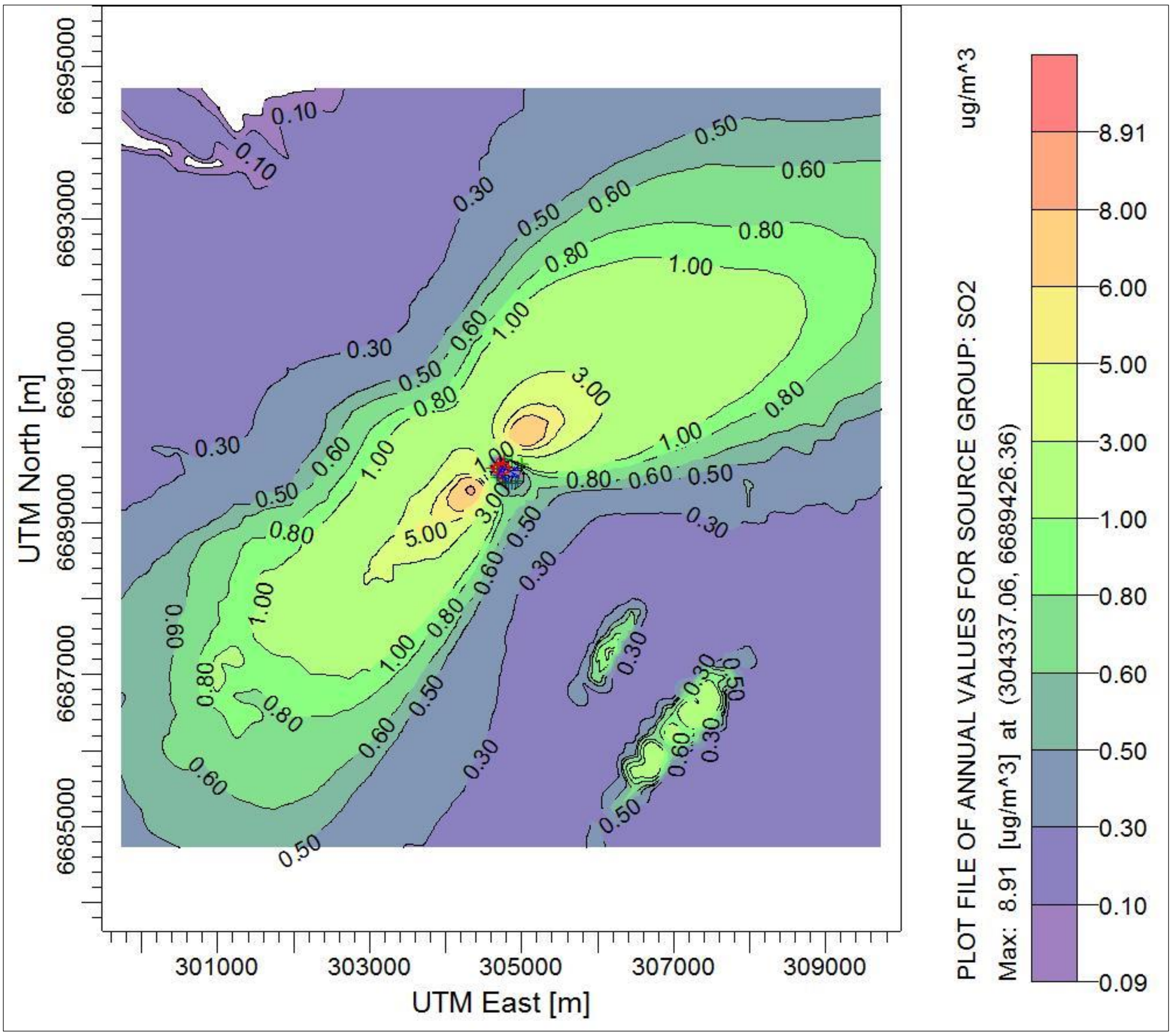


Figure 4-35: Isopleths depicting annual SO_2 dispersion

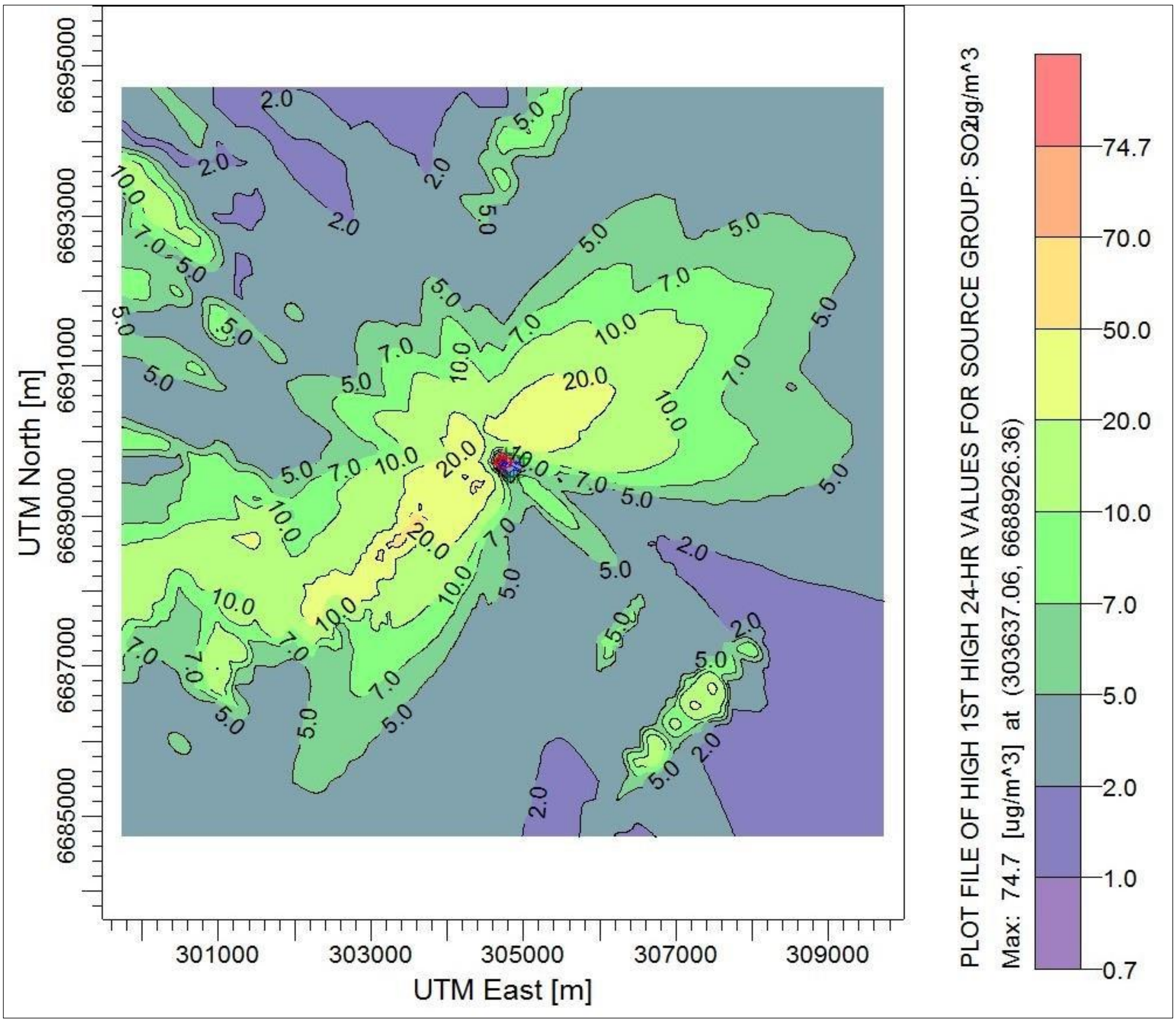


Figure 4-36: Isopleths depicting SO_2 dispersion for a 24 hour period

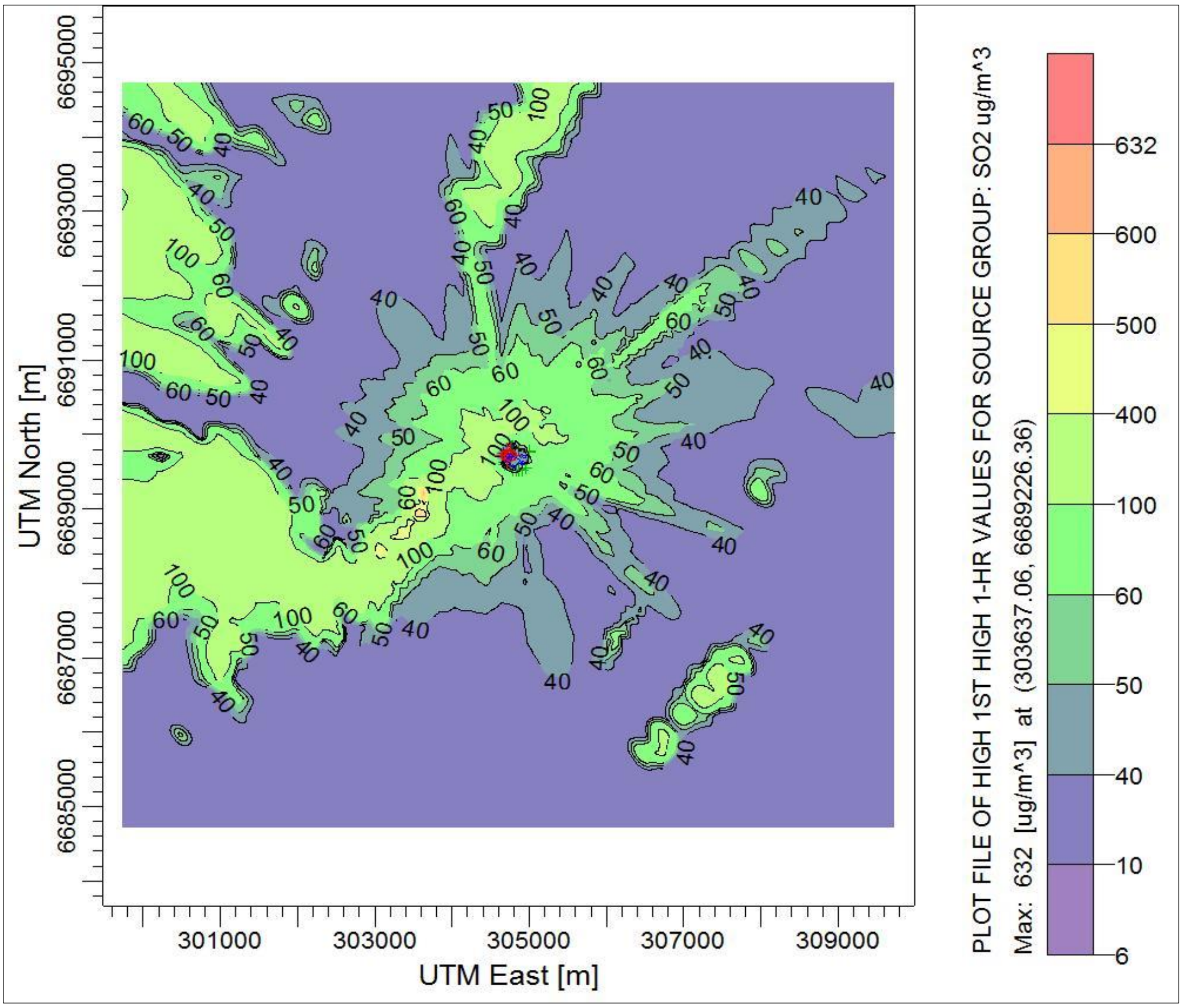


Figure 4-37: Isopleths depicting SO_2 dispersion for a 1 hour period

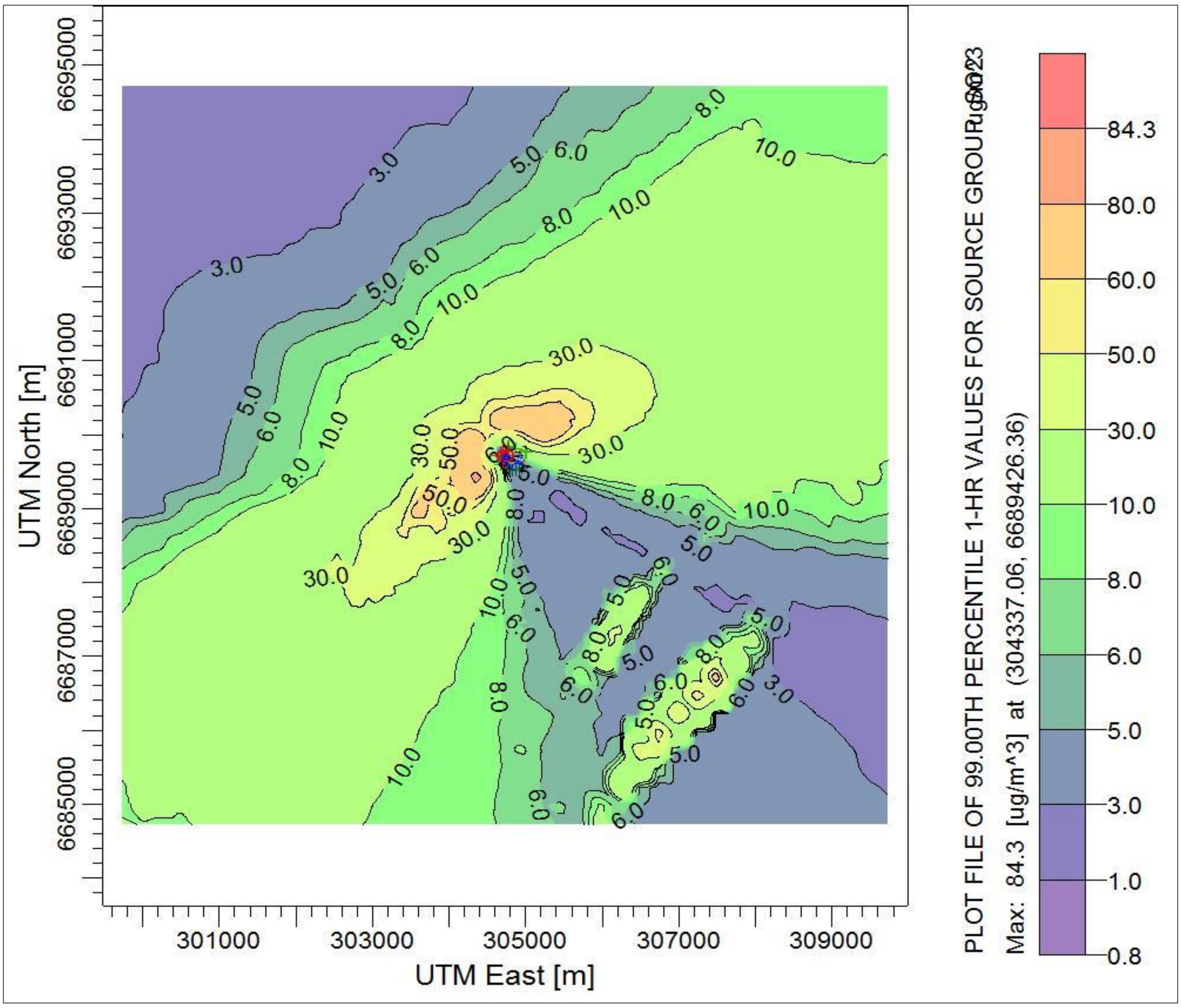


Figure 4-38: Isopleths depicting SO_2 dispersion for a 10 minute period

4.6.4. Comparison of actual and modelled results

Table 4-10 shows the comparison of ground level concentrations with modelled results for PM_{10}, NO_2 and SO_2.The predicted ground level concentration, as a result of PM_{10} emission concentration emitted from the boiler stack was compared with the annual and 24-Hours averaging periods. The permitted frequency of exceedance for an annual average is zero (0), whereas that of 24-Hours average is four (4). This means that for PM_{10} annual averaging period, no exceedance is allowed throughout the year. However, for PM_{10} 24-Hours averaging period the exceedances should not be experienced for more than four (4) times.

Table 4-10: Comparison of background concentrations with modelled concentrations

Pollutant	**Averaging Period**	**Permitted Frequency of Exceedance**	**Background Concentration ($\mu g/m^3$)**	**Modelled Results ($\mu g/m^3$)**
PM_{10}	Annual	0	17.5	18.3
	24 Hours	4	35.0	105
NO_2	Annual	0	18.0	10.1
	1 Hour	88	16.0	492.8
SO_2	Annual	0	10.0	8.9
	24 Hours	4	20.0	74.7
	1 Hour	88	20.0	632.6

The modelled PM_{10} ground level annual average concentration of 18.3 $\mu g/m^3$, was higher than the background concentration which was 17.5$\mu g/m^3$. It is therefore noted that the modelled ground level annual PM_{10} concentration of 18.3$\mu g/m^3$ was below the set NAAQS (40 $\mu g/m^3$). In this case, the receiving environment in the vicinity of emission source was not impacted by PM_{10} emissions.

The compliance in terms of NO_2 is defined using the annual and 1-Hour averaging period. Similarly, for PM_{10} annual averaging period, the permitted frequency of exceedance is zero (0). However, the permitted frequency of exceedance for NO_2 1-Hour averaging period is 88. It is noted that the background concentration was significantly low (16 $\mu g/m^3$) compared to modelled ground level concentration of 492.8 $\mu g/m^3$ which exceeded even the NAAQS. However, since the allowable frequency of exceedance should not exceed 88 over an hourly period thus there was no impact to the receiving environment.

The averaging period for SO_2 is divided into annual, daily and 1-Hour. It is noted that the annual averaging period for all three pollutants (PM_{10}, NO_2 and SO_2) was zero i.e. they should not be exceeded. However, the daily averaging period for SO_2 was similar to that of PM_{10} with only 4 permitted frequency of exceedances. On the other hand, the SO_2 daily averages with 4 permitted frequency of exceedance was similar to PM_{10} (4 permitted frequency of exceedances). It is noted that all ground level concentrations for SO_2 complied with NAAQS with an exception of the hourly average which was 632.6 $\mu g/m^3$ (350$\mu g/m^3$). The permitted frequency of exceedance was exceeded only once and this was below the allowable frequency of 88. As such the community in the vicinity of the source of emission was not adversely impacted by emission.

4.7. Conclusion

The atmospheric emission dispersion was used to predict the downwind emission concentrations of air pollutants discharged from coal fired boilers. The predicted results assisted to anticipate emission events that posed adverse health impact for the receiving environment. The results of the distribution of sulphur dioxide, nitrogen dioxide and particulate matters concentration were derived from the point sources using Gaussian Dispersion Model. The results revealed that the concentration of NO_2 for 1-Hour was 492.8 µg/m^3 which exceeded the NAAQS of 200 µg/m^3 but compliant with the permitted frequency of exceedance and did not pose adverse health impact on the receiving environment. The results further revealed that the concentration of SO_2 for 1-Hour was 632.2 µg/m^3 which exceeded the NAAQS of 350 µg/m^3 but compliant with the permitted frequency of exceedance of 88 which in this regard did not pose adverse health impact on the receiving environment. The 24-Hours PM_{10} concentration also exceeded the NAAQS of 75 µg/m^3 but was compliant with the permitted frequency of exceedance which was four.

The atmospheric impact assessment of coal fired boilers concludes that all cumulative ambient concentration complied with the National Ambient Air Quality Standards beyond the site where the receiving environment were likely to be exposed.

CHAPTER FIVE

5. Conclusion and recommendation

5.1. Conclusion

There were two main objectives in this research. The first objective was to examine the concentration of particulate matter, sulphur dioxide and oxides of nitrogen emitted from the existing coal fired boilers located close to residential areas in the South Durban Industrial Basin while the second objective focused on the Dispersion modelling of emissions based on the data obtained from the stack emissions measurements.

The primary atmospheric pollutants that were assessed included SO_2, NO_2 and PM. Stack emission testing was conducted at periodic interval. The sampling site was selected such that a laminar flow of air was present in a stack. The minimum required number of transverse points were calculated. Gas sampling was performed isokinetically in order to take a representative sample of gas, liquid phase mist and solid phase material. Isokinetic sampling was achieved when the gas enters the sampling nozzle at the same velocity and direction as the gas travelling in the duct. In addition, to allow for non-uniformity of distribution samples were obtained from multiple points across the sampling plane in order to give an overall average of the emission.

Results indicate that Nitrogen Oxide was released at 7.91 g/s second whereas sulphur dioxide and particulate matter were released at 40.86 and 18.35 g/s respectively. The temperature at which these gases were released was 450.20 K for boiler, 320 and 504 for boiler 3 and 4 respectively. The distance at which the plume rises is determined by the rate at which pollutants are emitted and whether it has a higher temperature than the surrounding air. The stack height was 47.5m with a diameter of 2.60m for boiler 1 while it was 27.5 and 30.5 for boiler 3 and boiler 4.

The air pollution dispersion modelling was based on assessment of short and long term air pollution exposure arising from the emission discharge and background pollution. The modelling process used vertical and horizontal components of motion. The horizontal dispersion of emission in the boundary layer was a primary function of wind field whereas the vertical component was defined by the stability of the atmosphere and the depth of the surface mixing layer. This atmospheric impact assessment was combined with ambient air monitoring as well as the stack emission sampling.

Dispersion modelling simulation predicted long term, short term and 1-Hour average concentrations. Dispersion modelling simulation included the plume dispersion, the highest predicted emission concentrations, long term and short term SO_2, PM and NO_2 off-site concentrations. Pre-processed site specific data which included meteorological data, wind speed, wind direction, ambient air temperature, relative humidity atmospheric pressure and cloud cover were used. The NO_2 annual average concentrations for 2014, 2015 and 2016 meteorology demonstrated compliance with the annual average NO_2 standard. The highest predicted NO_2 annual average concentration of 10.1 µg/m^3 occurred at the 304437.06 mE, 6689526.36 mS receptor.

The concentration recorded during typical operations was compliant with the NAAQS (40 µg /m^3), whereas the concentration of 492.8 exceeded an averaging period of 1-Hour which was 200 µg /m^3 by 41%. This exceedance occurred in the south easterly direction of the source. However, the permitted frequency of exceedance was not exceeded. In this regard, the community was not adversely impacted. The 24-hour, 10 minutes and annual SO_2 concentrations were well below the NAAQS of 500,125 and 50 µg /m^3 respectively. However, the concentration of 632.2 for 1-hour averaging period exceeded the NAAQS of 350 µg /m^3 by 55.3%. This exceedance occurred in the south easterly direction from the source (304483.90 S, 66895467.92 E). The permitted frequency of exceedance was not exceeded, as such, the exposure did not cause any adverse impact to the community.

5.2. Recommendations

Based on the stack emission measurements and results, it is recommended that the facility undertakes frequent technological assessment to stay abreast with changing industrial best technology for minimising emissions from all coal fired boilers. This will enable the facility to keep up with ever changing air quality legislation. With reference to stack emission monitoring, it is recommended that the facility considers ambient monitoring rather than stack monitoring. With reference to coal sulphur monitoring, it is recommended that the sulphur content of coal used in the boilers shall not exceed 0.5. The following should also be taken into consideration:

- A grab sample of the coal supplied for the boiler should be collected once per week and sent to accredited laboratory for analysis.
- If the coal blend changes, then a representative sample and analysis should be conducted as soon as practicable preferably within five working days.
- If the coal source is changed, then a representative sample of coal should be used to confirm compliance with set standards
- The annual coal analysis report should be used to summarise grab sample taken during the year including a comparison with limit specified.

The use of low sulphur content is recommended as an interim solution. However, the Department of Environment, Forestry and Fisheries should legalise phasing out of dirty fuels. In addition to these recommendations, the use of cleaner fuels, such as methane gas and adoption of newer, cleaner production methods and technology will contribute to a reduction in ambient pollution levels.

Mandatory annual stack emission testing is required to provide a snapshot of actual emission control performance. It is proposed that data collation of continuous wind direction, wind speed data occurs annually for a minimum period of one month during peak operation period. Should this exercise depict exceedances of ambient concentration standard, then a formal stack emission testing for PM_{10} should be conducted.

From the findings of Dispersion modelling, the discharge stack height should be increased in order to increase emissions dispersion. This should be used as mitigation option. The increase of stack height does not reduce the concentration level, but it reduces the intensity of exposure at the most impacted areas of the receiving environment. The stack height elevates the transportation of plume and dispersion on pollution in the upper air. The facility should consider fumigation of the upper atmosphere during the low wind velocity periods. This can be done in association with a high-pressure zone, inversion breakup fumigation and recirculation of emissions when the atmosphere is stratified.

APPENDICES

AERMET Frequency of distribution for PLF

No.	Direction / Wind Classes (m/s)	0.50-2.10	2.10 - 3.60	3.60-5.70	5.70-8.80	8.80-11.10	>=11.10	Total
1.	348.75-11.25	65	220	520	23	2	0	830
2.	11.25-33.75	137	352	1388	258	3	0	2138
3.	33.75-56.25	133	599	1552	1035	33	0	3352
4.	56.25-78.75	128	575	1008	662	0	0	2373
5.	78.75-101.25	134	550	518	20	0	0	1222
6.	101.25-123.75	154	428	245	0	0	0	827
7.	123.75-146.25	206	385	274	0	0	0	865
8.	146.25-168.75	157	407	408	56	0	0	1028
9.	168.75-191.25	154	405	830	580	20	8	1997
10.	191.25-213.75	127	444	1331	931	86	16	2935
11.	213.75-236.25	132	334	1599	925	41	2	3033
12.	236.25-258.75	106	231	1298	290	6	0	1931
13.	258.75-281.25	110	227	749	25	0	0	1111
14.	281.25-303.75	99	219	522	21	0	0	861
15.	303.75-326.25	98	218	436	33	1	0	786
16.	326.25-348.75	93	200	425	18	0	0	736
	Sub-Total	2033	5794	13103	4877	192	26	26025
	Calm							279
	Missing /Incomplete							0
	Total							26304

Start Date: 2015-01-01 – 00:00
End Date: 2017-12-31-23:59
Frequency of Calm Winds: 1,06%
Average Wind Speed: 4,12m/s

AERMET Frequency of Distribution for PFL: Normalised

No.	Wind Direction	0.50-2.10	2.10 - 3.60	3.60-5.70	5.70-8.80	8.80-11.10	>=11.10	Total
1.	348.75-11.25	0,002471	0,008364	0,019769	0,000874	0,000076	0,000000	0,031554
2.	11.25-33.75	0,005208	0,013382	0,052768	0,009808	0,000114	0,000000	81,2800
3.	33.75-56.25	0,005056	0,022772	0,059002	0,039348	0,001255	0,000000	0,127433
4.	56.25-78.75	0,004866	0,021860	0,038321	0,025167	0,000000	0,000000	0,090214
5.	78.75-101.25	0,005094	0,020909	0,019693	0,000760	0,000000	0,000000	0,046457
6.	101.25-123.75	0,005855	0,016271	0,009314	0,000000	0,000000	0,000000	0,031440
7.	123.75-146.25	0,007832	0,014637	0,010417	0,000000	0,000000	0,000000	0,032885
8.	146.25-168.75	0,005969	0,015473	0,015511	0,002129	0,000000	0,000000	0,039082
9.	168.75-191.25	0,005855	0,015397	0,031554	0,022050	0,000760	0,000304	75,9200
10.	191.25-213.75	0,004828	0,016880	0,050601	0,035394	0,003269	0,000608	0,111580
11.	213.75-236.25	0,005018	0,012698	0,060789	0,035166	0,001559	0,000076	0,115306
12.	236.25-258.75	0,004030	0,008782	0,049346	0,011025	0,000228	0,000000	0,073411
13.	258.75-281.25	0,004182	0,008630	0,028475	0,000950	0,000000	0,000000	0,042237
14.	281.25-303.75	0,003764	0,008326	0,019845	0,000798	0,000000	0,000000	0,032733
15.	303,75 - 326,25	0,003726	0,008288	0,016575	0,001255	0,000038	0,000000	0,029881
16.	326,25 - 348,75	0,003536	0,007603	0,016157	0,000684	0,000000	0,000000	0,027981
	Sub-Total	77,290	0,220271	498,137	0,185409	7,299	988	0,989393
	Calm							0,10607
	Missing /Incomplete							0,000000
	Total							1,000000

Start Date: 2015-01-01 – 00:00

End Date: 2017-12-31-23:59

Frequency of Calm Winds: 1,06%

Average Wind Speed: 4,12m/s

AERMET: Frequency Count for SFL

No.	Direction / Wind Classes (m/s)	0.50-2.10	2.10 -3.60	3.60-5.70	5.70-8.80	8.80-11.10	>=11.10	Total
1.	348.75-11.25	130	440	1040	46	4	0	1660
2.	11.25-33.75	274	704	2776	516	6	0	4276
3.	33.75-56.25	266	1198	3104	2070	66	0	6704
4.	56.25-78.75	256	1150	2016	1324	0	0	4746
5.	78.75-101.25	268	1100	1036	40	0	0	2444
6.	101.25-123.75	308	856	490	0	0	0	1654
7.	123.75-146.25	412	770	548	0	0	0	1730
8.	146.25-168.75	314	814	816	112	0	0	2056
9.	168.75-191.25	308	810	1660	1160	40	16	3994
10.	191.25-213.75	254	888	2662	1862	172	32	5870
11.	213.75-236.25	264	668	3198	1850	82	4	6066
12.	236.25-258.75	212	462	2596	580	12	0	3862
13.	258.75-281.25	220	454	1498	50	0	0	2222
14.	281.25-303.75	198	438	1044	42	0	0	1722
15.	303.75-326.25	196	436	872	66	2	0	1572
16.	326.25-348.75	186	400	850	36	0	0	1472
	Sub-Total	4066	11588	26206	9754	384	52	52050
	Calm							558
	Missing /Incomplete							0
	Total							52608

Station ID:66666
Start Date: 2015-01-01-00:00
End Date: 2017-12-31-23:59
Frequency of Calm Winds: 1,06%
Average Wind Speed: 4,12m/s

AERMET Frequency Distribution for SFL: Normalised

No.	Wind Direction	0.50-2.10	2.10 - 3.60	3.60-5.70	5.70-8.80	8.80-11.10	>=11.10	Total
1.	348.75-11.25	0,002471	0,008364	0,019769	0,000874	0,000076	0,000000	0,031554
2.	11.25-33.75	0,005208	0,013382	0,052768	0,009808	0,000114	0,000000	81,2800
3.	33.75-56.25	0,005056	0,022772	0,059002	0,039348	0,001255	0,000000	0,127433
4.	56.25-78.75	0,004866	0,021860	0,038321	0,025167	0,000000	0,000000	0,090214
5.	78.75-101.25	0,005094	0,020909	0,019693	0,000760	0,000000	0,000000	0,046457
6.	101.25-123.75	0,005855	0,016271	0,009314	0,000000	0,000000	0,000000	0,031440
7.	123.75-146.25	0,007832	0,014637	0,010417	0,000000	0,000000	0,000000	0,032885
8.	146.25-168.75	0,005969	0,015473	0,015511	0,002129	0,000000	0,000000	0,039082
9.	168.75-191.25	0,005855	0,015397	0,031554	0,022050	0,000760	0,000304	75,9200
10.	191.25-213.75	0,004828	0,016880	0,050601	0,035394	0,003269	0,000608	0,111580
11.	213.75-236.25	0,005018	0,012698	0,060789	0,035166	0,001559	0,000076	0,115306
12.	236.25-258.75	0,004030	0,008782	0,049346	0,011025	0,000228	0,000000	0,073411
13.	258.75-281.25	0,004182	0,008630	0,028475	0,000950	0,000000	0,000000	0,042237
14.	281.25-303.75	0,003764	0,008326	0,019845	0,000798	0,000000	0,000000	0,032733
15.	303,75 - 326,25	0,003726	0,008288	0,016575	0,001255	0,000038	0,000000	0,029881
16.	326,25 - 348,75	0,003536	0,007603	0,016157	0,000684	0,000000	0,000000	0,027981
	Sub-Total	77,290	0,220271	498,137	0,185409	7,299	988	0,989393
	Calm							0,10607
	Missing /Incomplete							0,000000
	Total							1,000000

Station ID:66666

Start Date: 2015-01-01-00:00

End Date: 2017-12-31-23:59

Frequency of Calm Winds: 1,06%

Average Wind Speed: 4,12m/s

Technical Stack Parameters

Historical data						
Run Number		Run 1	Run 2	Run 3	Average	Unit of measure
Run Start Time		12:10	13:40	15:00		hh:mm
Run stop time		13:10	14:40	16:00		Hh:mm
Meter calibration factor	(Y)	0.986	0.986	0.986		
Pitot tube coefficient	(C_P)	0.840	0.840	0.840		
Actual nozzle diameter	(D_{na})	4.572	4.572	4.572		mm
Stack Sampling Data						
Initial Meter Volume	$(V_m)_i$	327.393	327.393	327.393		m^3
Final Meter Volume	$(V_m)_f$	327.956	328.555	329.156		m^3
Total Meter Volume	(V_m)	0.563	0.596	0.597	0.585	m^3
Total sampling time	(Θ)	60.0	60.0	60.0	60.0	min
Average Meter Temperature	$(t_m)_{avg}$	27.0	27.8	27.7	27.5	°C
Average stack temperature	$(t_s)_{avg}$	17407	177.3	179.7	177.2	°C
Barometric Pressure	(P_b)	764.31	764.31	764.31	764.31	mm Hg
Stack Static Pressure	(P_{static})	-11.00	-11.0	-11.0	-11.0	mm H_2O
Absolute Static Pressure	(P_s)	763.50	763.50	763.50	763.50	mm Hg
Average Orifice Pressure Drop	$(\square H)_{avg}$	9.78	10.82	11.03	10.54	mm H_2O
Absolute Meter Pressure	(P_m)	765.03	765.11	765.12	765.09	mm Hg
Average Square Root Pitot Pressure	$((\square p_{1/2})_{avg}$	3.60	3.71	3.84	3.72	mm H_2O
Moisture Content						
Impingers 1 to 4 Water Volume Gain	(V_n)	6.7	25.0	20.7	17.5	ml
Impinger 4 Silica Gel Weight Gain	(W_n)	3.5	2.1	1.5	2.4	g
Total Water Volume Collected	(W_{ic})	10.2	27.1	22.2	19.8	ml
Standard Water Vapour Volume	$(V_w)_{std}$	0.014	0.036	0.030	0.026	scm
Standard Meter Volume	$(V_m)_{std}$	0.0509	0.537	0.538	0.528	dcm
Calculated Stack Moisture	$(B_{ws(calc)})$	2.6	6.3	5.2	4.7	%
Saturated Stack Moisture	$(B_{ws(svp)})$	100.0	100.0	100.0	100.0	%
Reported Stack Moisture Content	(B_{ws})	2.6	6.3	5.2	4.7	%

Gas Analysis Data						
Carbon Dioxide Percentage	(%CO2)	8.3	8.2	8.1	8.2	%
Oxygen Percentage	(%O2)	11.8	11.9	12.0	11.9	%
Carbon Monoxide Percentage	(%CO)	0.0001	0.0001	0.0001	0.0001	%
Nitrogen Percentage	(%N2)	79.9	79.9	79.9	79.9	%
Dry Gas Molecular Weight	(Md)	29.80	29.78	29.78	29.79	g/g-mole
Wet Gas Molecular Weight	(Ms)	29.49	29.04	29.17	29.23	g/g-mole

Volumetric Flow Rate Data						
Average Stack Gas Velocity	(V_s)	14.90	15.52	16.09	15.50	m/sec
Stack Cross-sectional area	(A_s)	5.31	5.31	5.31	-	m^2
Actual stack flow rate	(Q_{aw})	4746.04	4943.43	5126.65	4938.71	acm/m
Wet standard flow Rate	(Q_{aw})	174.46	180.64	186.37	180.49	wkcmh
Dry standard flow rate	(Q_{sd})	2831.85	2820.78	2944.16	2865.60	dscm/m

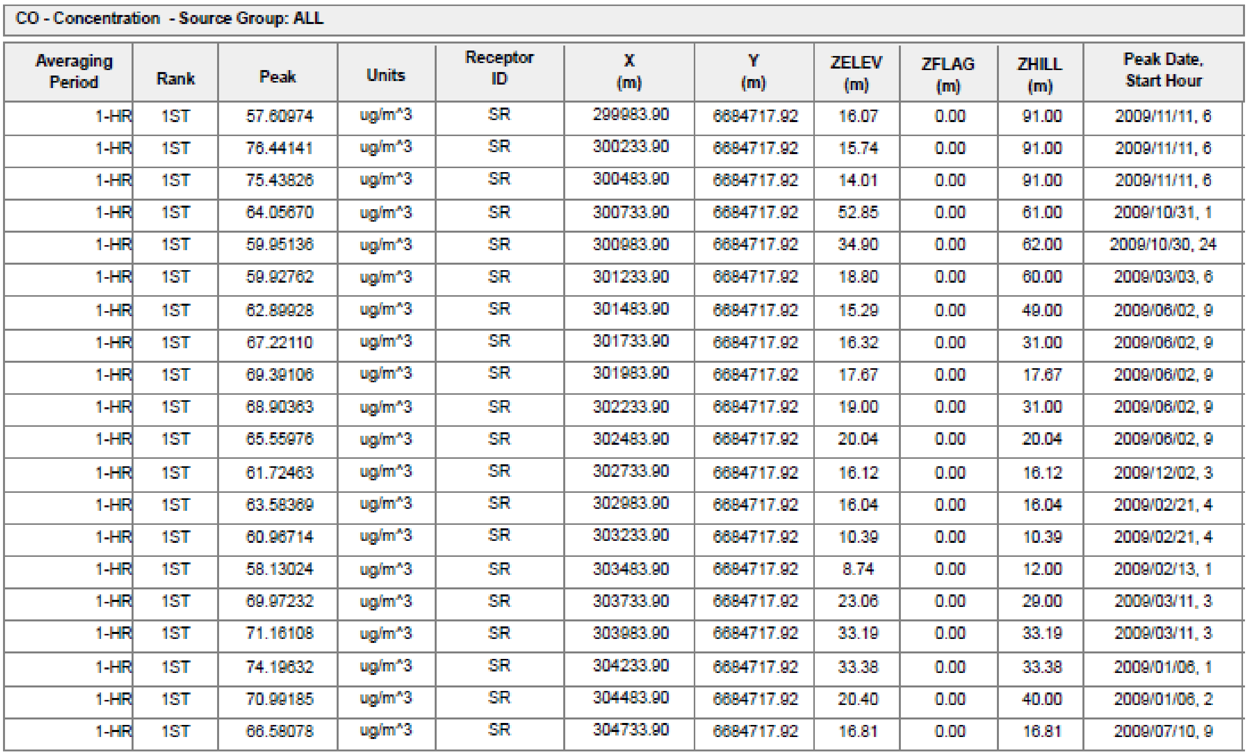
Percentage of Isokinetic Rate	(I)	96.8	102.6	98.5	99.3	%

Analytical Data						
Mass of Particulate on Filter	(m_f)	91.3	105.7	102.7	99.7	mg
Mass of Particulate in Acetone	(m_a)	104.5	100.7	104.0	103.1	mg
Mass due to acetone	(W_a)	0.0	0.0	0.0	0.0	mg
Total Mass of Particulate	(m_n)	195.8	206.4	206.2	202.8	mg

Concentration Data						
Run number		1	2	3	Average	
Stack Particulate Concentration	PM(C_s)	0.38499	0.38445	0.38321	0.38422	g/dscm
		384.99	384.45	383.21	384.22	mg/dscm
		466.25	465.60	464.10	465.32	mg/Nm^3
Stack Particulate Concentration	PM_{10}(C_s)	129.45	132.16	131.03	130.88	mg/dscm
		156.77	160.06	158.69	158.50	mg/Nm^3
Sulphur Dioxide Concentration	SO_2(C_s)	853.03	862.42	851.50	855.65	mg/dscm
		1033.08	1044.45	1031.23	1036.25	mg/Nm^3
Nitrogen Oxide Concentration	NO_x(C_s)	170.82	164.17	161.85	165.61	mg/dscm
		206.87	198.82	196.01	200.57	mg/Nm^3

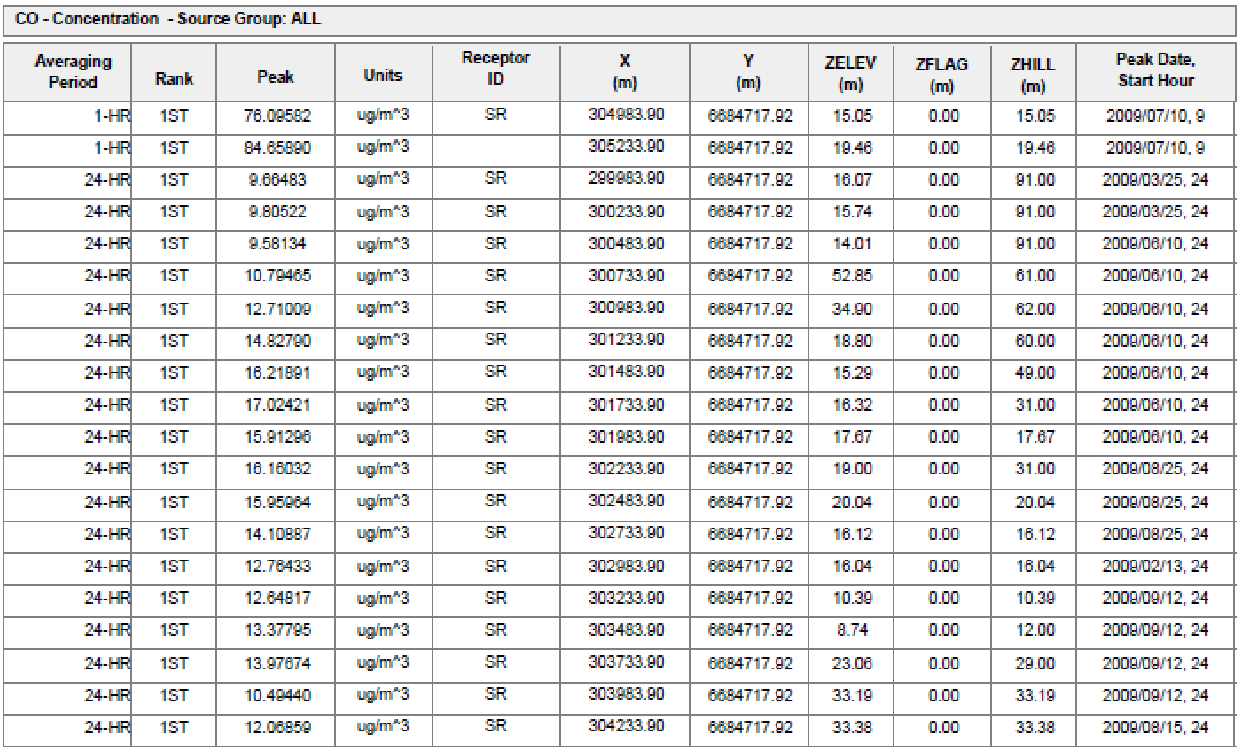
Emission Rate Data						
Particulate Matter Emission Rate (PM)	PM (E)	65.41	65..07	67.69	66.06	kg/hr
		1569.92	1561.61	1624.67	1585.40	kg/day
		1.57	1.56	1.62	1.59	tons/day
		521.21	518.45	539.39	526.35	tons p.a
Particulate Emission Rate (PM_{10})	PM_{10} (E)	21.99	22.37	23.15	22.50	kg/hr
		527.86	536.82	555.52	540.07	kg/hr
		0.528	0.537	0.556	0.540	tons/day
		175.25	178.23	184.43	179.30	tons/a
Sulphur Dioxide Emission Rate	SO_2 (E)	144.94	145.96	150.42	147.11	kg/hr
		3478.53	3503.07	3610.01	3530.54	kg/day
		3.48	3.50	3.61	3.53	tons/day
		1154.87	1163.02	11.98.52	1172.14	tons p.a
Nitrogen Dioxide Emission Rate	NO_X (E)	29.02	27.79	28.59	28.47	kg/hr
		696.57	666.84	686.17	683.19	kg/day
		0.70	0.67	0.69	0.68	tons/day
		231.26	22139	227.81	226.82	tons p.a

Sensitive Receptor Summary (For All)



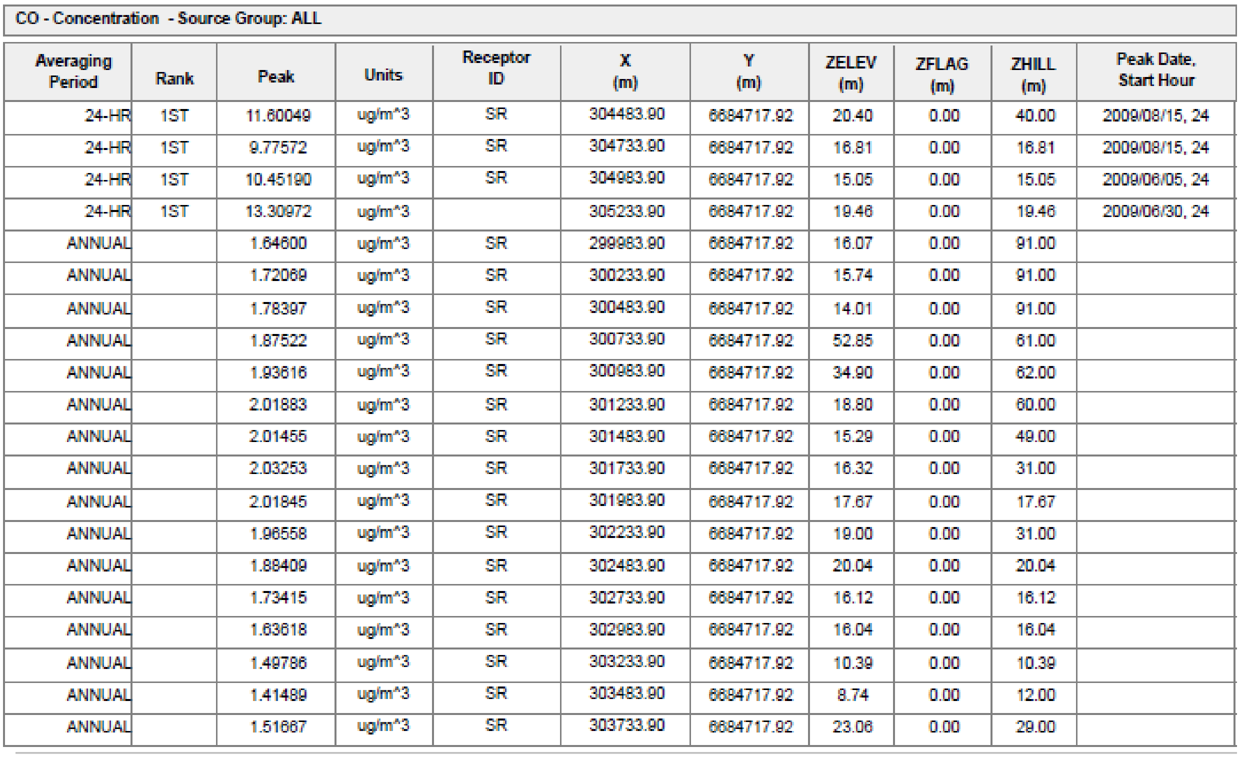
CO - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	57.60974	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	2009/11/11, 6
1-HR	1ST	76.44141	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	2009/11/11, 6
1-HR	1ST	75.43826	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	2009/11/11, 6
1-HR	1ST	64.05670	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	2009/10/31, 1
1-HR	1ST	59.95136	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	2009/10/30, 24
1-HR	1ST	59.92762	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	2009/03/03, 6
1-HR	1ST	62.89928	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	2009/06/02, 9
1-HR	1ST	67.22110	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	2009/06/02, 9
1-HR	1ST	69.39106	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	2009/06/02, 9
1-HR	1ST	68.90363	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	2009/06/02, 9
1-HR	1ST	65.55976	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	2009/06/02, 9
1-HR	1ST	61.72463	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	2009/12/02, 3
1-HR	1ST	63.58369	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	2009/02/21, 4
1-HR	1ST	60.96714	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	2009/02/21, 4
1-HR	1ST	58.13024	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	2009/02/13, 1
1-HR	1ST	69.97232	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	2009/03/11, 3
1-HR	1ST	71.16108	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	2009/03/11, 3
1-HR	1ST	74.19632	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	2009/01/06, 1
1-HR	1ST	70.99185	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	2009/01/06, 2
1-HR	1ST	66.58078	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	2009/07/10, 9



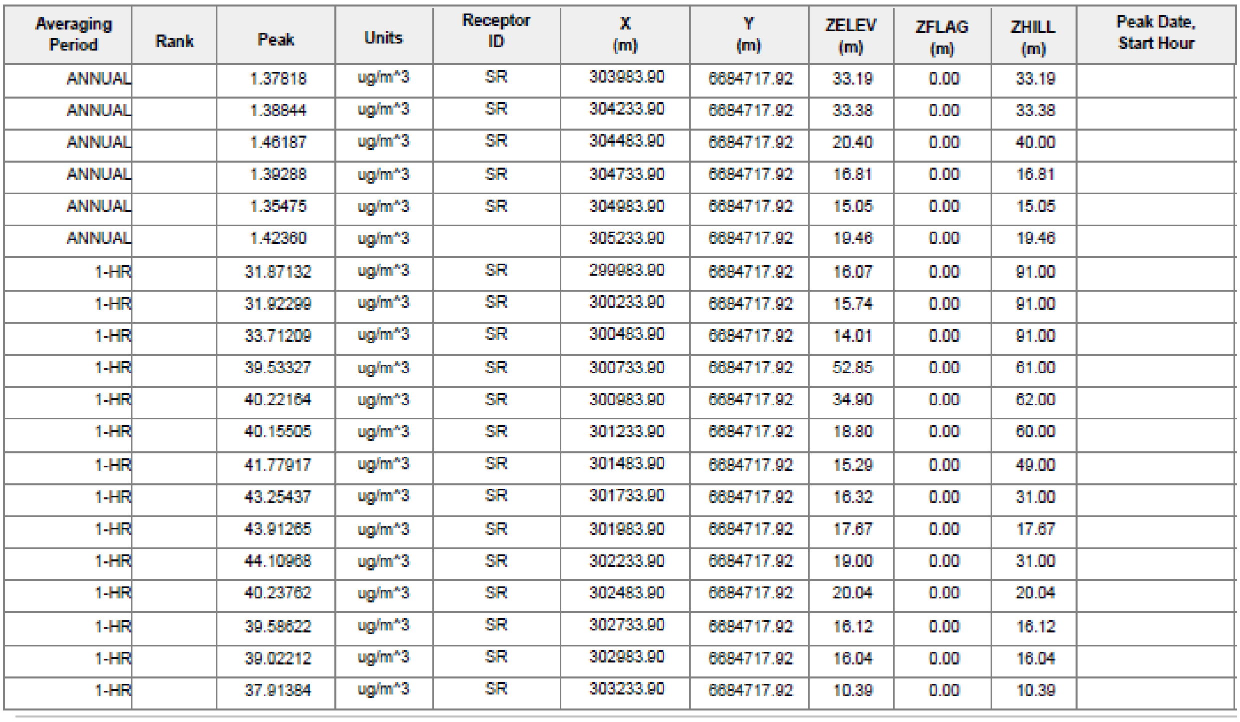
CO - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	76.09582	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	2009/07/10, 9
1-HR	1ST	84.65890	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	2009/07/10, 9
24-HR	1ST	9.66483	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	2009/03/25, 24
24-HR	1ST	9.80522	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	2009/03/25, 24
24-HR	1ST	9.58134	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	2009/06/10, 24
24-HR	1ST	10.79465	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	2009/06/10, 24
24-HR	1ST	12.71009	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	2009/06/10, 24
24-HR	1ST	14.82790	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	2009/06/10, 24
24-HR	1ST	16.21891	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	2009/06/10, 24
24-HR	1ST	17.02421	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	2009/06/10, 24
24-HR	1ST	15.91296	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	2009/06/10, 24
24-HR	1ST	16.16032	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	2009/08/25, 24
24-HR	1ST	15.95964	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	2009/08/25, 24
24-HR	1ST	14.10887	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	2009/08/25, 24
24-HR	1ST	12.76433	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	2009/02/13, 24
24-HR	1ST	12.64817	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	2009/09/12, 24
24-HR	1ST	13.37795	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	2009/09/12, 24
24-HR	1ST	13.97674	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	2009/09/12, 24
24-HR	1ST	10.49440	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	2009/09/12, 24
24-HR	1ST	12.06859	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	2009/08/15, 24

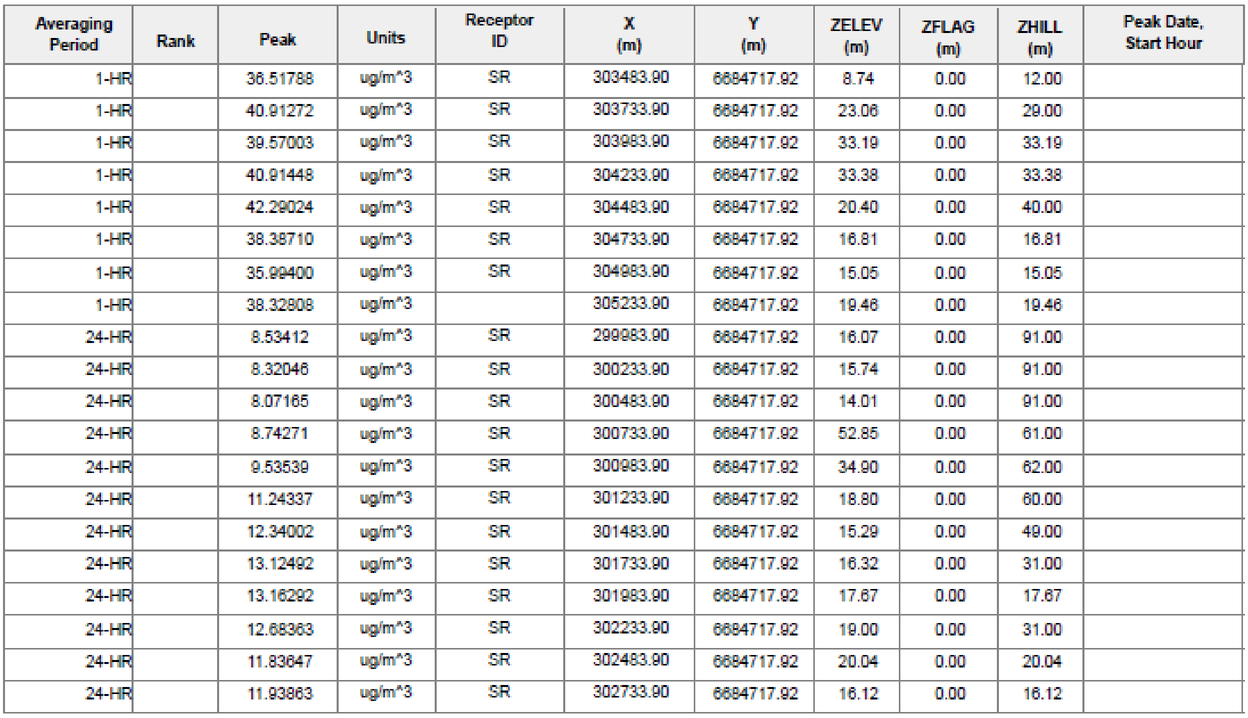


CO - Concentration - Source Group: ALL

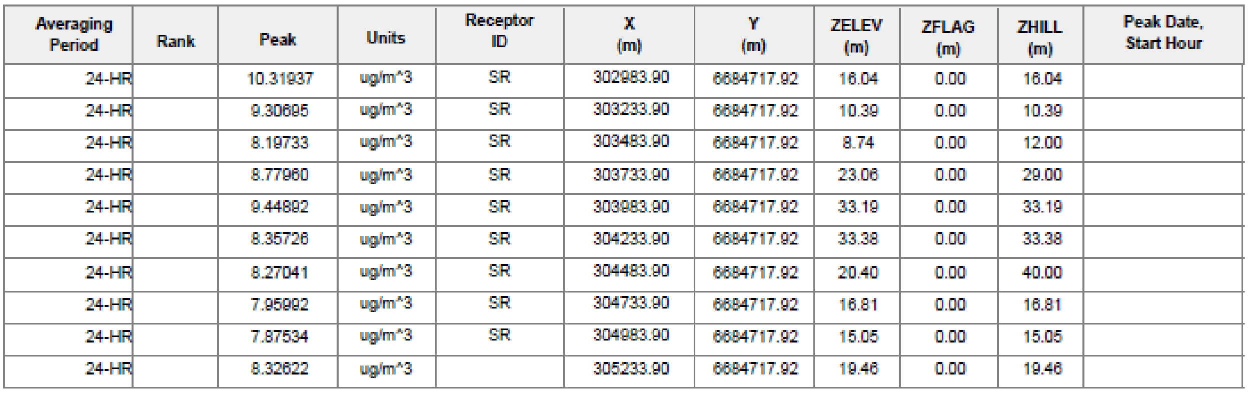
Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR	1ST	11.60049	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	2009/08/15, 24
24-HR	1ST	9.77572	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	2009/08/15, 24
24-HR	1ST	10.45190	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	2009/06/05, 24
24-HR	1ST	13.30972	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	2009/06/30, 24
ANNUAL		1.64600	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
ANNUAL		1.72069	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
ANNUAL		1.78397	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
ANNUAL		1.87522	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
ANNUAL		1.93616	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
ANNUAL		2.01883	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
ANNUAL		2.01455	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
ANNUAL		2.03253	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
ANNUAL		2.01845	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
ANNUAL		1.96558	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
ANNUAL		1.88409	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
ANNUAL		1.73415	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	
ANNUAL		1.63618	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
ANNUAL		1.49786	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	
ANNUAL		1.41489	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
ANNUAL		1.51667	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	



Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
ANNUAL		1.37818	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
ANNUAL		1.38844	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
ANNUAL		1.46187	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
ANNUAL		1.39288	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
ANNUAL		1.35475	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
ANNUAL		1.42360	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	
1-HR		31.87132	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
1-HR		31.92299	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
1-HR		33.71209	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
1-HR		39.53327	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
1-HR		40.22164	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
1-HR		40.15505	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
1-HR		41.77917	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
1-HR		43.25437	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
1-HR		43.91265	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
1-HR		44.10968	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
1-HR		40.23762	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
1-HR		39.58622	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	
1-HR		39.02212	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
1-HR		37.91384	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	

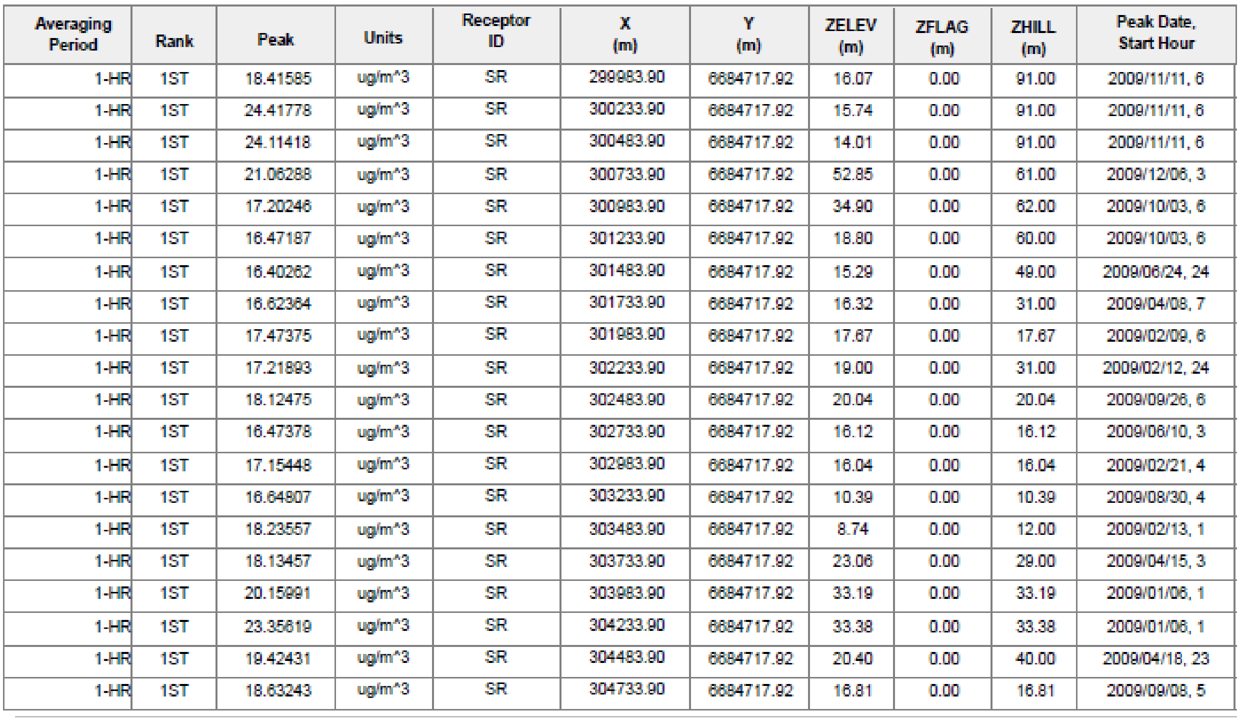


Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR		36.51788	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
1-HR		40.91272	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	
1-HR		39.57003	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
1-HR		40.91448	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
1-HR		42.29024	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
1-HR		38.38710	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
1-HR		35.99400	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
1-HR		38.32808	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	
24-HR		8.53412	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
24-HR		8.32046	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
24-HR		8.07165	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
24-HR		8.74271	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
24-HR		9.53539	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
24-HR		11.24337	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
24-HR		12.34002	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
24-HR		13.12492	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
24-HR		13.16292	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
24-HR		12.68363	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
24-HR		11.83647	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
24-HR		11.93863	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	

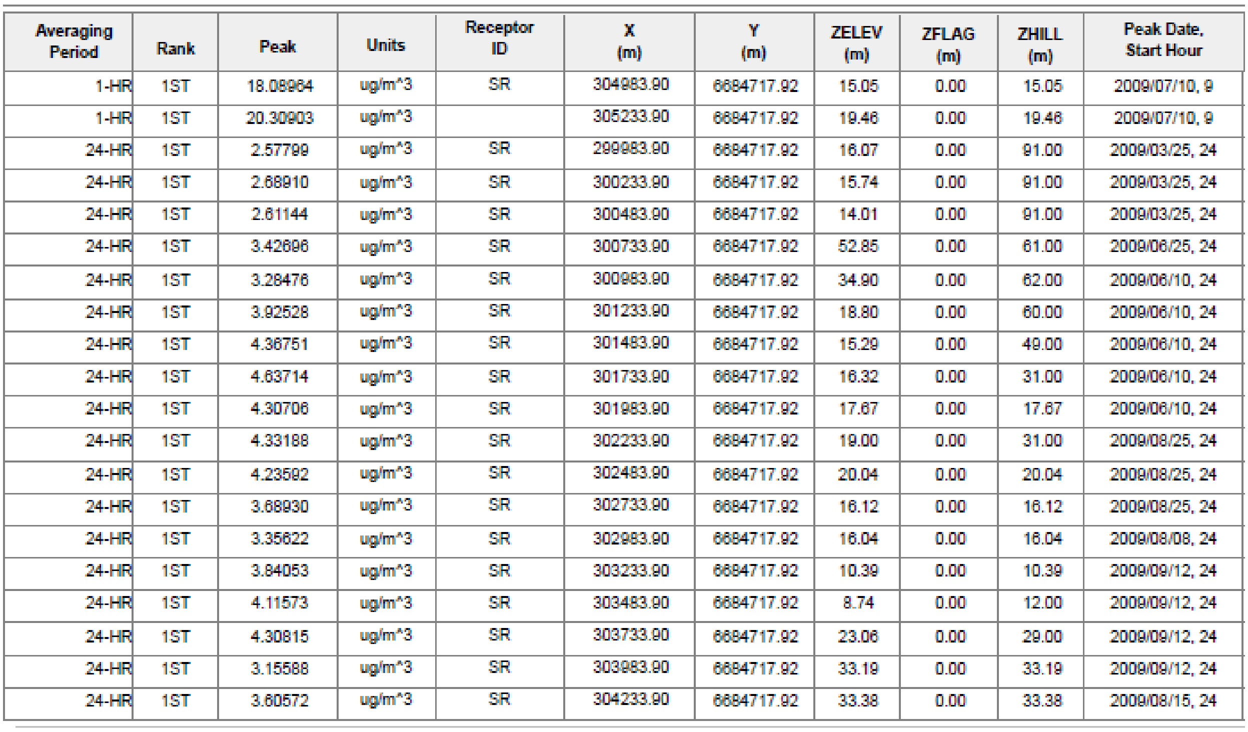


Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR		10.31937	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
24-HR		9.30695	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	
24-HR		8.19733	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
24-HR		8.77960	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	
24-HR		9.44892	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
24-HR		8.35726	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
24-HR		8.27041	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
24-HR		7.95992	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
24-HR		7.87534	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
24-HR		8.32622	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	

Sensitive Receptor Summary (For NO_x)



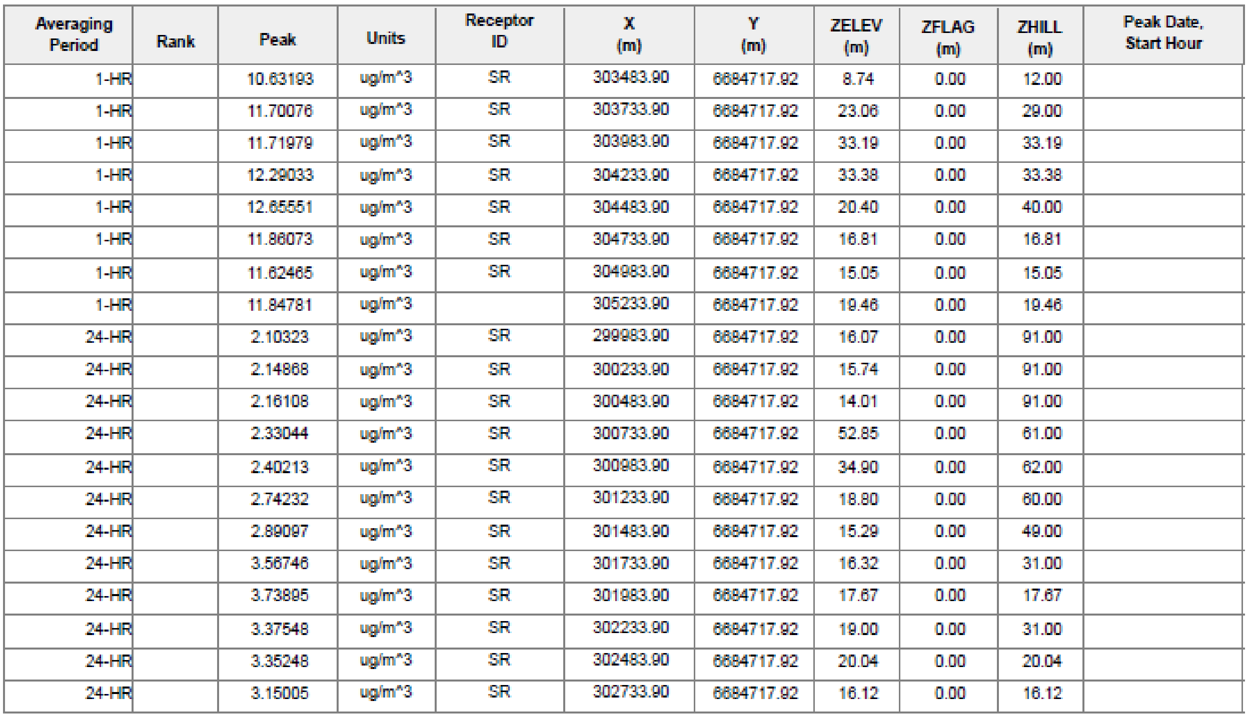
Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	18.41585	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	2009/11/11, 6
1-HR	1ST	24.41778	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	2009/11/11, 6
1-HR	1ST	24.11418	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	2009/11/11, 6
1-HR	1ST	21.06288	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	2009/12/06, 3
1-HR	1ST	17.20246	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	2009/10/03, 6
1-HR	1ST	16.47187	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	2009/10/03, 6
1-HR	1ST	16.40262	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	2009/06/24, 24
1-HR	1ST	16.62364	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	2009/04/08, 7
1-HR	1ST	17.47375	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	2009/02/09, 6
1-HR	1ST	17.21893	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	2009/02/12, 24
1-HR	1ST	18.12475	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	2009/09/26, 6
1-HR	1ST	16.47378	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	2009/06/10, 3
1-HR	1ST	17.15448	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	2009/02/21, 4
1-HR	1ST	16.64807	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	2009/08/30, 4
1-HR	1ST	18.23557	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	2009/02/13, 1
1-HR	1ST	18.13457	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	2009/04/15, 3
1-HR	1ST	20.15991	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	2009/01/06, 1
1-HR	1ST	23.35619	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	2009/01/06, 1
1-HR	1ST	19.42431	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	2009/04/18, 23
1-HR	1ST	18.63243	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	2009/09/08, 5



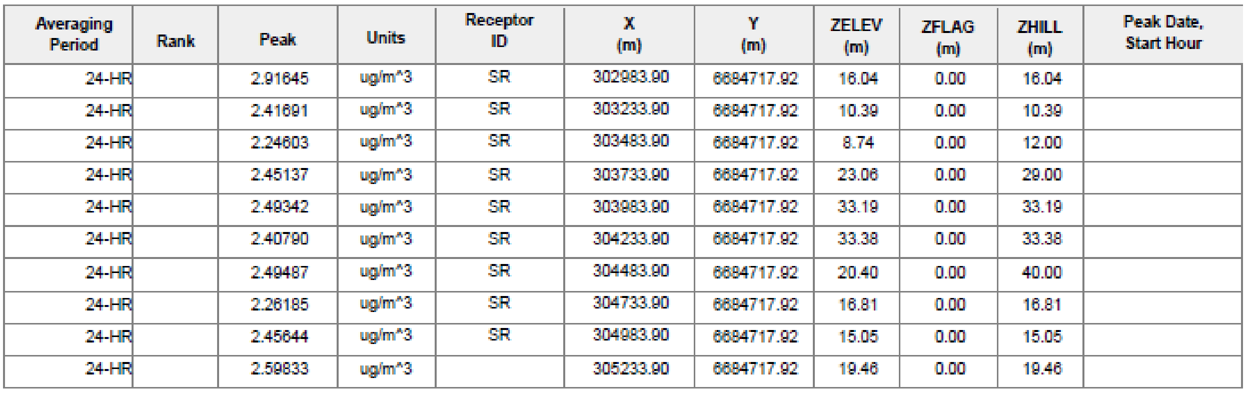
Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	18.08964	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	2009/07/10, 9
1-HR	1ST	20.30903	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	2009/07/10, 9
24-HR	1ST	2.57799	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	2009/03/25, 24
24-HR	1ST	2.68910	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	2009/03/25, 24
24-HR	1ST	2.61144	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	2009/03/25, 24
24-HR	1ST	3.42696	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	2009/06/25, 24
24-HR	1ST	3.28476	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	2009/06/10, 24
24-HR	1ST	3.92528	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	2009/06/10, 24
24-HR	1ST	4.36751	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	2009/06/10, 24
24-HR	1ST	4.63714	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	2009/06/10, 24
24-HR	1ST	4.30706	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	2009/06/10, 24
24-HR	1ST	4.33188	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	2009/08/25, 24
24-HR	1ST	4.23592	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	2009/08/25, 24
24-HR	1ST	3.68930	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	2009/08/25, 24
24-HR	1ST	3.35622	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	2009/08/08, 24
24-HR	1ST	3.84053	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	2009/09/12, 24
24-HR	1ST	4.11573	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	2009/09/12, 24
24-HR	1ST	4.30815	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	2009/09/12, 24
24-HR	1ST	3.15588	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	2009/09/12, 24
24-HR	1ST	3.60572	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	2009/08/15, 24

Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR	1ST	3.48053	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	2009/08/15, 24
24-HR	1ST	3.01061	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	2009/08/15, 24
24-HR	1ST	3.21299	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	2009/06/05, 24
24-HR	1ST	4.16816	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	2009/06/30, 24
ANNUAL		0.40784	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
ANNUAL		0.42950	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
ANNUAL		0.44823	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
ANNUAL		0.47463	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
ANNUAL		0.48975	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
ANNUAL		0.51818	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
ANNUAL		0.51947	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
ANNUAL		0.52902	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
ANNUAL		0.53117	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
ANNUAL		0.52352	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
ANNUAL		0.50841	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
ANNUAL		0.47267	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	
ANNUAL		0.45123	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
ANNUAL		0.41660	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	
ANNUAL		0.39760	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
ANNUAL		0.43421	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	

Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
ANNUAL		0.39114	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
ANNUAL		0.39801	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
ANNUAL		0.42923	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
ANNUAL		0.41233	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
ANNUAL		0.40619	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
ANNUAL		0.43490	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	
1-HR		8.32564	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
1-HR		8.64849	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
1-HR		8.99129	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
1-HR		10.64504	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
1-HR		11.09175	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
1-HR		10.58234	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
1-HR		11.08950	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
1-HR		11.65128	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
1-HR		11.68253	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
1-HR		11.82903	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
1-HR		11.64935	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
1-HR		11.07388	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	
1-HR		11.07176	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
1-HR		11.11197	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	

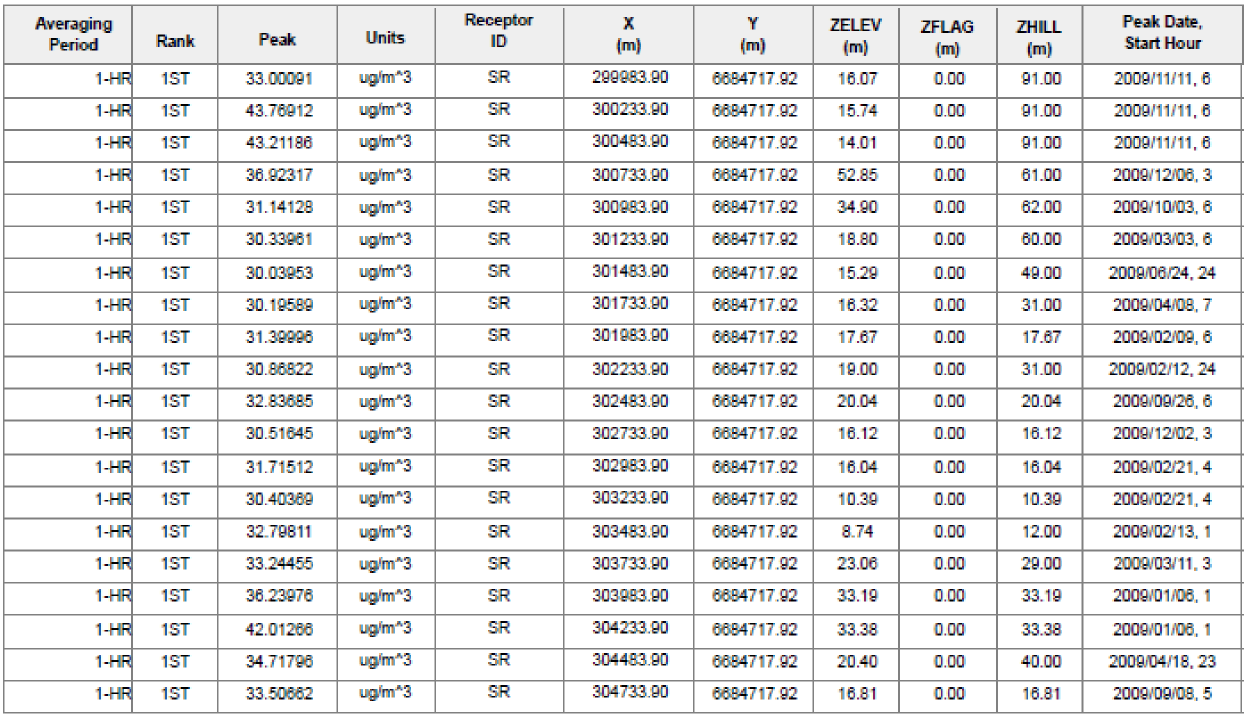


Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR		10.63193	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
1-HR		11.70076	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	
1-HR		11.71979	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
1-HR		12.29033	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
1-HR		12.65551	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
1-HR		11.86073	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
1-HR		11.62465	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
1-HR		11.84781	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	
24-HR		2.10323	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
24-HR		2.14868	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
24-HR		2.16108	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
24-HR		2.33044	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
24-HR		2.40213	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
24-HR		2.74232	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
24-HR		2.89097	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
24-HR		3.56746	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
24-HR		3.73895	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
24-HR		3.37548	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
24-HR		3.35248	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
24-HR		3.15005	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	

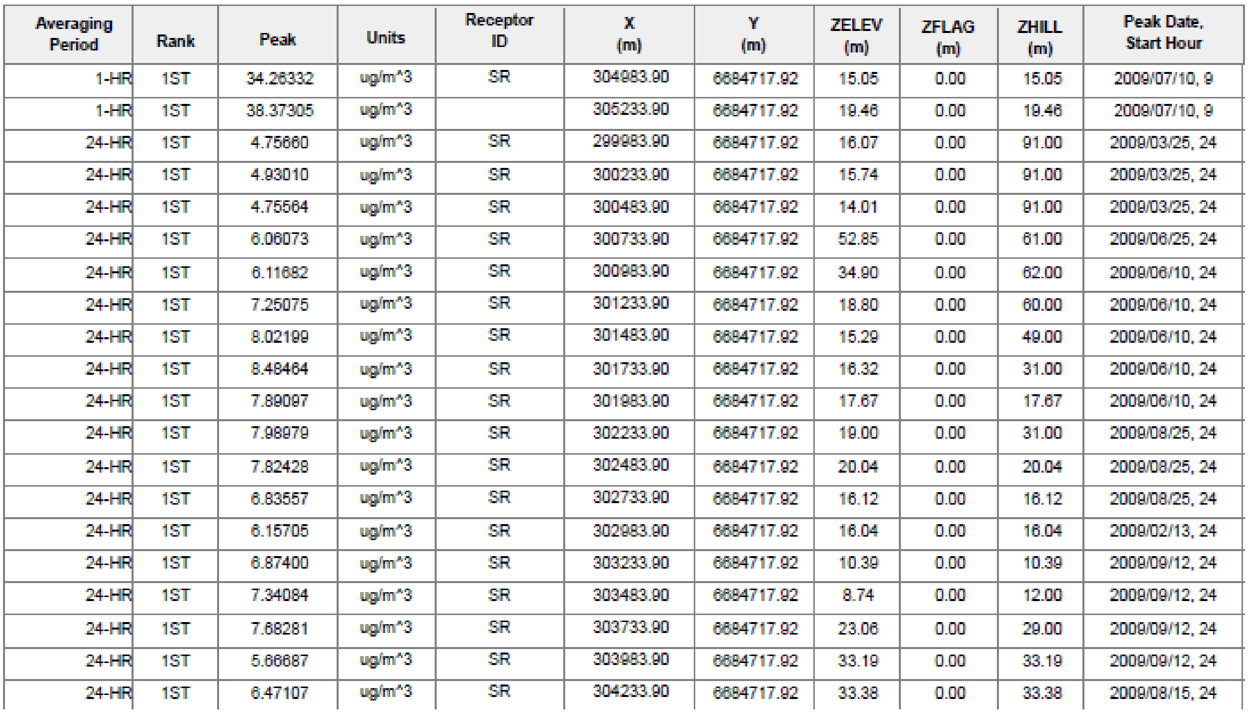


Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR		2.91645	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
24-HR		2.41691	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	
24-HR		2.24603	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
24-HR		2.45137	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	
24-HR		2.49342	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
24-HR		2.40790	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
24-HR		2.49487	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
24-HR		2.26185	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
24-HR		2.45644	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
24-HR		2.59833	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	

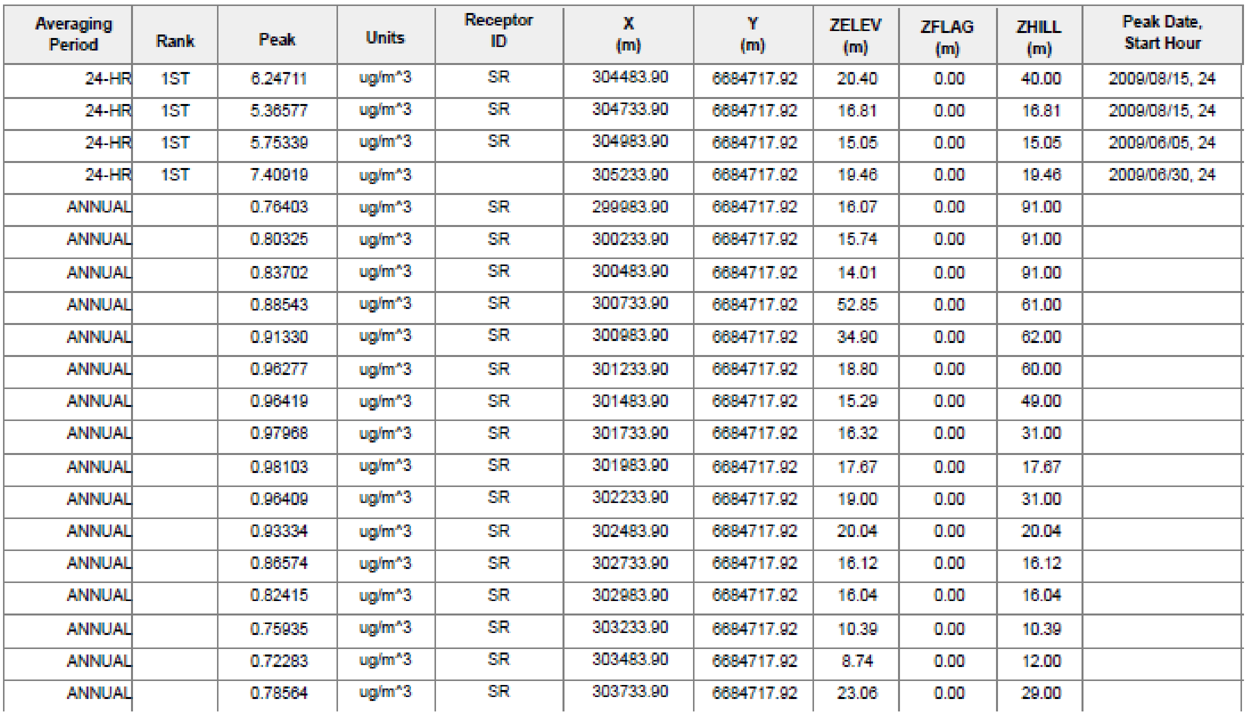
Sensitive Receptor Summary (For PM)



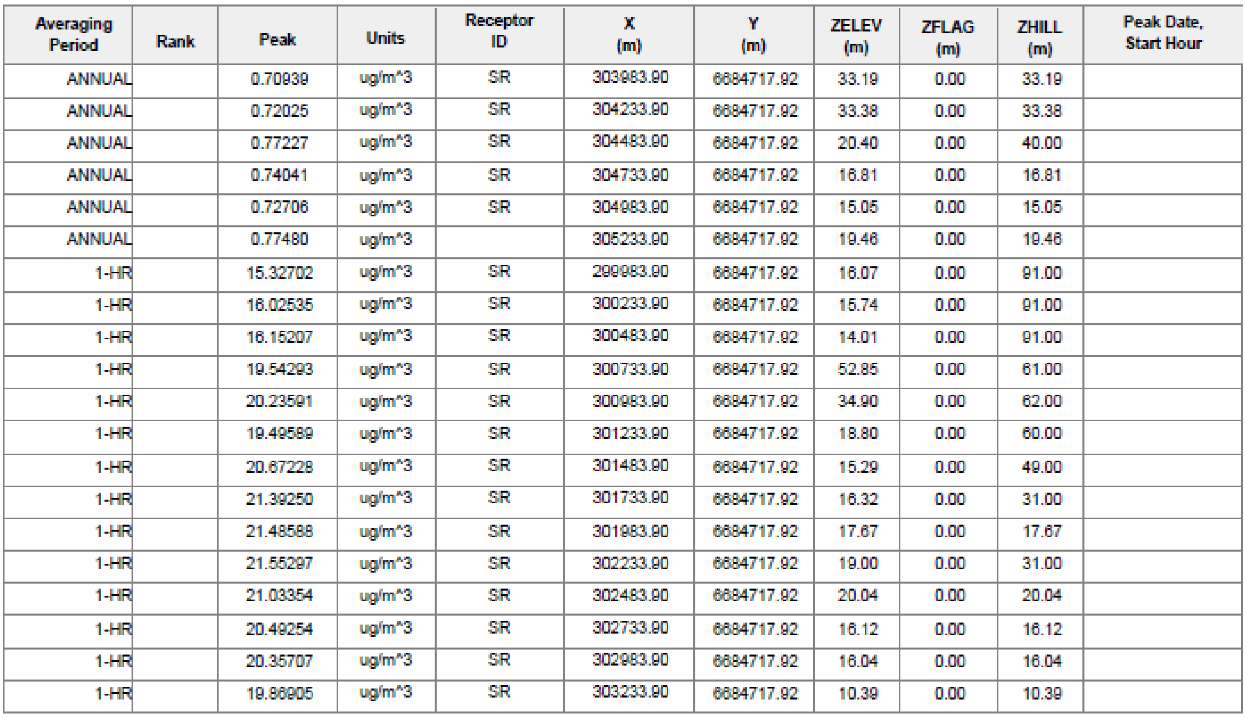
Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	33.00091	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	2009/11/11, 6
1-HR	1ST	43.76912	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	2009/11/11, 6
1-HR	1ST	43.21186	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	2009/11/11, 6
1-HR	1ST	36.92317	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	2009/12/06, 3
1-HR	1ST	31.14128	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	2009/10/03, 6
1-HR	1ST	30.33961	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	2009/03/03, 6
1-HR	1ST	30.03953	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	2009/06/24, 24
1-HR	1ST	30.19589	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	2009/04/08, 7
1-HR	1ST	31.39996	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	2009/02/09, 6
1-HR	1ST	30.86822	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	2009/02/12, 24
1-HR	1ST	32.83685	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	2009/09/26, 6
1-HR	1ST	30.51645	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	2009/12/02, 3
1-HR	1ST	31.71512	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	2009/02/21, 4
1-HR	1ST	30.40369	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	2009/02/21, 4
1-HR	1ST	32.79811	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	2009/02/13, 1
1-HR	1ST	33.24455	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	2009/03/11, 3
1-HR	1ST	36.23976	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	2009/01/06, 1
1-HR	1ST	42.01266	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	2009/01/06, 1
1-HR	1ST	34.71796	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	2009/04/18, 23
1-HR	1ST	33.50662	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	2009/09/08, 5



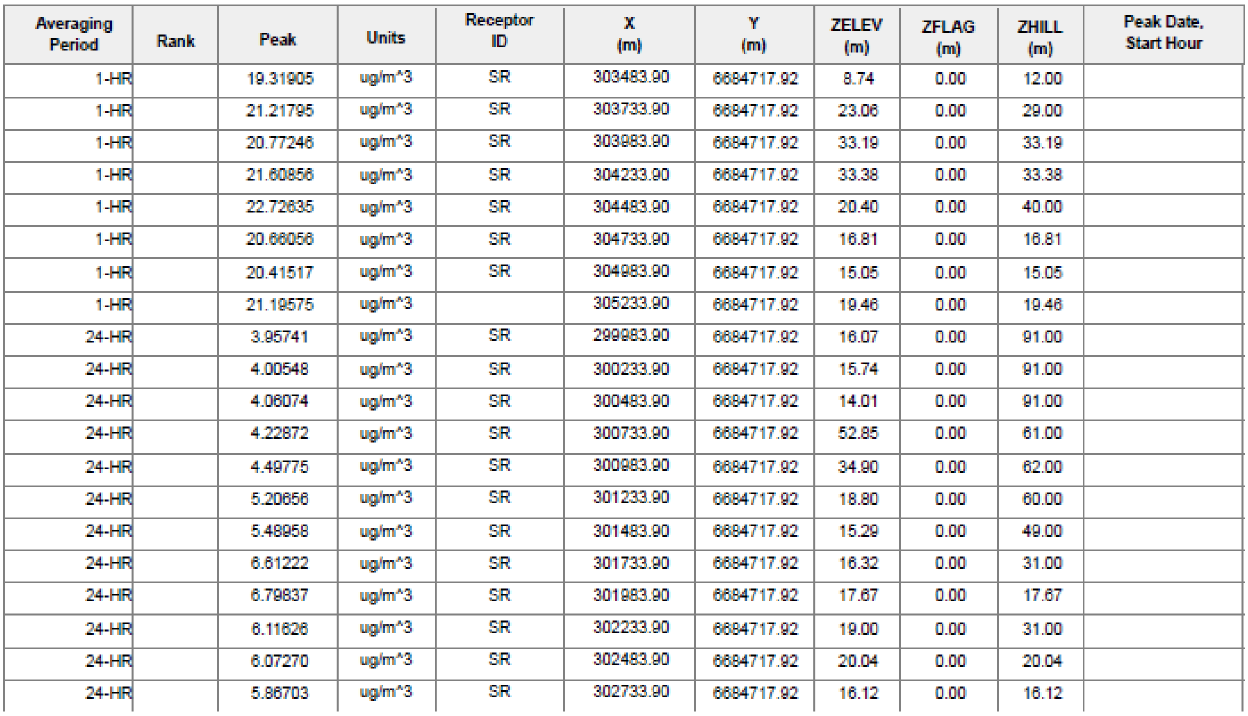
Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	34.26332	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	2009/07/10, 9
1-HR	1ST	38.37305	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	2009/07/10, 9
24-HR	1ST	4.75660	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	2009/03/25, 24
24-HR	1ST	4.93010	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	2009/03/25, 24
24-HR	1ST	4.75564	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	2009/03/25, 24
24-HR	1ST	6.06073	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	2009/06/25, 24
24-HR	1ST	6.11682	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	2009/06/10, 24
24-HR	1ST	7.25075	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	2009/06/10, 24
24-HR	1ST	8.02199	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	2009/06/10, 24
24-HR	1ST	8.48464	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	2009/06/10, 24
24-HR	1ST	7.89097	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	2009/06/10, 24
24-HR	1ST	7.98979	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	2009/08/25, 24
24-HR	1ST	7.82428	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	2009/08/25, 24
24-HR	1ST	6.83557	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	2009/08/25, 24
24-HR	1ST	6.15705	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	2009/02/13, 24
24-HR	1ST	6.87400	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	2009/09/12, 24
24-HR	1ST	7.34084	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	2009/09/12, 24
24-HR	1ST	7.68281	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	2009/09/12, 24
24-HR	1ST	5.66687	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	2009/09/12, 24
24-HR	1ST	6.47107	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	2009/08/15, 24



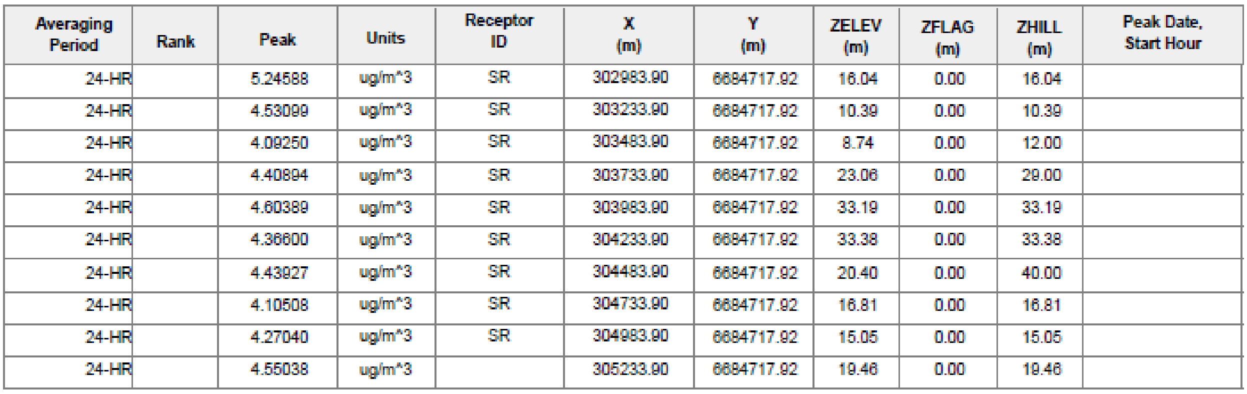
Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR	1ST	6.24711	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	2009/08/15, 24
24-HR	1ST	5.36577	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	2009/08/15, 24
24-HR	1ST	5.75339	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	2009/06/05, 24
24-HR	1ST	7.40919	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	2009/06/30, 24
ANNUAL		0.76403	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
ANNUAL		0.80325	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
ANNUAL		0.83702	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
ANNUAL		0.88543	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
ANNUAL		0.91330	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
ANNUAL		0.96277	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
ANNUAL		0.96419	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
ANNUAL		0.97968	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
ANNUAL		0.98103	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
ANNUAL		0.96409	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
ANNUAL		0.93334	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
ANNUAL		0.86574	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	
ANNUAL		0.82415	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
ANNUAL		0.75935	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	
ANNUAL		0.72283	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
ANNUAL		0.78564	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	



Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
ANNUAL		0.70939	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
ANNUAL		0.72025	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
ANNUAL		0.77227	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
ANNUAL		0.74041	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
ANNUAL		0.72706	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
ANNUAL		0.77480	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	
1-HR		15.32702	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
1-HR		16.02535	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
1-HR		16.15207	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
1-HR		19.54293	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
1-HR		20.23591	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
1-HR		19.49589	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
1-HR		20.67228	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
1-HR		21.39250	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
1-HR		21.48588	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
1-HR		21.55297	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
1-HR		21.03354	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
1-HR		20.49254	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	
1-HR		20.35707	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
1-HR		19.86905	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	

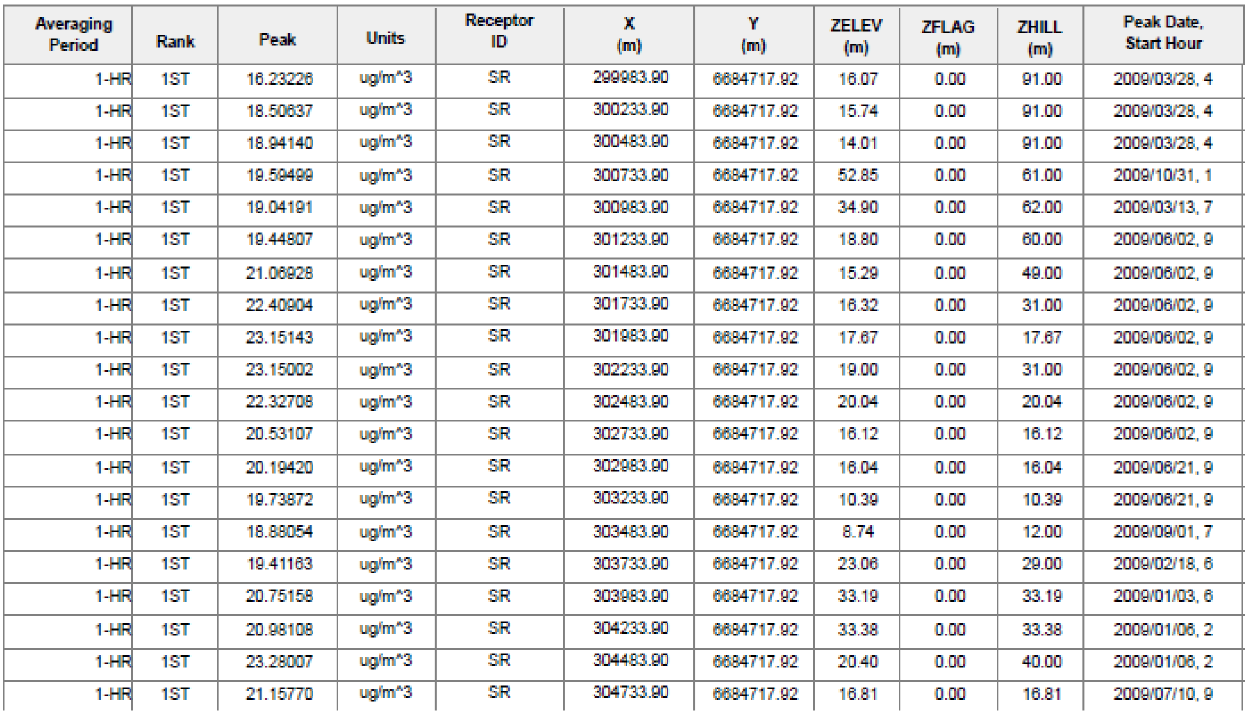


Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR		19.31905	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
1-HR		21.21795	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	
1-HR		20.77246	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
1-HR		21.60856	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
1-HR		22.72635	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
1-HR		20.66056	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
1-HR		20.41517	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
1-HR		21.19575	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	
24-HR		3.95741	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
24-HR		4.00548	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
24-HR		4.06074	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
24-HR		4.22872	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
24-HR		4.49775	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
24-HR		5.20656	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
24-HR		5.48958	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
24-HR		6.61222	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
24-HR		6.79837	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
24-HR		6.11626	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
24-HR		6.07270	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
24-HR		5.86703	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	

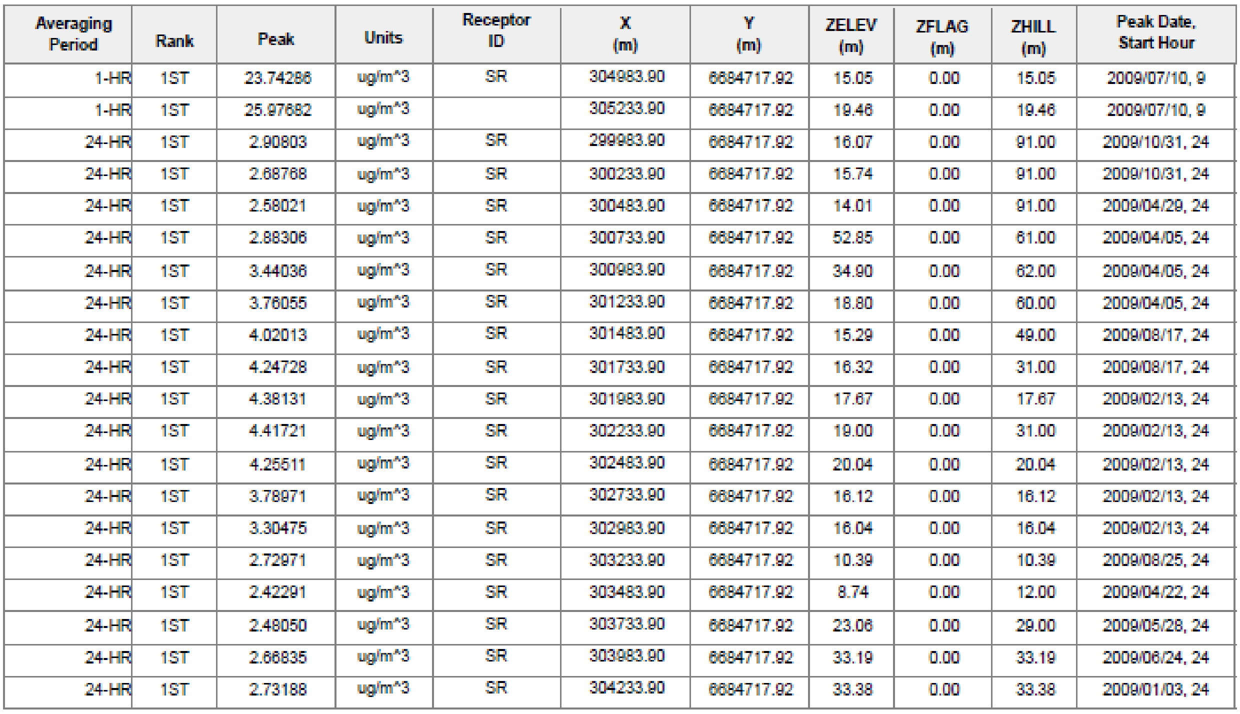


Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR		5.24588	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
24-HR		4.53099	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	
24-HR		4.09250	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
24-HR		4.40894	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	
24-HR		4.60389	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
24-HR		4.36600	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
24-HR		4.43927	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
24-HR		4.10508	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
24-HR		4.27040	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
24-HR		4.55038	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	

Sensitive Receptor Summary (For SO_2)

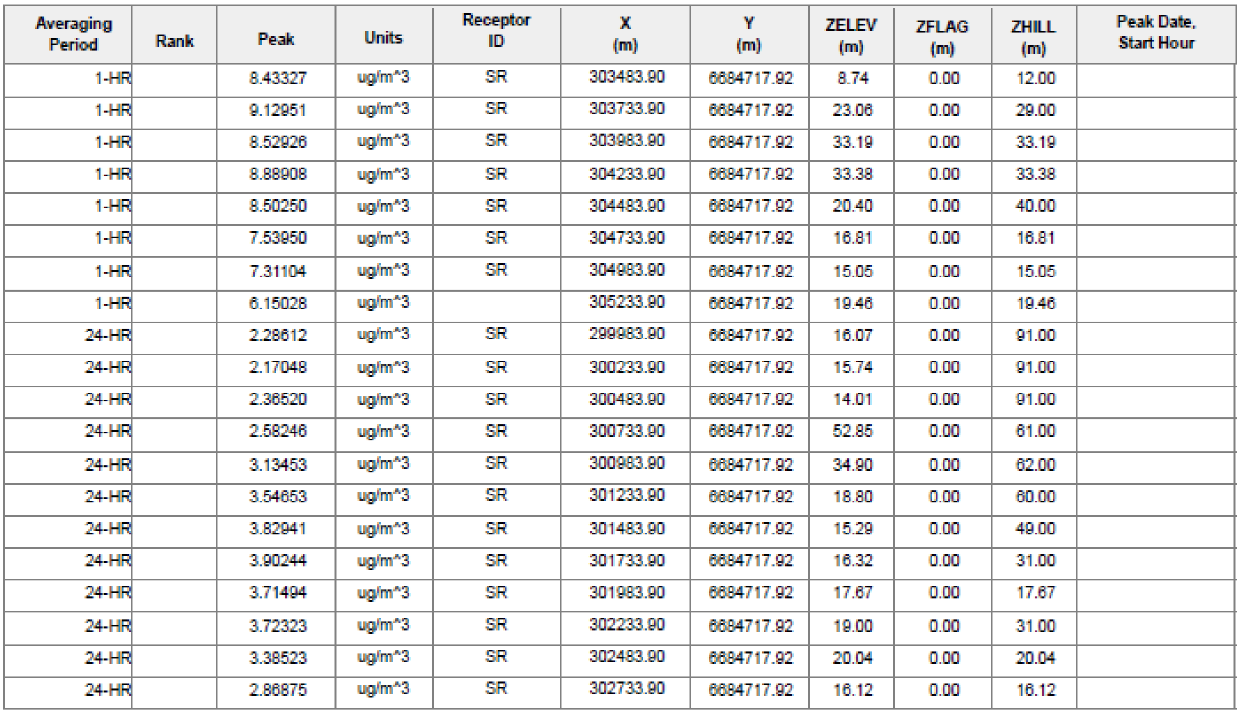


Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	16.23226	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	2009/03/28, 4
1-HR	1ST	18.50637	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	2009/03/28, 4
1-HR	1ST	18.94140	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	2009/03/28, 4
1-HR	1ST	19.59499	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	2009/10/31, 1
1-HR	1ST	19.04191	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	2009/03/13, 7
1-HR	1ST	19.44807	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	2009/06/02, 9
1-HR	1ST	21.06928	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	2009/06/02, 9
1-HR	1ST	22.40904	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	2009/06/02, 9
1-HR	1ST	23.15143	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	2009/06/02, 9
1-HR	1ST	23.15002	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	2009/06/02, 9
1-HR	1ST	22.32708	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	2009/06/02, 9
1-HR	1ST	20.53107	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	2009/06/02, 9
1-HR	1ST	20.19420	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	2009/06/21, 9
1-HR	1ST	19.73872	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	2009/06/21, 9
1-HR	1ST	18.88054	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	2009/09/01, 7
1-HR	1ST	19.41163	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	2009/02/18, 6
1-HR	1ST	20.75158	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	2009/01/03, 6
1-HR	1ST	20.98108	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	2009/01/06, 2
1-HR	1ST	23.28007	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	2009/01/06, 2
1-HR	1ST	21.15770	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	2009/07/10, 9

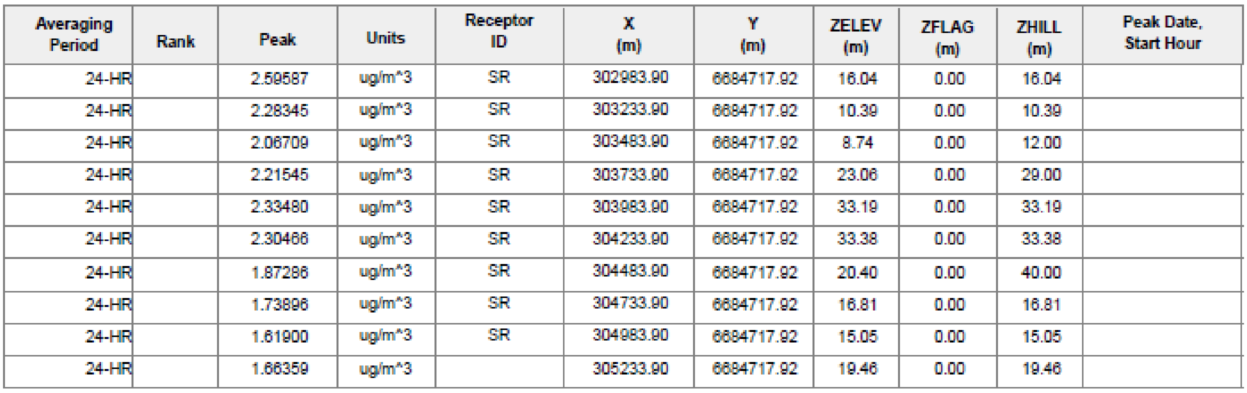


Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	23.74286	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	2009/07/10, 9
1-HR	1ST	25.97682	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	2009/07/10, 9
24-HR	1ST	2.90803	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	2009/10/31, 24
24-HR	1ST	2.68768	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	2009/10/31, 24
24-HR	1ST	2.58021	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	2009/04/29, 24
24-HR	1ST	2.88306	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	2009/04/05, 24
24-HR	1ST	3.44036	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	2009/04/05, 24
24-HR	1ST	3.76055	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	2009/04/05, 24
24-HR	1ST	4.02013	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	2009/08/17, 24
24-HR	1ST	4.24728	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	2009/08/17, 24
24-HR	1ST	4.38131	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	2009/02/13, 24
24-HR	1ST	4.41721	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	2009/02/13, 24
24-HR	1ST	4.25511	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	2009/02/13, 24
24-HR	1ST	3.78971	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	2009/02/13, 24
24-HR	1ST	3.30475	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	2009/02/13, 24
24-HR	1ST	2.72971	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	2009/08/25, 24
24-HR	1ST	2.42291	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	2009/04/22, 24
24-HR	1ST	2.48050	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	2009/05/28, 24
24-HR	1ST	2.66835	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	2009/06/24, 24
24-HR	1ST	2.73188	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	2009/01/03, 24

Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR	1ST	2.46521	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	2009/01/03, 24
24-HR	1ST	2.21705	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	2009/04/23, 24
24-HR	1ST	2.00058	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	2009/04/23, 24
24-HR	1ST	1.75951	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	2009/05/21, 24
ANNUAL		0.47412	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
ANNUAL		0.48794	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
ANNUAL		0.49872	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
ANNUAL		0.51515	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
ANNUAL		0.53311	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
ANNUAL		0.53788	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
ANNUAL		0.53089	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
ANNUAL		0.52383	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
ANNUAL		0.50625	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
ANNUAL		0.47797	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
ANNUAL		0.44234	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
ANNUAL		0.39575	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	
ANNUAL		0.36079	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
ANNUAL		0.32192	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	
ANNUAL		0.29446	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
ANNUAL		0.29683	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	
ANNUAL		0.27764	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
ANNUAL		0.27018	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
ANNUAL		0.26037	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
ANNUAL		0.24013	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
ANNUAL		0.22150	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
ANNUAL		0.21390	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	
1-HR		9.94266	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
1-HR		9.62494	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
1-HR		9.65122	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
1-HR		10.18930	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
1-HR		11.64407	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
1-HR		11.60622	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
1-HR		11.97315	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
1-HR		12.21605	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
1-HR		12.60413	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
1-HR		12.01590	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
1-HR		11.06043	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
1-HR		10.38836	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	
1-HR		9.67211	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
1-HR		8.70849	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	

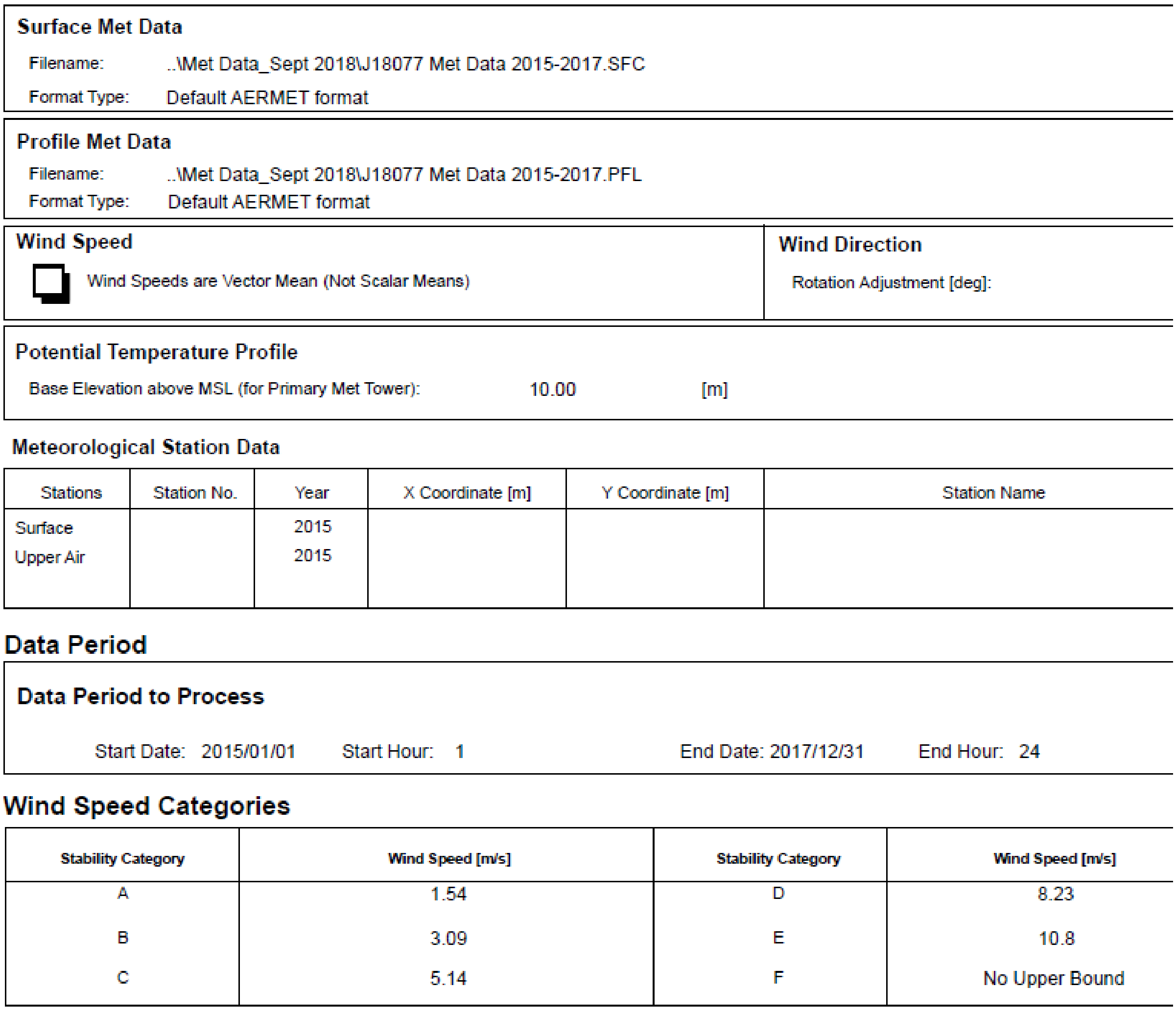


Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR		8.43327	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
1-HR		9.12951	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	
1-HR		8.52926	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
1-HR		8.88908	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
1-HR		8.50250	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
1-HR		7.53950	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
1-HR		7.31104	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
1-HR		6.15028	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	
24-HR		2.28612	ug/m^3	SR	299983.90	6684717.92	16.07	0.00	91.00	
24-HR		2.17048	ug/m^3	SR	300233.90	6684717.92	15.74	0.00	91.00	
24-HR		2.36520	ug/m^3	SR	300483.90	6684717.92	14.01	0.00	91.00	
24-HR		2.58246	ug/m^3	SR	300733.90	6684717.92	52.85	0.00	61.00	
24-HR		3.13453	ug/m^3	SR	300983.90	6684717.92	34.90	0.00	62.00	
24-HR		3.54653	ug/m^3	SR	301233.90	6684717.92	18.80	0.00	60.00	
24-HR		3.82941	ug/m^3	SR	301483.90	6684717.92	15.29	0.00	49.00	
24-HR		3.90244	ug/m^3	SR	301733.90	6684717.92	16.32	0.00	31.00	
24-HR		3.71494	ug/m^3	SR	301983.90	6684717.92	17.67	0.00	17.67	
24-HR		3.72323	ug/m^3	SR	302233.90	6684717.92	19.00	0.00	31.00	
24-HR		3.38523	ug/m^3	SR	302483.90	6684717.92	20.04	0.00	20.04	
24-HR		2.86875	ug/m^3	SR	302733.90	6684717.92	16.12	0.00	16.12	



Averaging Period	Rank	Peak	Units	Receptor ID	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR		2.59587	ug/m^3	SR	302983.90	6684717.92	16.04	0.00	16.04	
24-HR		2.28345	ug/m^3	SR	303233.90	6684717.92	10.39	0.00	10.39	
24-HR		2.06709	ug/m^3	SR	303483.90	6684717.92	8.74	0.00	12.00	
24-HR		2.21545	ug/m^3	SR	303733.90	6684717.92	23.06	0.00	29.00	
24-HR		2.33480	ug/m^3	SR	303983.90	6684717.92	33.19	0.00	33.19	
24-HR		2.30466	ug/m^3	SR	304233.90	6684717.92	33.38	0.00	33.38	
24-HR		1.87286	ug/m^3	SR	304483.90	6684717.92	20.40	0.00	40.00	
24-HR		1.73896	ug/m^3	SR	304733.90	6684717.92	16.81	0.00	16.81	
24-HR		1.61900	ug/m^3	SR	304983.90	6684717.92	15.05	0.00	15.05	
24-HR		1.66359	ug/m^3		305233.90	6684717.92	19.46	0.00	19.46	

Meteorological Pathway



Surface Met Data

Filename: ..\Met Data_Sept 2018\J18077 Met Data 2015-2017.SFC

Format Type: Default AERMET format

Profile Met Data

Filename: ..\Met Data_Sept 2018\J18077 Met Data 2015-2017.PFL

Format Type: Default AERMET format

Wind Speed

☐ Wind Speeds are Vector Mean (Not Scalar Means)

Wind Direction

Rotation Adjustment [deg]:

Potential Temperature Profile

Base Elevation above MSL (for Primary Met Tower): 10.00 [m]

Meteorological Station Data

Stations	Station No.	Year	X Coordinate [m]	Y Coordinate [m]	Station Name
Surface		2015			
Upper Air		2015			

Data Period

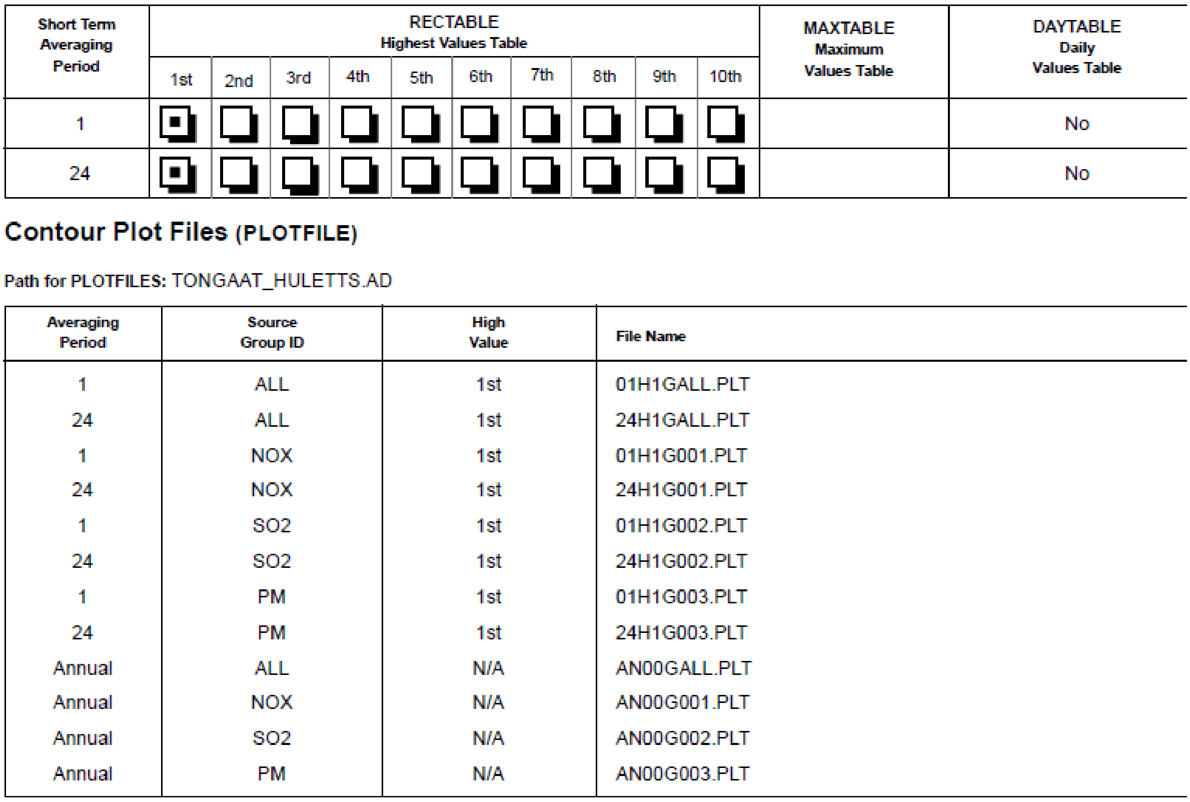
Data Period to Process

Start Date: 2015/01/01 Start Hour: 1 End Date: 2017/12/31 End Hour: 24

Wind Speed Categories

Stability Category	Wind Speed [m/s]	Stability Category	Wind Speed [m/s]
A	1.54	D	8.23
B	3.09	E	10.8
C	5.14	F	No Upper Bound

Output Pathway



Short Term Averaging Period	RECTABLE Highest Values Table										MAXTABLE Maximum Values Table	DAYTABLE Daily Values Table
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th		
1	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐		No
24	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐		No

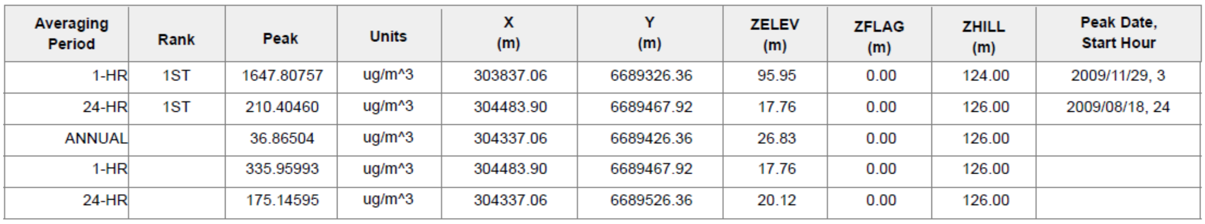
Contour Plot Files (PLOTFILE)

Path for PLOTFILES: TONGAAT_HULETTS.AD

Averaging Period	Source Group ID	High Value	File Name
1	ALL	1st	01H1GALL.PLT
24	ALL	1st	24H1GALL.PLT
1	NOX	1st	01H1G001.PLT
24	NOX	1st	24H1G001.PLT
1	SO2	1st	01H1G002.PLT
24	SO2	1st	24H1G002.PLT
1	PM	1st	01H1G003.PLT
24	PM	1st	24H1G003.PLT
Annual	ALL	N/A	AN00GALL.PLT
Annual	NOX	N/A	AN00G001.PLT
Annual	SO2	N/A	AN00G002.PLT
Annual	PM	N/A	AN00G003.PLT

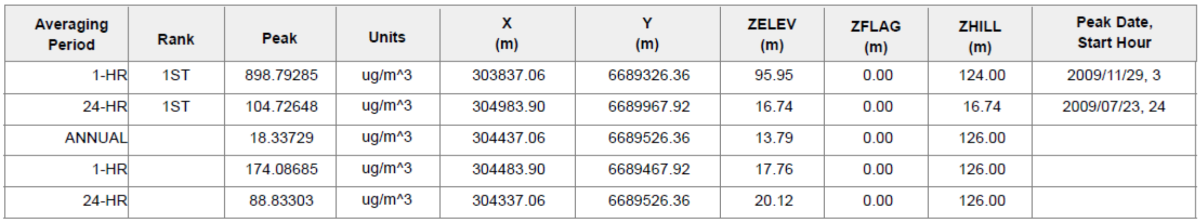
Results Summary

Source Group: All



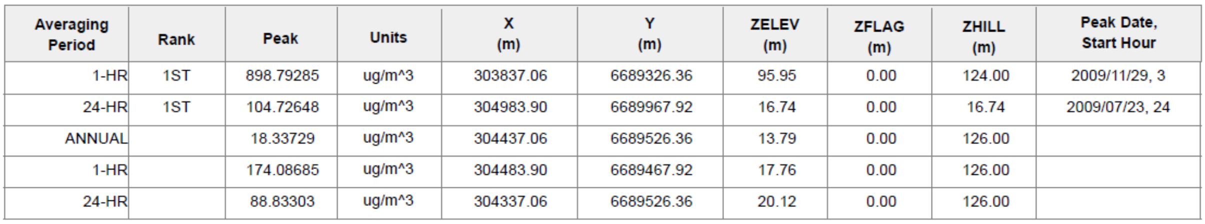
Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	1647.80757	ug/m^3	303837.06	6689326.36	95.95	0.00	124.00	2009/11/29, 3
24-HR	1ST	210.40460	ug/m^3	304483.90	6689467.92	17.76	0.00	126.00	2009/08/18, 24
ANNUAL		36.86504	ug/m^3	304337.06	6689426.36	26.83	0.00	126.00	
1-HR		335.95993	ug/m^3	304483.90	6689467.92	17.76	0.00	126.00	
24-HR		175.14595	ug/m^3	304337.06	6689526.36	20.12	0.00	126.00	

Source Group: NOx



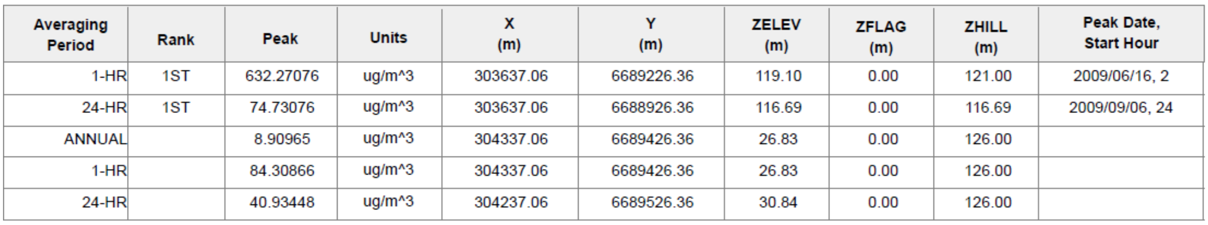
Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	898.79285	ug/m^3	303837.06	6689326.36	95.95	0.00	124.00	2009/11/29, 3
24-HR	1ST	104.72648	ug/m^3	304983.90	6689967.92	16.74	0.00	16.74	2009/07/23, 24
ANNUAL		18.33729	ug/m^3	304437.06	6689526.36	13.79	0.00	126.00	
1-HR		174.08685	ug/m^3	304483.90	6689467.92	17.76	0.00	126.00	
24-HR		88.83303	ug/m^3	304337.06	6689526.36	20.12	0.00	126.00	

Source Group: PM



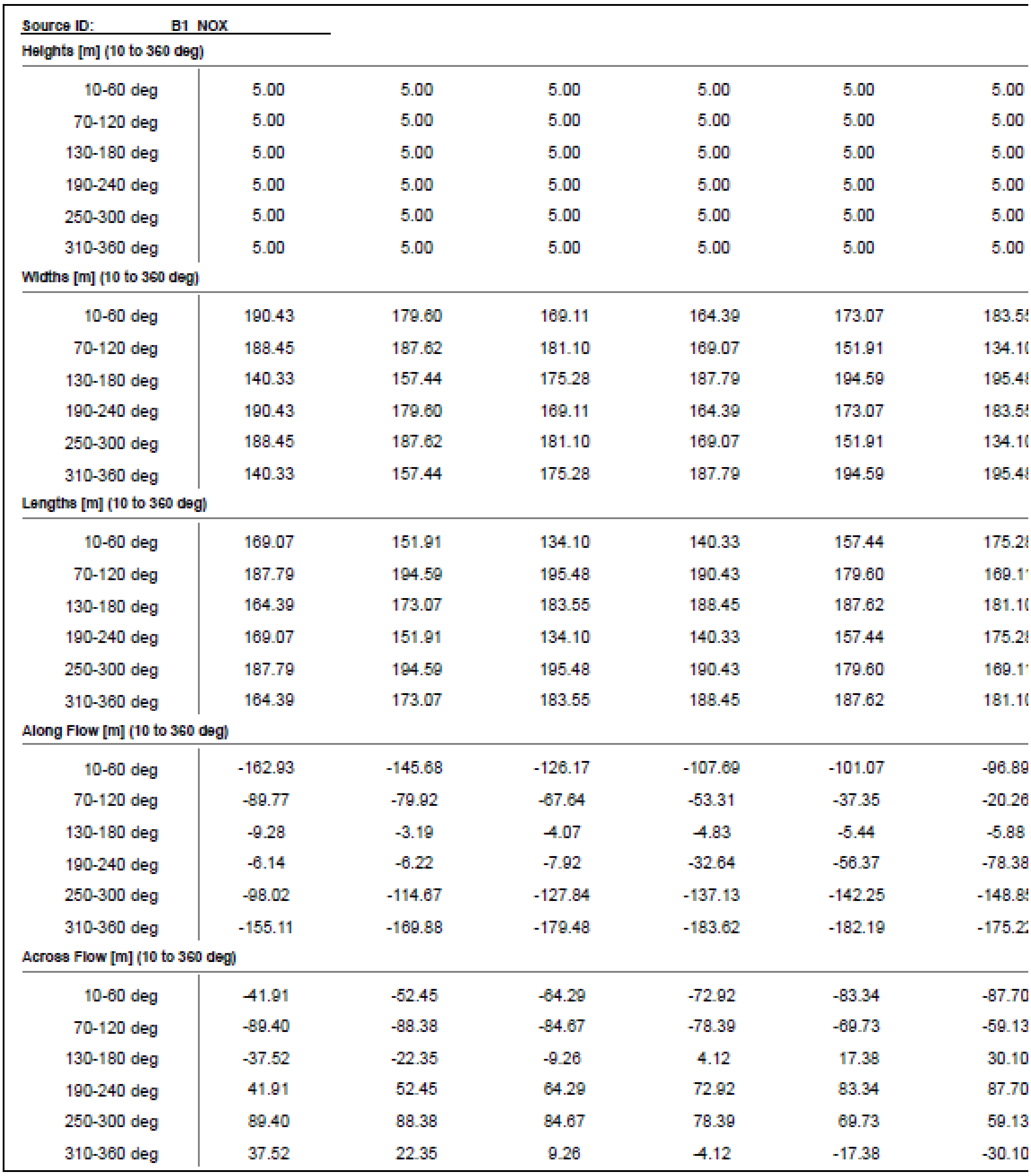
Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	898.79285	ug/m^3	303837.06	6689326.36	95.95	0.00	124.00	2009/11/29, 3
24-HR	1ST	104.72648	ug/m^3	304983.90	6689967.92	16.74	0.00	16.74	2009/07/23, 24
ANNUAL		18.33729	ug/m^3	304437.06	6689526.36	13.79	0.00	126.00	
1-HR		174.08685	ug/m^3	304483.90	6689467.92	17.76	0.00	126.00	
24-HR		88.83303	ug/m^3	304337.06	6689526.36	20.12	0.00	126.00	

Source Group: SO2



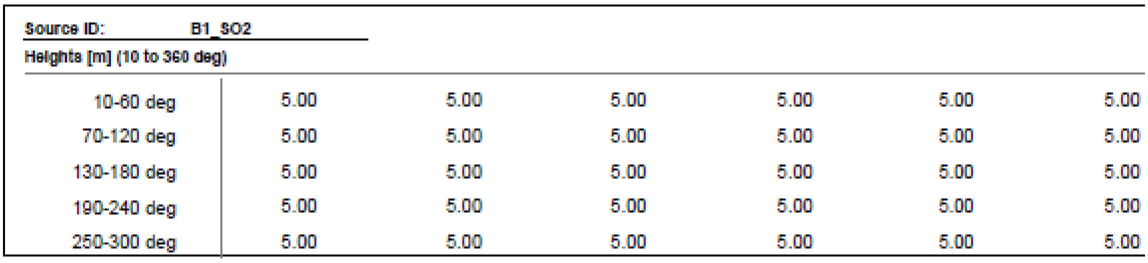
Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	632.27076	ug/m^3	303637.06	6689226.36	119.10	0.00	121.00	2009/06/16, 2
24-HR	1ST	74.73076	ug/m^3	303637.06	6688926.36	116.69	0.00	116.69	2009/09/06, 24
ANNUAL		8.90965	ug/m^3	304337.06	6689426.36	26.83	0.00	126.00	
1-HR		84.30866	ug/m^3	304337.06	6689426.36	26.83	0.00	126.00	
24-HR		40.93448	ug/m^3	304237.06	6689526.36	30.84	0.00	126.00	

Building Downwash Information



Source ID: B1_NOX

Heights [m] (10 to 360 deg)						
10-60 deg	5.00	5.00	5.00	5.00	5.00	5.00
70-120 deg	5.00	5.00	5.00	5.00	5.00	5.00
130-180 deg	5.00	5.00	5.00	5.00	5.00	5.00
190-240 deg	5.00	5.00	5.00	5.00	5.00	5.00
250-300 deg	5.00	5.00	5.00	5.00	5.00	5.00
310-360 deg	5.00	5.00	5.00	5.00	5.00	5.00
Widths [m] (10 to 360 deg)						
10-60 deg	190.43	179.60	169.11	164.39	173.07	183.5
70-120 deg	188.45	187.62	181.10	169.07	151.91	134.1
130-180 deg	140.33	157.44	175.28	187.79	194.59	195.4
190-240 deg	190.43	179.60	169.11	164.39	173.07	183.5
250-300 deg	188.45	187.62	181.10	169.07	151.91	134.1
310-360 deg	140.33	157.44	175.28	187.79	194.59	195.4
Lengths [m] (10 to 360 deg)						
10-60 deg	169.07	151.91	134.10	140.33	157.44	175.2
70-120 deg	187.79	194.59	195.48	190.43	179.60	169.1
130-180 deg	164.39	173.07	183.55	188.45	187.62	181.1
190-240 deg	169.07	151.91	134.10	140.33	157.44	175.2
250-300 deg	187.79	194.59	195.48	190.43	179.60	169.1
310-360 deg	164.39	173.07	183.55	188.45	187.62	181.1
Along Flow [m] (10 to 360 deg)						
10-60 deg	-162.93	-145.68	-126.17	-107.69	-101.07	-96.89
70-120 deg	-89.77	-79.92	-67.64	-53.31	-37.35	-20.26
130-180 deg	-9.28	-3.19	-4.07	-4.83	-5.44	-5.88
190-240 deg	-6.14	-6.22	-7.92	-32.64	-56.37	-78.38
250-300 deg	-98.02	-114.67	-127.84	-137.13	-142.25	-148.8
310-360 deg	-155.11	-169.88	-179.48	-183.62	-182.19	-175.2
Across Flow [m] (10 to 360 deg)						
10-60 deg	-41.91	-52.45	-64.29	-72.92	-83.34	-87.70
70-120 deg	-89.40	-88.38	-84.67	-78.39	-69.73	-59.13
130-180 deg	-37.52	-22.35	-9.26	4.12	17.38	30.10
190-240 deg	41.91	52.45	64.29	72.92	83.34	87.70
250-300 deg	89.40	88.38	84.67	78.39	69.73	59.13
310-360 deg	37.52	22.35	9.26	-4.12	-17.38	-30.10



Source ID: B1_SO2

Heights [m] (10 to 360 deg)						
10-60 deg	5.00	5.00	5.00	5.00	5.00	5.00
70-120 deg	5.00	5.00	5.00	5.00	5.00	5.00
130-180 deg	5.00	5.00	5.00	5.00	5.00	5.00
190-240 deg	5.00	5.00	5.00	5.00	5.00	5.00
250-300 deg	5.00	5.00	5.00	5.00	5.00	5.00

310-360 deg	5.00	5.00	5.00	5.00	5.00	5.00
Widths [m] (10 to 360 deg)						
10-60 deg	190.43	179.60	169.11	164.39	173.07	183.55
70-120 deg	188.45	187.62	181.10	169.07	151.91	134.10
130-180 deg	140.33	157.44	175.28	187.79	194.59	195.48
190-240 deg	190.43	179.60	169.11	164.39	173.07	183.55
250-300 deg	188.45	187.62	181.10	169.07	151.91	134.10
310-360 deg	140.33	157.44	175.28	187.79	194.59	195.48
Lengths [m] (10 to 360 deg)						
10-60 deg	169.07	151.91	134.10	140.33	157.44	175.28
70-120 deg	187.79	194.59	195.48	190.43	179.60	169.11
130-180 deg	164.39	173.07	183.55	188.45	187.62	181.10
190-240 deg	169.07	151.91	134.10	140.33	157.44	175.28
250-300 deg	187.79	194.59	195.48	190.43	179.60	169.11
310-360 deg	164.39	173.07	183.55	188.45	187.62	181.10
Along Flow [m] (10 to 360 deg)						
10-60 deg	-162.93	-145.68	-126.17	-107.69	-101.07	-96.89
70-120 deg	-89.77	-79.92	-67.64	-53.31	-37.35	-20.26
130-180 deg	-9.28	-3.19	-4.07	-4.83	-5.44	-5.88
190-240 deg	-6.14	-6.22	-7.92	-32.64	-56.37	-78.38
250-300 deg	-98.02	-114.67	-127.84	-137.13	-142.25	-148.85
310-360 deg	-155.11	-169.88	-179.48	-183.62	-182.19	-175.22
Across Flow [m] (10 to 360 deg)						
10-60 deg	-41.91	-52.45	-64.29	-72.92	-83.34	-87.70
70-120 deg	-89.40	-88.38	-84.67	-78.39	-69.73	-59.13
130-180 deg	-37.52	-22.35	-9.26	4.12	17.38	30.10
190-240 deg	41.91	52.45	64.29	72.92	83.34	87.70
250-300 deg	89.40	88.38	84.67	78.39	69.73	59.13
310-360 deg	37.52	22.35	9.26	-4.12	-17.38	-30.10

Source ID: B1_PM

Heights [m] (10 to 360 deg)						
10-60 deg	5.00	5.00	5.00	5.00	5.00	5.00
70-120 deg	5.00	5.00	5.00	5.00	5.00	5.00
130-180 deg	5.00	5.00	5.00	5.00	5.00	5.00
190-240 deg	5.00	5.00	5.00	5.00	5.00	5.00
250-300 deg	5.00	5.00	5.00	5.00	5.00	5.00
310-360 deg	5.00	5.00	5.00	5.00	5.00	5.00
Widths [m] (10 to 360 deg)						
10-60 deg	190.43	179.60	169.11	164.39	173.07	183.55
70-120 deg	188.45	187.62	181.10	169.07	151.91	134.10
130-180 deg	140.33	157.44	175.28	187.79	194.59	195.48
190-240 deg	190.43	179.60	169.11	164.39	173.07	183.55
250-300 deg	188.45	187.62	181.10	169.07	151.91	134.10
310-360 deg	140.33	157.44	175.28	187.79	194.59	195.48

Lengths [m] (10 to 360 deg)

10-60 deg	169.07	151.91	134.10	140.33	157.44	175.2
70-120 deg	187.79	194.59	195.48	190.43	179.60	169.1
130-180 deg	164.39	173.07	183.55	188.45	187.62	181.1
190-240 deg	169.07	151.91	134.10	140.33	157.44	175.2
250-300 deg	187.79	194.59	195.48	190.43	179.60	169.1
310-360 deg	164.39	173.07	183.55	188.45	187.62	181.1

Along Flow [m] (10 to 360 deg)

10-60 deg	-162.93	-145.68	-126.17	-107.69	-101.07	-96.89
70-120 deg	-89.77	-79.92	-67.64	-53.31	-37.35	-20.26
130-180 deg	-9.28	-3.19	-4.07	-4.83	-5.44	-5.88
190-240 deg	-6.14	-6.22	-7.92	-32.64	-56.37	-78.38
250-300 deg	-98.02	-114.67	-127.84	-137.13	-142.25	-148.8
310-360 deg	-155.11	-169.88	-179.48	-183.62	-182.19	-175.2

Across Flow [m] (10 to 360 deg)

10-60 deg	-41.91	-52.45	-64.29	-72.92	-83.34	-87.70
70-120 deg	-89.40	-88.38	-84.67	-78.39	-69.73	-59.13
130-180 deg	-37.52	-22.35	-9.26	4.12	17.38	30.10
190-240 deg	41.91	52.45	64.29	72.92	83.34	87.70
250-300 deg	89.40	88.38	84.67	78.39	69.73	59.13
310-360 deg	37.52	22.35	9.26	-4.12	-17.38	-30.10

Source ID: B2_NOX

Heights [m] (10 to 360 deg)

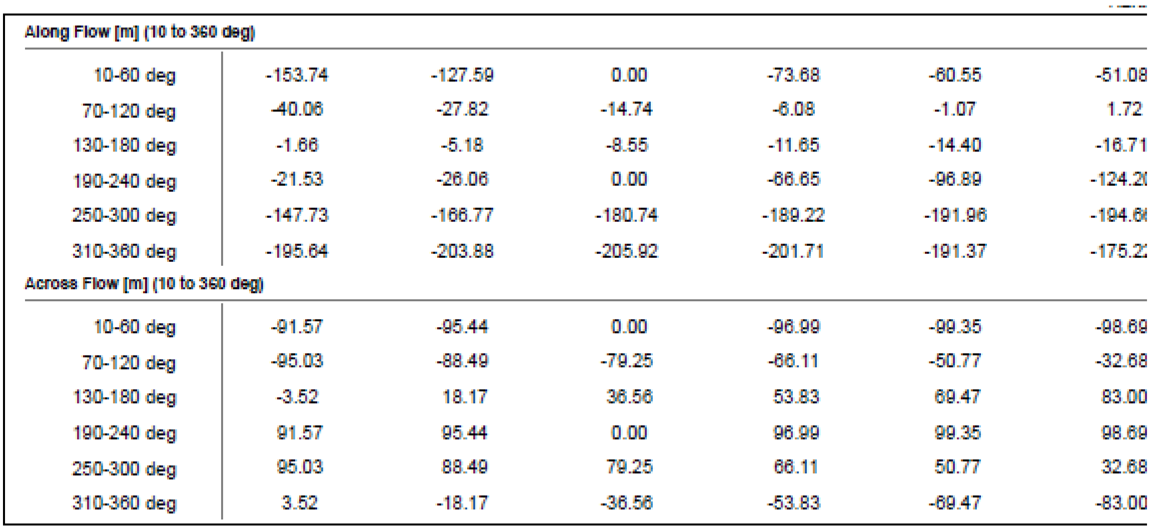
10-60 deg	2.00	2.00	0.00	2.00	2.00	2.00
70-120 deg	2.00	2.00	2.00	2.00	2.00	2.00
130-180 deg	2.00	2.00	2.00	2.00	2.00	2.00
190-240 deg	2.00	2.00	0.00	2.00	2.00	2.00
250-300 deg	2.00	2.00	2.00	2.00	2.00	2.00
310-360 deg	2.00	2.00	2.00	2.00	2.00	2.00

Widths [m] (10 to 360 deg)

10-60 deg	195.31	193.03	0.00	197.30	209.06	214.4
70-120 deg	213.36	205.77	191.93	175.27	153.65	134.1
130-180 deg	140.33	157.44	175.28	187.79	194.59	195.4
190-240 deg	195.31	193.03	0.00	197.30	209.06	214.4
250-300 deg	213.36	205.77	191.93	175.27	153.65	134.1
310-360 deg	140.33	157.44	175.28	187.79	194.59	195.4

Lengths [m] (10 to 360 deg)

10-60 deg	175.27	153.65	0.00	140.33	157.44	175.2
70-120 deg	187.79	194.59	195.48	195.31	193.03	192.9
130-180 deg	197.30	209.06	214.47	213.36	205.77	191.9
190-240 deg	175.27	153.65	0.00	140.33	157.44	175.2
250-300 deg	187.79	194.59	195.48	195.31	193.03	192.9
310-360 deg	197.30	209.06	214.47	213.36	205.77	191.9

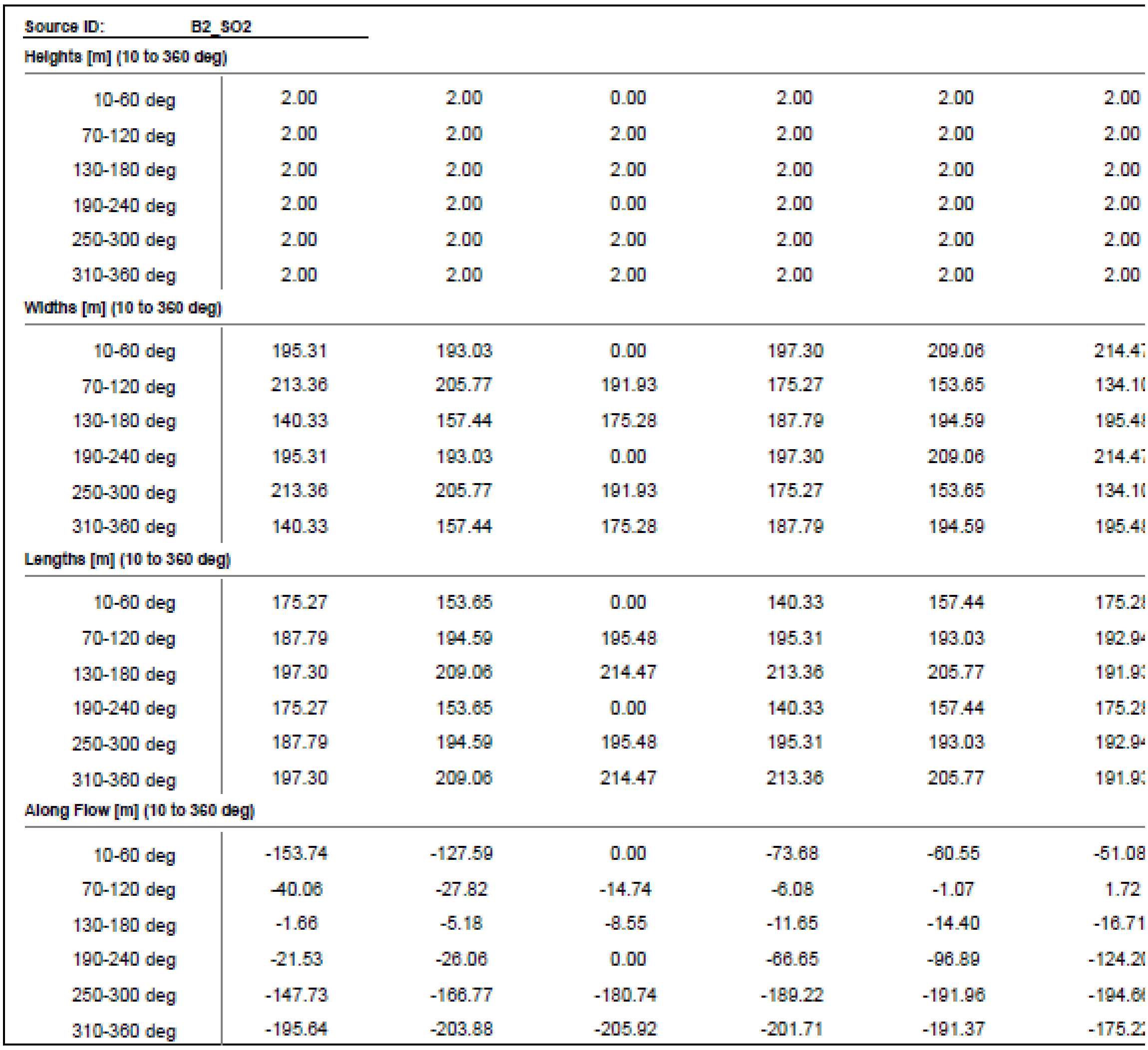


Along Flow [m] (10 to 360 deg)

10-60 deg	-153.74	-127.59	0.00	-73.68	-60.55	-51.08
70-120 deg	-40.06	-27.82	-14.74	-6.08	-1.07	1.72
130-180 deg	-1.66	-5.18	-8.55	-11.65	-14.40	-16.71
190-240 deg	-21.53	-26.06	0.00	-66.65	-96.89	-124.2
250-300 deg	-147.73	-166.77	-180.74	-189.22	-191.96	-194.6
310-360 deg	-195.64	-203.88	-205.92	-201.71	-191.37	-175.2

Across Flow [m] (10 to 360 deg)

10-60 deg	-91.57	-95.44	0.00	-96.99	-99.35	-98.69
70-120 deg	-95.03	-88.49	-79.25	-66.11	-50.77	-32.68
130-180 deg	-3.52	18.17	36.56	53.83	69.47	83.00
190-240 deg	91.57	95.44	0.00	96.99	99.35	98.69
250-300 deg	95.03	88.49	79.25	66.11	50.77	32.68
310-360 deg	3.52	-18.17	-36.56	-53.83	-69.47	-83.00



Source ID: B2_SO2

Heights [m] (10 to 360 deg)

10-60 deg	2.00	2.00	0.00	2.00	2.00	2.00
70-120 deg	2.00	2.00	2.00	2.00	2.00	2.00
130-180 deg	2.00	2.00	2.00	2.00	2.00	2.00
190-240 deg	2.00	2.00	0.00	2.00	2.00	2.00
250-300 deg	2.00	2.00	2.00	2.00	2.00	2.00
310-360 deg	2.00	2.00	2.00	2.00	2.00	2.00

Widths [m] (10 to 360 deg)

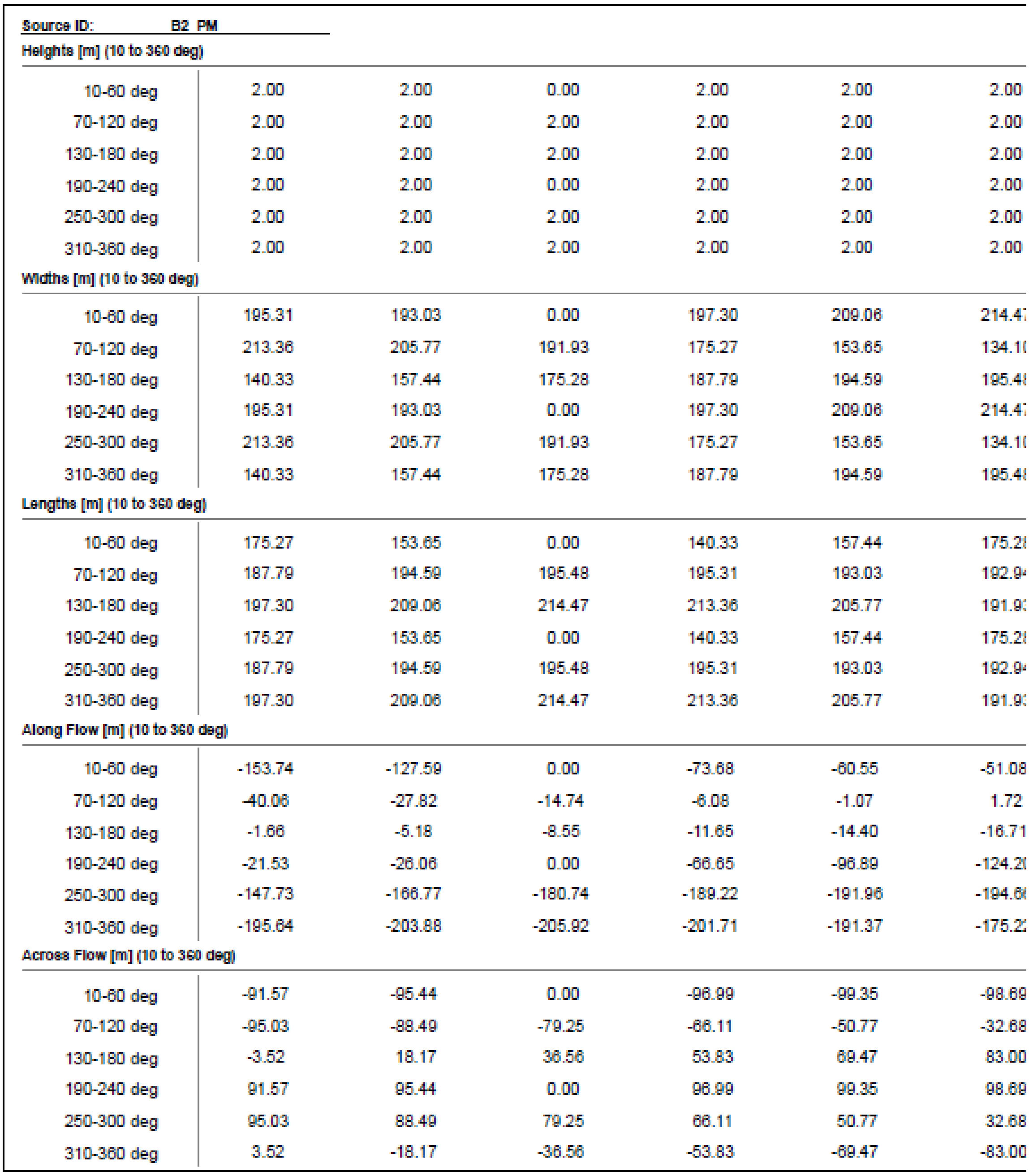
10-60 deg	195.31	193.03	0.00	197.30	209.06	214.4
70-120 deg	213.36	205.77	191.93	175.27	153.65	134.1
130-180 deg	140.33	157.44	175.28	187.79	194.59	195.4
190-240 deg	195.31	193.03	0.00	197.30	209.06	214.4
250-300 deg	213.36	205.77	191.93	175.27	153.65	134.1
310-360 deg	140.33	157.44	175.28	187.79	194.59	195.4

Lengths [m] (10 to 360 deg)

10-60 deg	175.27	153.65	0.00	140.33	157.44	175.2
70-120 deg	187.79	194.59	195.48	195.31	193.03	192.9
130-180 deg	197.30	209.06	214.47	213.36	205.77	191.9
190-240 deg	175.27	153.65	0.00	140.33	157.44	175.2
250-300 deg	187.79	194.59	195.48	195.31	193.03	192.9
310-360 deg	197.30	209.06	214.47	213.36	205.77	191.9

Along Flow [m] (10 to 360 deg)

10-60 deg	-153.74	-127.59	0.00	-73.68	-60.55	-51.08
70-120 deg	-40.06	-27.82	-14.74	-6.08	-1.07	1.72
130-180 deg	-1.66	-5.18	-8.55	-11.65	-14.40	-16.71
190-240 deg	-21.53	-26.06	0.00	-66.65	-96.89	-124.2
250-300 deg	-147.73	-166.77	-180.74	-189.22	-191.96	-194.6
310-360 deg	-195.64	-203.88	-205.92	-201.71	-191.37	-175.2



Source ID: B2_PM

Heights [m] (10 to 360 deg)

10-60 deg	2.00	2.00	0.00	2.00	2.00	2.00
70-120 deg	2.00	2.00	2.00	2.00	2.00	2.00
130-180 deg	2.00	2.00	2.00	2.00	2.00	2.00
190-240 deg	2.00	2.00	0.00	2.00	2.00	2.00
250-300 deg	2.00	2.00	2.00	2.00	2.00	2.00
310-360 deg	2.00	2.00	2.00	2.00	2.00	2.00

Widths [m] (10 to 360 deg)

10-60 deg	195.31	193.03	0.00	197.30	209.06	214.47
70-120 deg	213.36	205.77	191.93	175.27	153.65	134.10
130-180 deg	140.33	157.44	175.28	187.79	194.59	195.48
190-240 deg	195.31	193.03	0.00	197.30	209.06	214.47
250-300 deg	213.36	205.77	191.93	175.27	153.65	134.10
310-360 deg	140.33	157.44	175.28	187.79	194.59	195.48

Lengths [m] (10 to 360 deg)

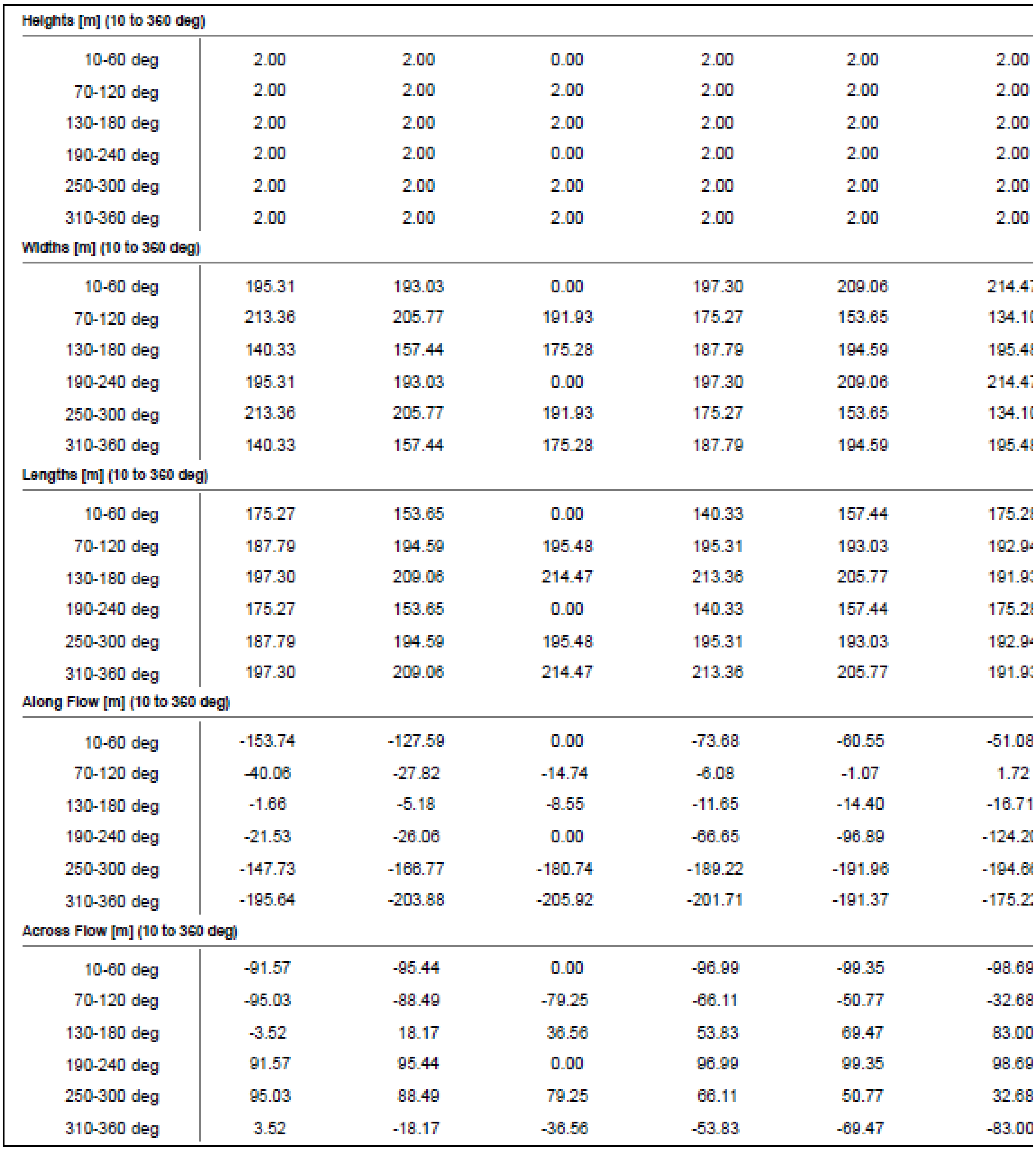
10-60 deg	175.27	153.65	0.00	140.33	157.44	175.28
70-120 deg	187.79	194.59	195.48	195.31	193.03	192.94
130-180 deg	197.30	209.06	214.47	213.36	205.77	191.93
190-240 deg	175.27	153.65	0.00	140.33	157.44	175.28
250-300 deg	187.79	194.59	195.48	195.31	193.03	192.94
310-360 deg	197.30	209.06	214.47	213.36	205.77	191.93

Along Flow [m] (10 to 360 deg)

10-60 deg	-153.74	-127.59	0.00	-73.68	-60.55	-51.08
70-120 deg	-40.06	-27.82	-14.74	-6.08	-1.07	1.72
130-180 deg	-1.66	-5.18	-8.55	-11.65	-14.40	-16.71
190-240 deg	-21.53	-26.06	0.00	-66.65	-96.89	-124.20
250-300 deg	-147.73	-166.77	-180.74	-189.22	-191.96	-194.66
310-360 deg	-195.64	-203.88	-205.92	-201.71	-191.37	-175.22

Across Flow [m] (10 to 360 deg)

10-60 deg	-91.57	-95.44	0.00	-96.99	-99.35	-98.69
70-120 deg	-95.03	-88.49	-79.25	-66.11	-50.77	-32.68
130-180 deg	-3.52	18.17	36.56	53.83	69.47	83.00
190-240 deg	91.57	95.44	0.00	96.99	99.35	98.69
250-300 deg	95.03	88.49	79.25	66.11	50.77	32.68
310-360 deg	3.52	-18.17	-36.56	-53.83	-69.47	-83.00



Heights [m] (10 to 360 deg)						
10-60 deg	2.00	2.00	0.00	2.00	2.00	2.00
70-120 deg	2.00	2.00	2.00	2.00	2.00	2.00
130-180 deg	2.00	2.00	2.00	2.00	2.00	2.00
190-240 deg	2.00	2.00	0.00	2.00	2.00	2.00
250-300 deg	2.00	2.00	2.00	2.00	2.00	2.00
310-360 deg	2.00	2.00	2.00	2.00	2.00	2.00
Widths [m] (10 to 360 deg)						
10-60 deg	195.31	193.03	0.00	197.30	209.06	214.4
70-120 deg	213.36	205.77	191.93	175.27	153.65	134.1
130-180 deg	140.33	157.44	175.28	187.79	194.59	195.4
190-240 deg	195.31	193.03	0.00	197.30	209.06	214.4
250-300 deg	213.36	205.77	191.93	175.27	153.65	134.1
310-360 deg	140.33	157.44	175.28	187.79	194.59	195.4
Lengths [m] (10 to 360 deg)						
10-60 deg	175.27	153.65	0.00	140.33	157.44	175.2
70-120 deg	187.79	194.59	195.48	195.31	193.03	192.9
130-180 deg	197.30	209.06	214.47	213.36	205.77	191.9
190-240 deg	175.27	153.65	0.00	140.33	157.44	175.2
250-300 deg	187.79	194.59	195.48	195.31	193.03	192.9
310-360 deg	197.30	209.06	214.47	213.36	205.77	191.9
Along Flow [m] (10 to 360 deg)						
10-60 deg	-153.74	-127.59	0.00	-73.68	-60.55	-51.08
70-120 deg	-40.06	-27.82	-14.74	-6.08	-1.07	1.72
130-180 deg	-1.66	-5.18	-8.55	-11.65	-14.40	-16.71
190-240 deg	-21.53	-26.06	0.00	-66.65	-96.89	-124.2
250-300 deg	-147.73	-166.77	-180.74	-189.22	-191.96	-194.6
310-360 deg	-195.64	-203.88	-205.92	-201.71	-191.37	-175.2
Across Flow [m] (10 to 360 deg)						
10-60 deg	-91.57	-95.44	0.00	-96.99	-99.35	-98.69
70-120 deg	-95.03	-88.49	-79.25	-66.11	-50.77	-32.68
130-180 deg	-3.52	18.17	36.56	53.83	69.47	83.00
190-240 deg	91.57	95.44	0.00	96.99	99.35	98.69
250-300 deg	95.03	88.49	79.25	66.11	50.77	32.68
310-360 deg	3.52	-18.17	-36.56	-53.83	-69.47	-83.00

Source ID: **B3_SO2**

Heights [m] (10 to 360 deg)

10-60 deg	2.00	2.00	0.00	2.00	2.00	2.00
70-120 deg	2.00	2.00	2.00	2.00	2.00	2.00
130-180 deg	2.00	2.00	2.00	2.00	2.00	2.00
190-240 deg	2.00	2.00	0.00	2.00	2.00	2.00
250-300 deg	2.00	2.00	2.00	2.00	2.00	2.00
310-360 deg	2.00	2.00	2.00	2.00	2.00	2.00

Widths [m] (10 to 360 deg)

10-60 deg	195.31	193.03	0.00	197.30	209.06	214.4
70-120 deg	213.36	205.77	191.93	175.27	153.65	134.1
130-180 deg	140.33	157.44	175.28	187.79	194.59	195.4
190-240 deg	195.31	193.03	0.00	197.30	209.06	214.4
250-300 deg	213.36	205.77	191.93	175.27	153.65	134.1
310-360 deg	140.33	157.44	175.28	187.79	194.59	195.4

Lengths [m] (10 to 360 deg)

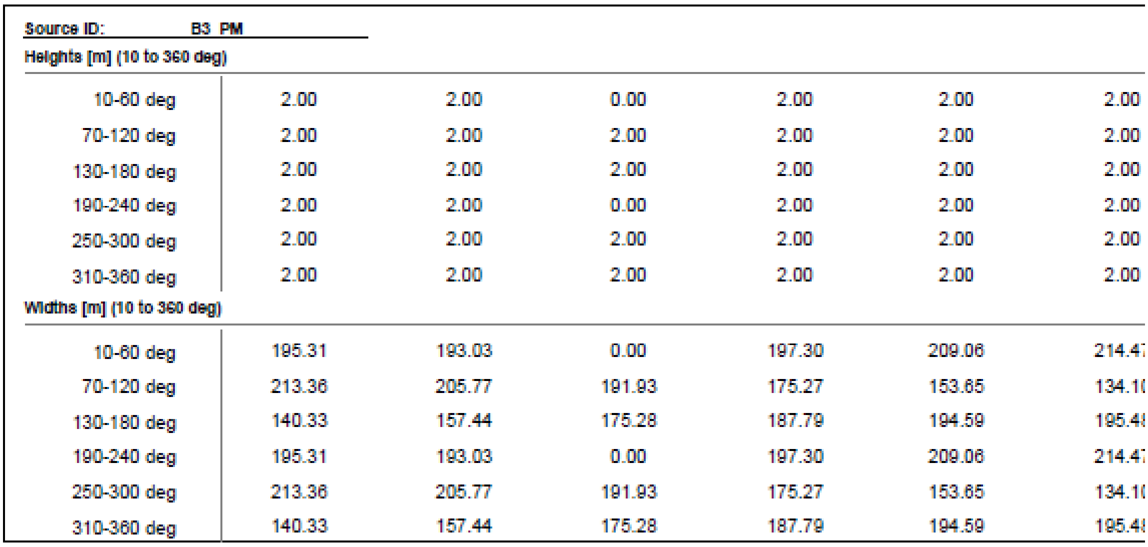
10-60 deg	175.27	153.65	0.00	140.33	157.44	175.2
70-120 deg	187.79	194.59	195.48	195.31	193.03	192.9
130-180 deg	197.30	209.06	214.47	213.36	205.77	191.9
190-240 deg	175.27	153.65	0.00	140.33	157.44	175.2
250-300 deg	187.79	194.59	195.48	195.31	193.03	192.9
310-360 deg	197.30	209.06	214.47	213.36	205.77	191.9

Along Flow [m] (10 to 360 deg)

10-60 deg	-153.74	-127.59	0.00	-73.68	-60.55	-51.08
70-120 deg	-40.06	-27.82	-14.74	-6.08	-1.07	1.72
130-180 deg	-1.66	-5.18	-8.55	-11.65	-14.40	-16.71
190-240 deg	-21.53	-26.06	0.00	-66.65	-96.89	-124.2
250-300 deg	-147.73	-166.77	-180.74	-189.22	-191.96	-194.6
310-360 deg	-195.64	-203.88	-205.92	-201.71	-191.37	-175.2

Across Flow [m] (10 to 360 deg)

10-60 deg	-91.57	-95.44	0.00	-96.99	-99.35	-98.69
70-120 deg	-95.03	-88.49	-79.25	-66.11	-50.77	-32.68
130-180 deg	-3.52	18.17	36.56	53.83	69.47	83.00
190-240 deg	91.57	95.44	0.00	96.99	99.35	98.69
250-300 deg	95.03	88.49	79.25	66.11	50.77	32.68
310-360 deg	3.52	-18.17	-36.56	-53.83	-69.47	-83.00



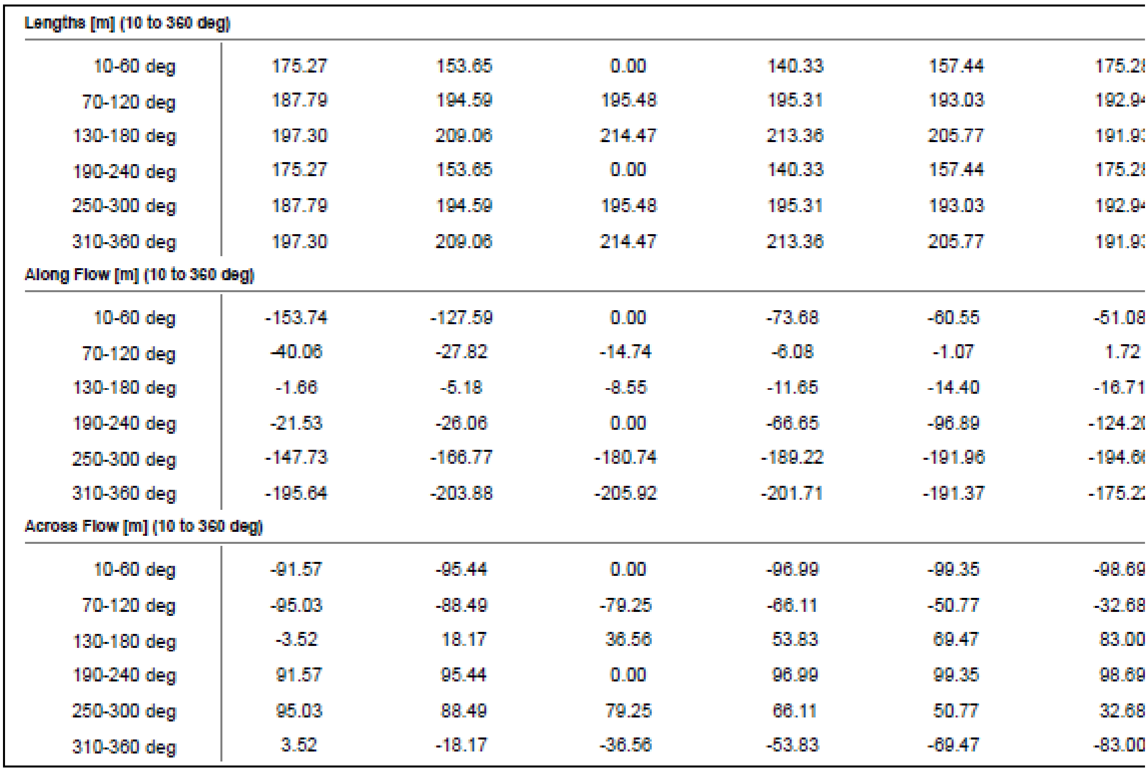
Source ID: B3_PM

Heights [m] (10 to 360 deg)

10-60 deg	2.00	2.00	0.00	2.00	2.00	2.00
70-120 deg	2.00	2.00	2.00	2.00	2.00	2.00
130-180 deg	2.00	2.00	2.00	2.00	2.00	2.00
190-240 deg	2.00	2.00	0.00	2.00	2.00	2.00
250-300 deg	2.00	2.00	2.00	2.00	2.00	2.00
310-360 deg	2.00	2.00	2.00	2.00	2.00	2.00

Widths [m] (10 to 360 deg)

10-60 deg	195.31	193.03	0.00	197.30	209.06	214.4
70-120 deg	213.36	205.77	191.93	175.27	153.65	134.1
130-180 deg	140.33	157.44	175.28	187.79	194.59	195.4
190-240 deg	195.31	193.03	0.00	197.30	209.06	214.4
250-300 deg	213.36	205.77	191.93	175.27	153.65	134.1
310-360 deg	140.33	157.44	175.28	187.79	194.59	195.4



Lengths [m] (10 to 360 deg)

10-60 deg	175.27	153.65	0.00	140.33	157.44	175.2
70-120 deg	187.79	194.59	195.48	195.31	193.03	192.9
130-180 deg	197.30	209.06	214.47	213.36	205.77	191.9
190-240 deg	175.27	153.65	0.00	140.33	157.44	175.2
250-300 deg	187.79	194.59	195.48	195.31	193.03	192.9
310-360 deg	197.30	209.06	214.47	213.36	205.77	191.9

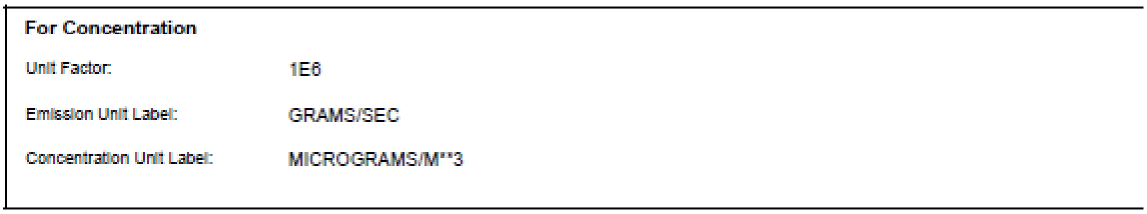
Along Flow [m] (10 to 360 deg)

10-60 deg	-153.74	-127.59	0.00	-73.68	-60.55	-51.08
70-120 deg	-40.06	-27.82	-14.74	-6.08	-1.07	1.72
130-180 deg	-1.66	-5.18	-8.55	-11.65	-14.40	-16.71
190-240 deg	-21.53	-26.06	0.00	-66.65	-96.89	-124.2
250-300 deg	-147.73	-166.77	-180.74	-189.22	-191.96	-194.6
310-360 deg	-195.64	-203.88	-205.92	-201.71	-191.37	-175.2

Across Flow [m] (10 to 360 deg)

10-60 deg	-91.57	-95.44	0.00	-96.99	-99.35	-98.69
70-120 deg	-95.03	-88.49	-79.25	-66.11	-50.77	-32.68
130-180 deg	-3.52	18.17	36.56	53.83	69.47	83.00
190-240 deg	91.57	95.44	0.00	96.99	99.35	98.69
250-300 deg	95.03	88.49	79.25	66.11	50.77	32.68
310-360 deg	3.52	-18.17	-36.56	-53.83	-69.47	-83.00

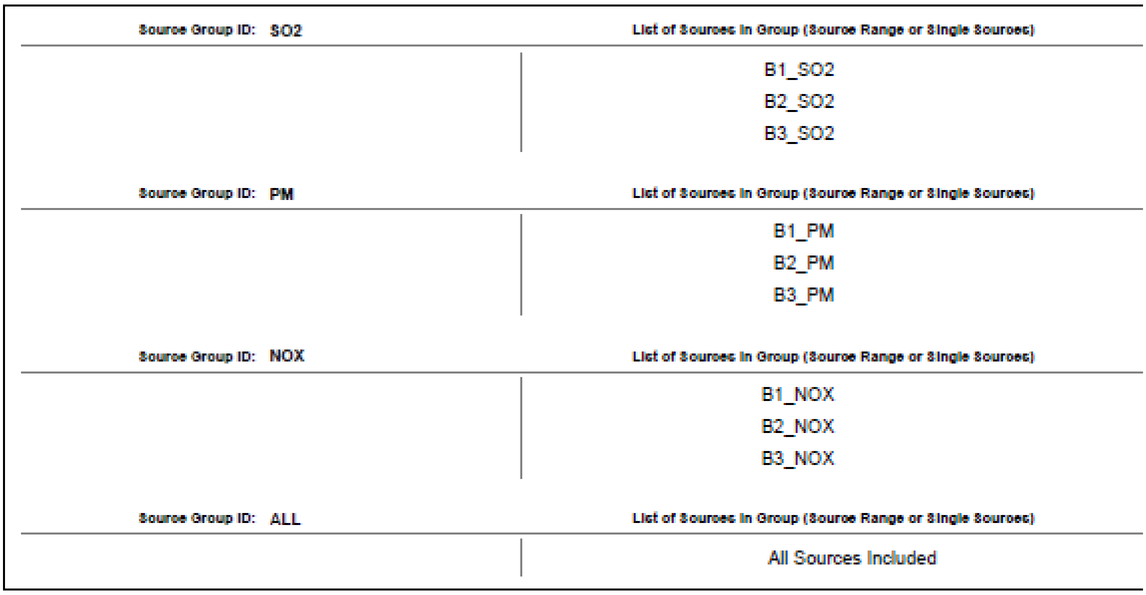
Emission Rate Units for Output



For Concentration

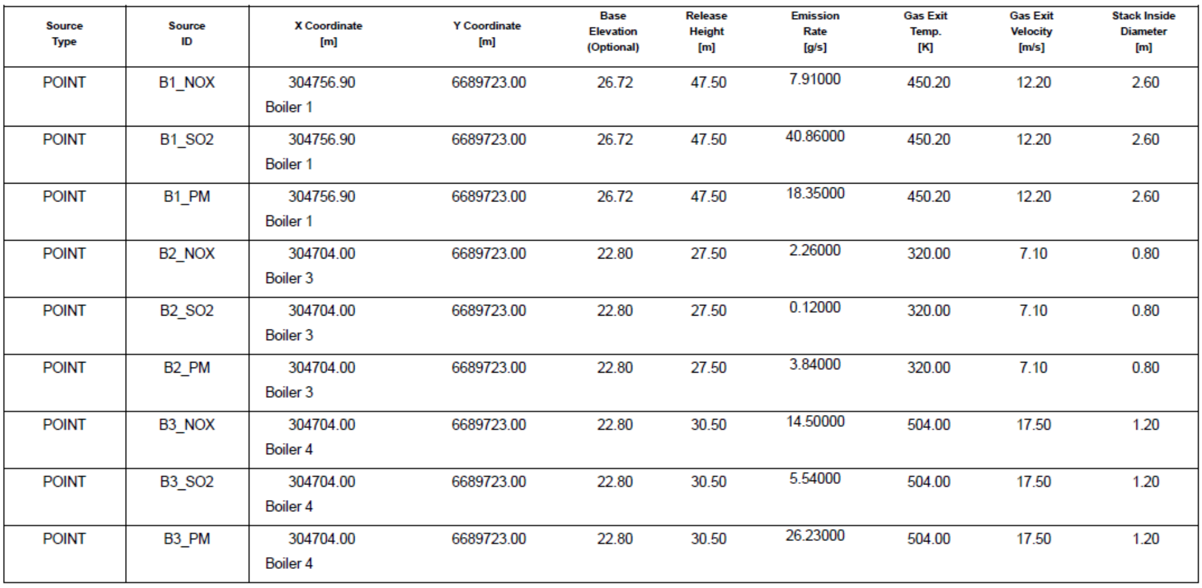
Unit Factor:	1E6
Emission Unit Label:	GRAMS/SEC
Concentration Unit Label:	MICROGRAMS/M**3

Source Group



Source Group ID:	List of Sources in Group (Source Range or Single Sources)
SO2	B1_SO2 B2_SO2 B3_SO2
PM	B1_PM B2_PM B3_PM
NOX	B1_NOX B2_NOX B3_NOX
ALL	All Sources Included

Point Source Inputs



Source Type	Source ID	X Coordinate [m]	Y Coordinate [m]	Base Elevation (Optional)	Release Height [m]	Emission Rate [g/s]	Gas Exit Temp. [K]	Gas Exit Velocity [m/s]	Stack Inside Diameter [m]
POINT	B1_NOX	304756.90 Boiler 1	6689723.00	26.72	47.50	7.91000	450.20	12.20	2.60
POINT	B1_SO2	304756.90 Boiler 1	6689723.00	26.72	47.50	40.86000	450.20	12.20	2.60
POINT	B1_PM	304756.90 Boiler 1	6689723.00	26.72	47.50	18.35000	450.20	12.20	2.60
POINT	B2_NOX	304704.00 Boiler 3	6689723.00	22.80	27.50	2.26000	320.00	7.10	0.80
POINT	B2_SO2	304704.00 Boiler 3	6689723.00	22.80	27.50	0.12000	320.00	7.10	0.80
POINT	B2_PM	304704.00 Boiler 3	6689723.00	22.80	27.50	3.84000	320.00	7.10	0.80
POINT	B3_NOX	304704.00 Boiler 4	6689723.00	22.80	30.50	14.50000	504.00	17.50	1.20
POINT	B3_SO2	304704.00 Boiler 4	6689723.00	22.80	30.50	5.54000	504.00	17.50	1.20
POINT	B3_PM	304704.00 Boiler 4	6689723.00	22.80	30.50	26.23000	504.00	17.50	1.20

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