AIR QUALITY MANAGEMENT IN THE uMHLATHUZE MUNICIPALITY USING AIR DISPERSION MODELLING

BY

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PREFACE

This thesis represents original work by the author and has not been submitted in any form to another university. Where use has been made of work by others, it has been duly acknowledged in text.

The research described in this thesis was conducted in the School of Environmental Sciences, University of KwaZulu-Natal, Durban, under the supervision of Professor Roseanne Diab.

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- Above all, I thank God almighty for making this journey possible for me.

ABSTRACT

Air pollution has increased over time due to human population growth, industrialisation and other economic activities which have led to global and localised deterioration in air quality. The uMhlathuze Municipality, located on the KwaZulu-Natal North Coast is one such local area that has a rapidly developing Industrial Development Zone, currently comprising many large and small scale industries. These large-scale operations are amongst South Africa's largest process industries and operate continuous combustion processes which release significant quantities of air pollutants into the atmosphere. These pollutants include reduced sulphur gases, mercaptans, hydrogen sulphide, sulphur dioxide (SO_2), sulphur trioxide, carbon dioxide, particulate fluoride and ammonia.

In light of the promulgation of the National Environmental Management: Air Quality Act (AQA) of 2004 and the need to assess ambient air quality, the contribution of air dispersion modelling to ambient air quality management in the uMhlathuze Municipality was assessed using SO_2 as an indicator pollutant. The Gaussian puff urban air dispersion model called Calpuff was used to model five scenarios including a control run with actual emissions data; a worst-case run using permitted emissions data; and three emissions reduction scenarios using 25%, 50% and 75% reductions of the permitted data.. The results of these modelling scenarios were compared with results of other modelling studies recently conducted in the uMhlathuze Municipality, as well as with the South African Ambient Air Quality Standards (SAAAQS) for SO_2.

The results revealed that the permitted emissions scenario led to exceedances of the SAAAQS 1-hour and 24-hour average concentrations over most of the uMhlathuze Municipal area. The use of the permitted emissions values produced higher SO_2 concentrations over the study area than the control run that comprised current emissions

values. The control scenario produced similar results to the scenario in which there was a 50% reduction in permitted emissions data and suggests that the industries are operating at half of their permitted levels of SO_2 emissions. The reduction of the permitted emission by 75% shows a significant decrease in the area exceeding the SAAAQS 1-hour standard, and compliance with the SAAAQS 24-hour and annual average standards.

The results of this study for the control scenario based on actual emissions were higher than previous studies conducted in uMhlathuze due to a larger quantity of SO_2 emissions used in the modelling exercises, different meteorological data sets and different air dispersion models used. However, there is a close correspondence between the Airshed (2006) results and this study when similar quantities of SO_2 emissions were modelled in the permitted emissions scenario.

In view of the exceedances experienced in the control run and permitted emissions scenarios, it is likely that under the AQA, some reduction in emissions will be required. In line with the Department of Environmental Affairs and Tourism National Framework classification system, the City of uMhlathuze is likely to fall under a Class 4 area, in which ambient concentrations of SO_2 can pose a threat to the health and well-being of people. Immediate air quality management action plans that have specific timeframes for compliance with the ambient standards are required. The National Framework notes that the air quality impact of an industry will be assessed before an Atmospheric Emission License is granted and implies that each industry is required to undertake an air quality specialist study to determine its individual impact on ambient air quality. The air quality specialist study should include air dispersion modelling to assess the ambient SO_2 concentrations; a health risk assessment based on the results of the dispersion modelling;

and mitigation measures that are required to ensure compliance with ambient standards through the use of the Best Practicable Environmental Option (BPEO).

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The management of air quality has progressed over time from assessing the impact of air pollution through simple methods such as visual monitoring to sophisticated management approaches that take into consideration the spatial and temporal impacts of air pollutants from a multitude of sources and predict pollutant concentrations over time and space (BCME, 2006). Human population growth and industrialisation have led to an increase in sulphur emissions, leading to air pollution impacts such as acidification of the water bodies through removal of sulphur gases via wet scavenging and dry deposition (Pham *et al.*, 1995). The increase in sulphur dioxide emissions has led to global as well as localised deterioration in air quality which is influenced by local meteorology and topographical factors (Nunnari *et al.*, 2004).

Generally, in most countries in the world, ambient air quality is regulated through compliance with ambient air quality standards, which are designed to protect public health. Standards are set by legislation and the achievement of ambient air quality standards forms part of an air quality management planning process. An Air Quality Management Plan (AQMP) usually comprises an emissions inventory; point source monitoring data; ambient monitoring data; meteorological data; air dispersion modelling results; public participation processes; and emission reduction measures (South Africa, 2001a). This study focuses on the air dispersion modelling component of an AQMP and its role in ambient air quality regulation in the uMhlathuze Municipality.

1.2 Rationale for this Study

In order to formulate an ambient air quality management strategy for a specific area, the concentration of pollutants in the atmosphere must first be determined. Two methods can be used to determine ambient air quality concentrations at a specific location, namely ambient air quality monitoring or air dispersion modelling (South Africa, 2001a).

In order to conduct ambient air quality monitoring, a range of equipment is required, including instruments that are capable of continuous gaseous, particulate and meteorological monitoring. The equipment must be housed in secure temperature controlled shelters and must be calibrated and maintained periodically, while the continuous data output from the analyzers require validation, interpretation and reporting (Ministry for the Environment, 2000; National Air Quality Management Programme, 2007; United States Environmental Protection Agency, 2000a). This method of determining the status of ambient air quality is expensive and the results are limited to the area in which the analyzers are located. The accuracy of ambient monitoring is dependent on the limitations of the instruments used, as well as human error during maintenance and calibration of analyzers. In the case of upset conditions arising 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 (UNESCO, 1995).

Air dispersion modelling is a software tool that requires input data from emissions inventories and localized meteorological data to calculate the concentrations of pollutants in ambient environments (Earth Tech, 2005). Modelling can provide spatial and temporal patterns of air pollutants and allows for the prediction of pollutant concentrations from a single source to multiple sources, with real time modelling capable of identifying major sources of pollution in the case of air pollution incidents. The results obtained from air pollutant dispersion modelling can be used to assess existing and future air quality impacts; to evaluate the potential for remedial measures when ambient guidelines are exceeded; to determine a suitable location for a monitoring station when developing an ambient air quality monitoring system; to predict 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. Individual sources can also be modelled to assess their contribution to ambient air quality. In this way modelling can be used as a prioritization tool to focus on the most significant sources contributing to poor air quality in a specific area. Ambient monitoring and air 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, 2000; UNESCO, 1995; South Africa, 2001a).

The uMhlathuze Municipality in KwaZulu-Natal was chosen as the location in which dispersion modelling could be used to inform air quality management in the municipal area. uMhlathuze has an established Industrial Development Zone, currently comprising industries such as a chemical fertilizer plant, two aluminum smelters, woodchip plants, a Kraft paper mill and numerous smaller offensive trade establishments. These large-scale operations are amongst South Africa’s largest process industries and operate continuous combustion processes which release significant quantities of air pollutants into the atmosphere, namely reduced sulphur gases, mercaptans, hydrogen sulphide, sulphur dioxide (SO_2), sulphur trioxide, carbon dioxide, particulate fluoride and ammonia as shown in Table 1.1 (uMhlathuze SER, 2002).

Table 1.1 Air Pollution Sources within the uMhlathuze Municipality (uMhlathuze SER, 2002)

Source type	Activity	Pollutant
Industrial	Bayside and Hillside Aluminium smelters	SO_2, Nitrogen Oxides (NOx), CO, gaseous and particulate fluoride, particulates
	Foskor Richards Bay	SO_2, sulphur trioxide, ammonia, NOx, gaseous and particulate fluoride, phosphate, particulates
	Mondi Felixton and Richards Bay pulp mills	SO_2, NOx, particulates, Volatile Organic Compounds (VOCs), reduced sulphur compounds (eg: hydrogen sulphide, methyl mercaptan, and dimethyl sulphide)
	Richards Bay Minerals	SO_2, NOx, particulates
	Tongaat-Hulett	SO_2, NOx, particulates
Transport	Ships, trains, aircraft and motor vehicles	SO_2, NOx, particulates, VOCs, CO
Fires	Veld, cane and forest	NOx, particulates
Low income housing	Wood and coal burning	NOx, particulates

The majority of industries are based in the town of Richards Bay. The high ambient concentrations of air pollutants, for example sulphur dioxide, particulates and odorous gases, such as mercaptans, have raised public concern over the health of the residents in the uMhlathuze area and have led to numerous public complaints as shown in Figure 1.1. Ratepayers formed the Richards Bay Clean Air Association (RBCAA) in 1996 to address air quality issues in the town. In order to meet their objectives, the RBCAA has established an air quality monitoring system comparing measurements of sulphur dioxide, particulates, ozone, pollen and meteorology around Richards Bay (RBCAA, 2002; 2003; 2004; 2005).

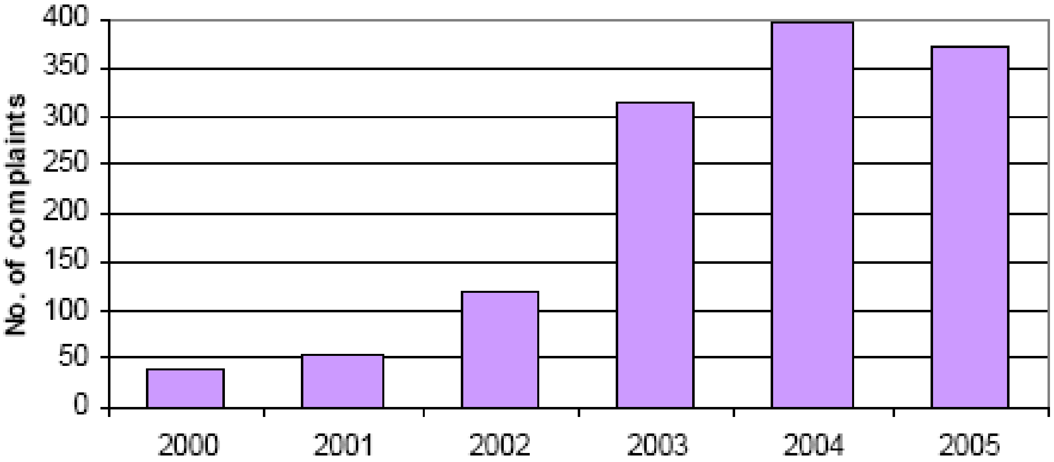


Figure 1.1 Community complaints recorded by the RBCAA from the year 2000 to 2005 (RBCAA, 2005). The RBCAA 2006 report was not yet published during the write up of this study.

Sulphur dioxide (SO_2) was chosen as an indicator pollutant for this study and it has been used in previous air quality impact assessments in the uMhlathuze Municipality (CSIR, 2004; 2005; Airshed, 2006a). SO_2 is a colourless gas that is emitted by anthropogenic sources such as fossil fuel burning and natural sources such as volcanoes. Gaseous SO_2 is water soluble and oxidizes to form sulphur trioxide and sulphuric acid. SO_2 can be removed by wet deposition in the troposphere by clouds (Speidel *et al*., 2007).

Due to its water soluble properties, SO_2 is absorbed by the mucous membranes of the nose and upper respiratory tract of humans. The results of controlled studies undertaken by the World Health Organization (WHO) reveal that short term exposure to high concentrations of SO_2 can cause respiratory changes in human beings. The WHO therefore recommends that a value of 500 $\mu g/m^3$ should not be exceeded over an averaging period of 10 minutes or less. The short term exposure period depends on the type of local SO_2 sources as well as the meteorological conditions at the time of the high SO_2 concentration, and it is therefore difficult to estimate guideline values for periods greater than 10-minutes. In addition, the

WHO recommends that the daily and long term periods of exposure to SO_2 be investigated in relation to the mixture of pollutants, for example particulate matter, in the atmosphere (WHO, 2000; 2005; 2006).

After conducting epidemiological studies, in the year 2000, the WHO proposed an SO_2 guideline of 125 $\mu g/m^3$ for a 24-hour averaging period. Subsequent studies by the WHO have considered the uncertainty of SO_2 in causalities; the uncertainty in the SO_2 level that will not cause any negative health effects; and the uncertainty in assuming that the reduction of SO_2 concentrations would lead to the reduction in exposure to correlated substances. These factors have led the WHO to revise the 24-hour guideline for SO_2 to 20 $\mu g/m^3$ **,** allowing for a gradual decrease from 125 $\mu g/m^3$ to 50 $\mu g/m^3$ until 20 $\mu g/m^3$, with a recommendation that each country implement emissions reduction plans to achieve these interim target values. A 50 $\mu g/m^3$ annual guideline was proposed by WHO in the year 2000 which will become unnecessary if 20 $\mu g/m^3$ is maintained over 24-hourly period in the latest guideline (WHO, 2006).

The WHO reports that SO_2 levels have decreased in large parts of Europe and North America due to international regulations that include protocols on trans-boundary air pollution. Figure 1.2 gives an overview of typical annual average SO_2 concentrations reported from selected cities in Asia, Africa, the Americas and Europe, based on data from the year 2000 to 2005. The city of Durban shown on the graph, which is approximately 180 km south of Richards Bay, shows an annual average SO_2 concentration below 20 $\mu g/m^3$ over a period of five years (2000-2005). The WHO reports that the ambient values reported for South Africa do not show an upward trend, but also underlines that these values should be assessed based on the lack of monitoring information available in South Africa.

A further comparison of the ambient levels of SO_2 in South Africa compared to international ambient levels is depicted in Figure 1.3. The stations named Arboretum, Wildenwiede, R Bay Caravan Park, Esikhaweni and uMhlathuze are located in the uMhlathuze Municipality. The 24-hour averages at these stations are low in comparison with the stations located in Europe and the South African city of Durban (Southern Works, Merewent, Sapref and Wentworth). The low values in Richards Bay can be attributed to the locations of the monitoring stations which are in the residential and central business areas, while the stations in Durban are located in the industrial areas and residential areas bordering the industrial clusters (http://www2.nilu.no/airquality/).

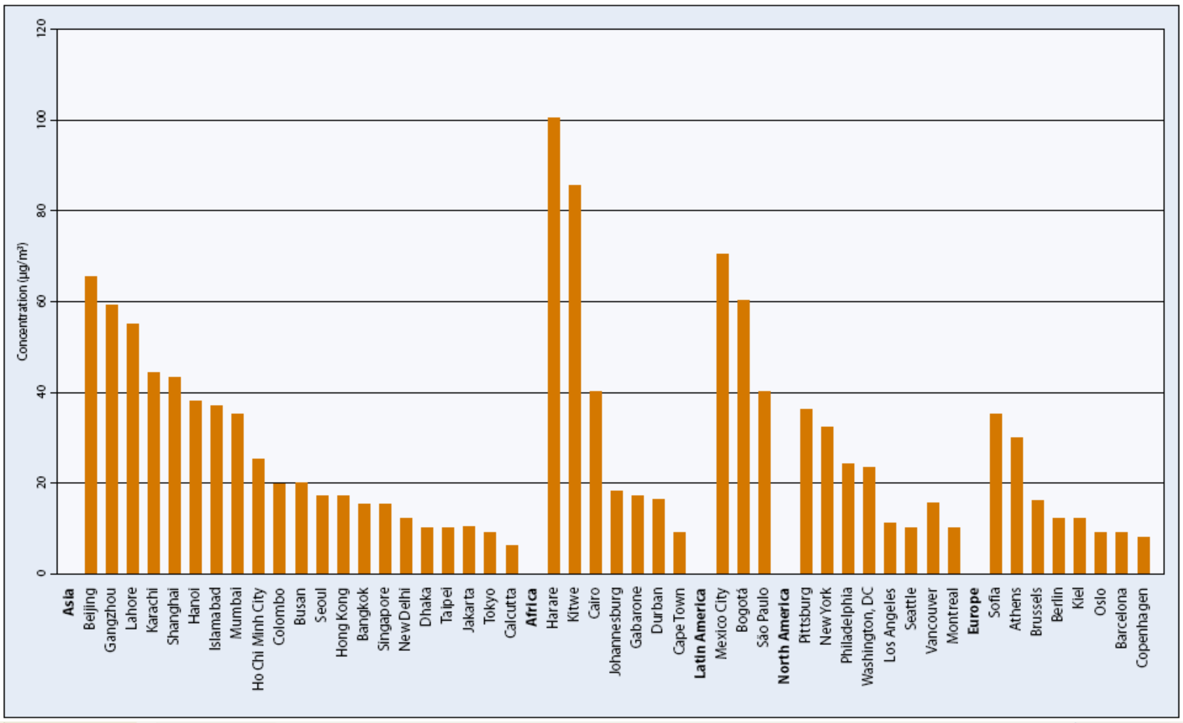


Figure 1.2 Overview of typical annual average sulphur dioxide concentrations reported from selected cities in Asia, Africa, the Americas and Europe, based on data from 2000–2005 (WHO, 2006)

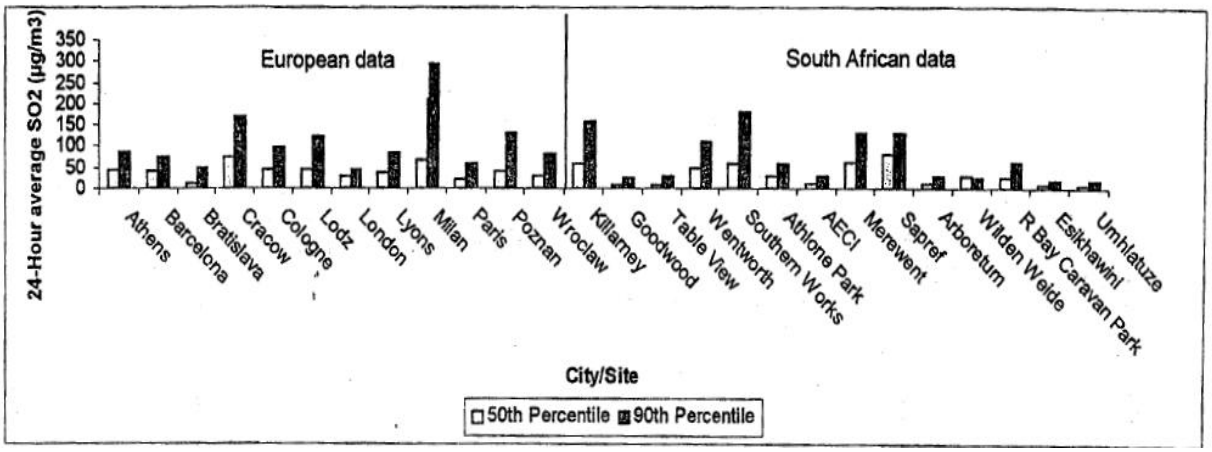


Figure 1.3 Comparison of ambient SO_2 levels in Europe and South Africa (South Africa, 2001a)

1.3 Aims and Objectives

The overarching aim of this dissertation is to assess the contribution of air dispersion modelling to air quality management in the uMhlathuze Municipality using SO_2 as an indicator pollutant. The objectives of the study are:

- To simulate maximum 1-hour, 24-hour and annual average concentrations of SO_2 over the study area based on current SO_2 emissions (baseline or control scenario);
- To simulate maximum 1-hour, 24-hour and annual average concentrations of SO_2 over the study area based on SO_2 permitted or allowable values (worst case scenario);
- To simulate maximum 1-hour, 24-hour and annual average concentration of SO_2 over the study area based on 25%, 50% and 75% reductions in permitted SO_2 emissions (Scenarios 3, 4 and 5 respectively);
- To compare the results of the Calpuff model used in this study with other recent modelled results in the uMhlathuze Municipality;

- To compare predicted model results with the South African Ambient Air Quality Standards (SAAAQS) for SO_2 and to make recommendations for air quality management in the uMhlathuze Municipality.

1.4 Study Area

The province of KwaZulu-Natal is situated along the eastern seaboard of South Africa (Fig. 1.4), with the uMhlathuze Municipality located on the north coast of KwaZulu-Natal (Fig. 1.5). The terrain is relatively flat ranging between 0 m and approximately 396 m above sea level and is drained by the uMhlathuze River flowing eastwards to the coast. The municipal area extends over 796 km^2 and consists of Richards Bay, Empangeni, Vulindlela, Esikhaweni, Nseleni, Felixton, Ngwelezane. The uMhlathuze Municipality is approximately 180 km north-east of Durban and approximately 200 km south of Swaziland.

The uMhlathuze Municipality harbour constructed in 1976 is located in the industrial town of Richards Bay and is situated at longitude 32º 02' E and latitude 28º 48' S. Empangeni and Richards Bay are the largest towns forming part of the uMhlathuze Municipal area, with Empangeni being the commercial and service centre and Richards Bay the rapidly developing industrial and business area (uMhlathuze SER, 2002; uMhlathuze Municipality SFP, 2007)

1.4.1 Land Use Zoning

The land-use zones within the uMhlathuze Municipality have been tabled below. They include industries, residential, business and agricultural areas and are included in the Spatial Framework Plan of the municipality (uMhlathuze Municipality SFP, 2007).

Figure 1.4 The location of 9 Provinces within South Africa

(http://www.demarcation.org.za/)

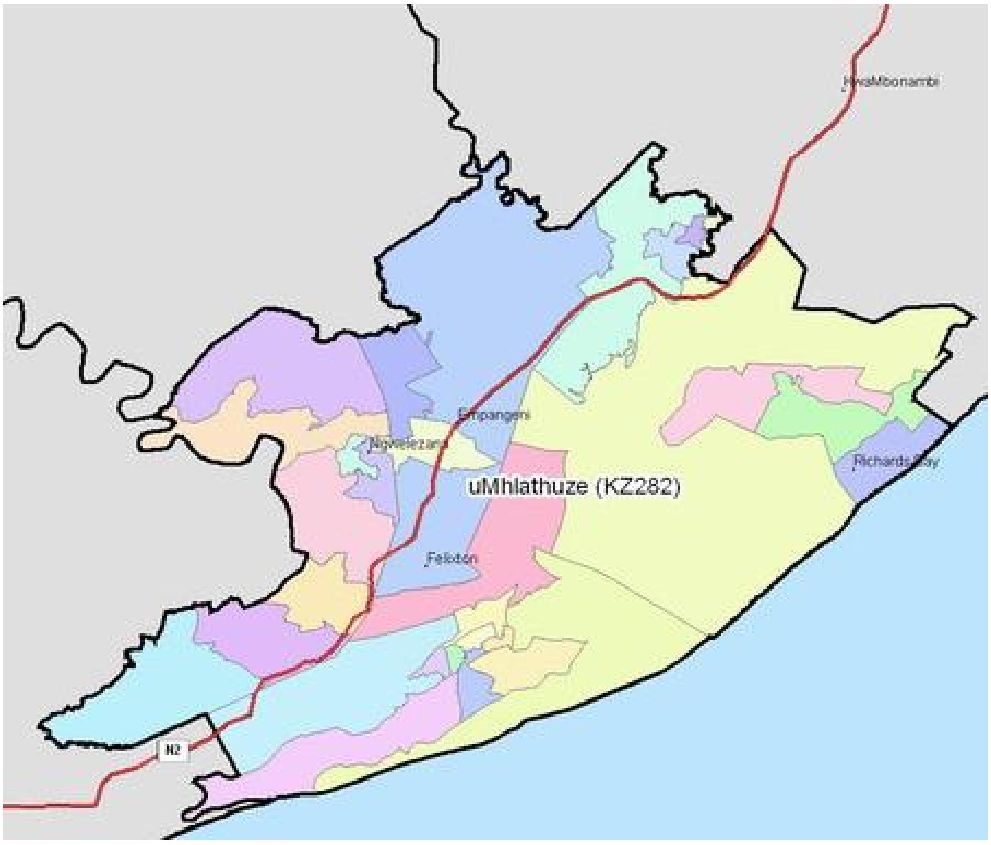
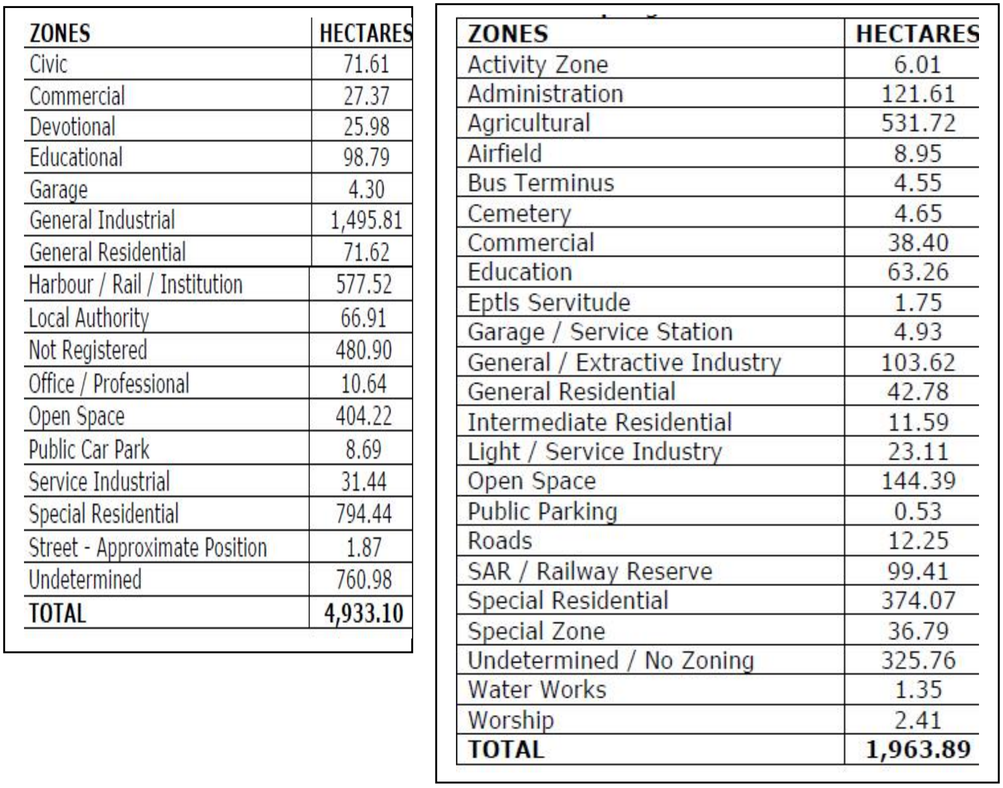


Figure 1.5: Map of the uMhlathuze Municipal area within the KwaZulu-Natal Province

(http://www.demarcation.org.za/)

Table 1.2 Land-use zones in the towns of Richards Bay (left) and Empangeni (right)



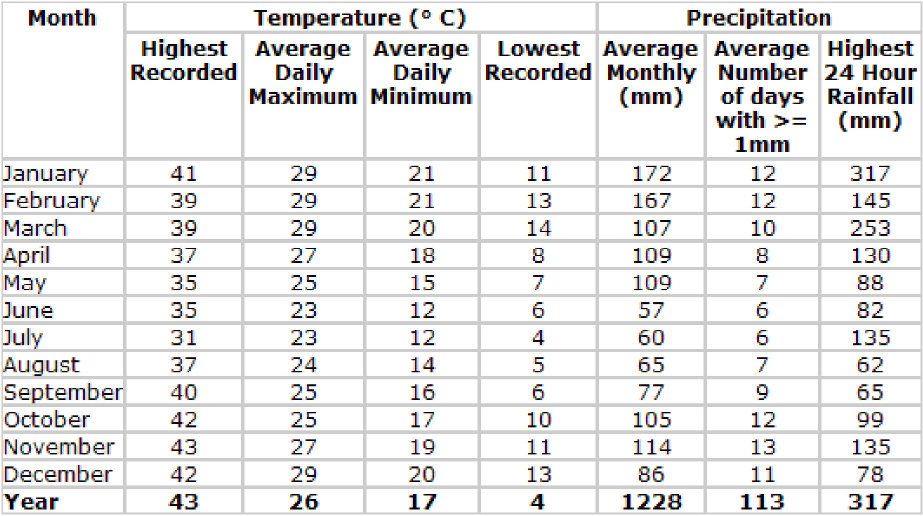
ZONES	HECTARES
Civic	71.61
Commercial	27.37
Devotional	25.98
Educational	98.79
Garage	4.30
General Industrial	1,495.81
General Residential	71.62
Harbour / Rail / Institution	577.52
Local Authority	66.91
Not Registered	480.90
Office / Professional	10.64
Open Space	404.22
Public Car Park	8.69
Service Industrial	31.44
Special Residential	794.44
Street - Approximate Position	1.87
Undetermined	760.98
TOTAL	**4,933.10**

ZONES	HECTARES
Activity Zone	6.01
Administration	121.61
Agricultural	531.72
Airfield	8.95
Bus Terminus	4.55
Cemetery	4.65
Commercial	38.40
Education	63.26
Eptls Servitude	1.75
Garage / Service Station	4.93
General / Extractive Industry	103.62
General Residential	42.78
Intermediate Residential	11.59
Light / Service Industry	23.11
Open Space	144.39
Public Parking	0.53
Roads	12.25
SAR / Railway Reserve	99.41
Special Residential	374.07
Special Zone	36.79
Undetermined / No Zoning	325.76
Water Works	1.35
Worship	2.41
TOTAL	**1,963.89**

1.4.2 Meteorological Characteristics of Richards Bay

Richards Bay experiences high relative humidity throughout the year, with temperatures reaching up to 40°C in summer and 113 rain days per annum (Table 1.3). The rain days are defined as those days with rainfall greater than 1mm (www.weathersa.co.za). The dominant wind directions are north-easterly and south-westerly as shown in Figure 1.6 (RBCAA, 2002). The north-easterly wind brings clear, fine weather, while the south-westerly wind brings cold fronts and overcast weather (CSIR, 2004). In coastal areas such as the uMhlathuze Municipality, local winds induced by the differential heating and cooling of the land mass and sea water are superimposed on the larger scale wind systems. The air near the surface of the sea blows toward the land during daytime as a sea breeze circulation and at night the land breeze blows toward sea (Bouchlaghem *et al*., 2007).

Table 1.3 Average temperature and rainfall results for Richards Bay from 1970-1990 (www.weathersa.co.za)



Month	Temperature (° C)				Precipitation		
	Highest Recorded	Average Daily Maximum	Average Daily Minimum	Lowest Recorded	Average Monthly (mm)	Average Number of days with >= 1mm	Highest 24 Hour Rainfall (mm)
January	41	29	21	11	172	12	317
February	39	29	21	13	167	12	145
March	39	29	20	14	107	10	253
April	37	27	18	8	109	8	130
May	35	25	15	7	109	7	88
June	35	23	12	6	57	6	82
July	31	23	12	4	60	6	135
August	37	24	14	5	65	7	62
September	40	25	16	6	77	9	65
October	42	25	17	10	105	12	99
November	43	27	19	11	114	13	135
December	42	29	20	13	86	11	78
Year	**43**	**26**	**17**	**4**	**1228**	**113**	**317**

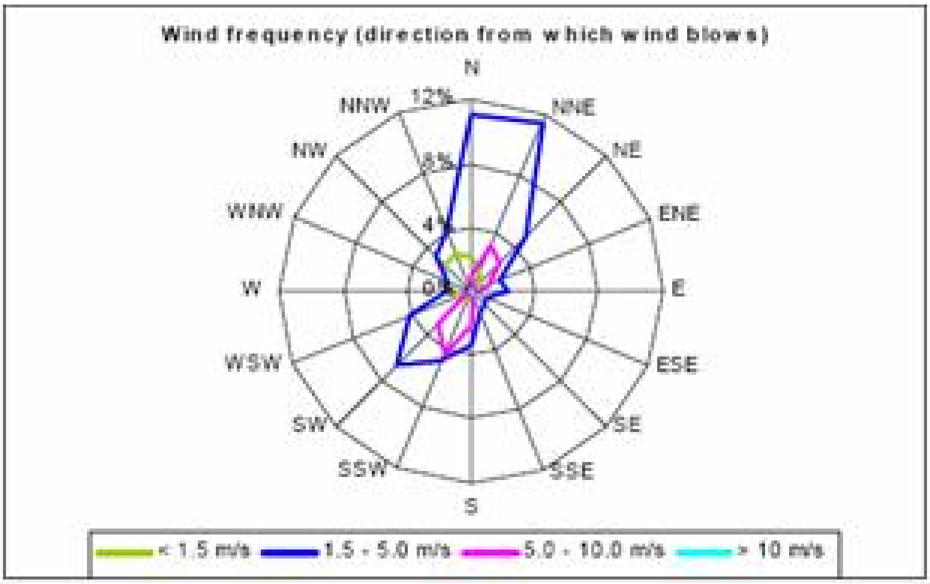


Figure 1.6 Annual wind direction and wind speed measured in Richards Bay for the year 2002 (RBCAA, 2002)

1.5 Structure of Dissertation

The legislative context, as well as the characteristics of urban air dispersions models, is highlighted in Chapter 2. The methodology in Chapter 3 provides a general background to the two air dispersion models used in this study and how the emissions inventory and meteorological data were obtained. The results contained in Chapter 4 comprise of five modelling scenarios with maximum 1-hour; 24-hour and annual average concentrations presented in isoline maps, and tables of comparisons with other studies conducted in the uMhlathuze Municipality. The implications for air quality management in the uMhlathuze Municipality are provided at the end of Chapter 4, with Chapter 5 incorporating the conclusions and recommendations.

CHAPTER 2

AIR QUALITY MANAGEMENT APPROACH AND URBAN AIR POLLUTION DISPERSION MODELLING

2.1 Introduction

Air quality in South Africa is regulated by the Atmospheric Pollution Prevention Act (No. 45 of 1965) (APPA) and is in the process of being replaced by the National Environmental Management: Air Quality Act (No. 39 of 2004) (AQA). The change in the air pollution legislation commenced with the Integrated Pollution Control and Waste Management Policy which was introduced in the year 2000 and provides a framework for the management of air quality (South Africa, 2000). The AQA came into effect on 11 September 2005, with Sections 21, 22, 36 to 49, 51(1) (e), 51(1) (f), 51(3), 60 and 61 being excluded until the finalization of the listed activities process (South Africa, 2005a). This chapter outlines the legislative context to air pollution control in South Africa, in particular the air quality management approach of the AQA, and then provides a background to air pollution dispersion modelling.

2.2 Legislative Context

2.2.1 Atmospheric Pollution Prevention Act (APPA)

APPA came into effect on 21 April 1965 (APPA, 1965). The act is based on the Best Practicable Means (BPM) approach to prevent and control air pollution. The BPM approach focuses on the maintenance and operation of emission sources based on a cost benefit analysis and technical feasibility of air pollution abatement equipment, while accommodating local conditions in air pollution control (National Framework, 2007). In the APPA, the BPM approach implied that the Chief Air Pollution Control Officer

(CAPCO) could use his/her own judgment in air pollution control without any specific principles to guide him/her. The BPM approach failed to consider principles such as the cumulative effects of pollutants in an area; dispersion of pollutants based on local meteorology; health risk assessments related to public exposure to pollutants; the economic effects of air pollution, for example the damage caused to the environment through acid rain; and specific ambient standards that should be met for the protection of public health (Barnard, 1999).

The APPA consists of six parts which are summarized as follows: Part one deals with the establishment of a National Air Pollution Advisory Committee (NAPAC) and the appointment of a CAPCO. The appointment of the NAPAC is briefly outlined, while the functions of the advisory committee are highlighted as informing the Minister of all air pollution control and prevention processes. This section further prescribes the appointment and functions of the CAPCO at the national government level.

In part two of the APPA, the Control of Noxious or Offensive Gases is described, as well as the declaration of controlled areas; the description of the premises on which a scheduled process can take place; and the process for application and issuing of provisional and final registration certificates. These certificates are based on the control and prevention of pollution from any scheduled process according to the BPM approach. Industrial operating conditions such as plant start-ups and shutdowns have been included in the certificates, while the CAPCO is responsible for regulating and reviewing the conditions of the certificates.

Atmospheric pollution by smoke is dealt with in part three of the APPA and makes provision for regulating fuel burning appliances through the local authority. It further highlights the manufacturing of fuel burning appliances; the installation and location of such appliances; the procedure where smoke or other products of combustion cause a nuisance; the smoke control regulations; and the establishment of smoke control zones. Part three also focuses on the regulation of smoke by assessing the visual appearance and nuisance impact in the atmosphere.

Part four of the APPA underlines the control of dust by declaring dust control areas, with regulations to prevent dust pollution. This section further refers to a dust control levy account that may be payable in case of non-compliance with the dust control regulations. Part five of the APPA deals with air pollution emitted by vehicles and the regulations in terms of fumes from vehicle sources. The general provisions are dealt with in part six and outline the rules in terms of payment of penalties; the disclosure of confidential information and the right of entry upon land.

The first schedule contains charts that are used to assess the shade of smoke pollution in the atmosphere while the second schedule has a list of 72 scheduled processes that require scheduled process certificates. The scheduled processes under schedule two of the APPA do not consider all pollution sources such as ships, aircraft, mine dumps, unpaved roads and landfill sites and trans-boundary air pollution. Enforcement of the APPA regulations was inadequate due to the responsibility of compliance monitoring and permitting remaining at the Department of Environmental Affairs and Tourism (DEAT) level and managed by the CAPCO. The APPA did not clearly define the roles of provincial and local government in the regulation of air quality and there remained limited involvement from other sectors of government (South Africa, 2006).

The APPA has become ineffective in its BPM approach to regulating air quality and necessitates legislation that has an integrated approach to air quality management, in line with international air quality legislation. In comparison with international trends in air quality management, the APPA has many shortfalls which necessitated the shift toward an international air quality management system. The United States (US), Europe (EU) and the United Kingdom (UK) have decentralized the regulation of air quality by focusing on municipal or district areas that are heavily polluted. The US has established air quality management districts, the EU has non-attainment areas, while the UK has local air quality management areas. Each of these areas has an air quality management plan for point, line, area and volume air pollution sources. The focus is on ambient air quality concentrations rather than source-based pollutant concentrations, with the use of air dispersion modelling tools and ambient monitoring systems to determine compliance with ambient air quality standards. In addition, a citizen’s right to a healthy environment is promoted through easily accessible air quality information (Environmental Matrix Solutions, 2004)

2.2.2 Air Quality Act (AQA)

The National Environmental Management Act (No.107 of 1998) (NEMA) came into effect on 27 November 1998. The NEMA serves as the overarching framework within which all South African environmental legislation is incorporated. The NEMA guides the interpretation, administration and implementation of laws protecting and managing the environment through the Best Practicable Environmental Option (BPEO). The definition of BPEO according to NEMA is protection of the environment by making decisions that are least harmful and most beneficial to the environment at a cost acceptable to society for current and future generations (NEMA, 1998). The National Framework highlights the use of Best Available Techniques (BAT) to achieve the BPEO. BAT considers best techniques that control pollution without economic costs. It defines “Best” as the most practical and beneficial according to international literature; and “Practicable” as the most feasible option after conducting a cost-benefit analysis, accessibility, and availability study; and “Environmental Option” based on an impact assessment of the living and non-living environment (National Framework, 2007). The BAT should be in line with international literature which includes the European Commission guideline documents for BAT to achieve the BPEO (www.ipcc.ch/).

The AQA is integrated under NEMA with the aim to manage air quality through the BPEO approach in order to achieve the sustainable development principles outlined in NEMA. The first chapter highlights the objectives of the AQA and refers to the sustainable development principles set out in the NEMA. The following chapter deals with the establishment of a National Framework for air quality management and the setting of national, provincial and local ambient air quality standards. The purpose of the National Framework is to provide the overarching plan for implementing the AQA and its objectives (NEMA, 1998; South Africa, 2005b; National Framework, 2007).

Information on the setting of ambient standards for priority pollutants as well as setting of specific emission standards for any pollutant of concern is outlined in Chapter 2. The air quality standards aim to ensure that the targets set in air quality management plans can be clearly defined and provides for the identification of priority pollutants. In Chapter 3 the establishment and functions of a multi-stakeholder National Air Quality Advisory

Committee are documented. The function of the committee is to provide the Minister with advice on the implementation of the act. This chapter further explains the need for air quality officers at each sphere of government and the purpose of air quality management plans (South Africa, 2006a; South Africa, 2003; South Africa, 2005b).

The regulatory tools to be used in the act are dealt with in Chapter 4 and include the identification and declaration of priority areas that require specific air quality management plans, the provision for specific regulations relating to a priority area and the identification of listed activities that will require Atmospheric Emission Licenses. The section also highlights the link between an Atmospheric Emission License (AEL) and the Environmental Impact Assessment (EIA) process, the compilation of pollution prevention plans and atmospheric impact reports. Chapter 4 concludes with the setting of emissions standards for controlled emitters and the control of noise and odour. Chapter 5 deals with licensing requirements of listed activities and details the contents, transfers, reviews and changes in the AEL, the appointment of emission control officers by industry and the definition of a fit and proper person. Trans-boundary air pollution is dealt with in Chapter 6, while Chapter 7 deals with offences and penalties. The transition between the registrations certificates issued under the APPA to the AEL is captured in Chapter 8, together with details on the consultative process that must be followed by industry and DEAT (South Africa, 2003; South Africa, 2005b; South Africa, 2006a).

2.2.2.1 Air Quality Guidelines and Standards

The DEAT has recognized that there are high levels of SO_2 emissions from both industrial processes and domestic coal burning, especially in areas such as the Vaal Triangle and the South Durban Industrial Basin, which has led to poor ambient air quality. Although industry may comply with permitted limits based on point source emissions, the health of people living close to industrialized areas is being impacted due to the high levels of SO_2 in the ambient environment. The DEAT published a set of SO_2 ambient guidelines in terms of the APPA in 2001, which is now part of schedule 2 of the AQA (South Africa, 2001b). An ambient air quality guideline is a recommendation on the limit value of the ambient concentration of a pollutant in the atmosphere which is necessary for the protection of human health. A guideline cannot be used for regulatory purposes, while a standard is an ambient concentration of a pollutant which is used for regulating ambient levels of pollutants. A standard is further defined by averaging periods, methods for measurement, data management, and permitted number of exceedances over a specific time period (South Africa, 2001a). The methods for measurement of ambient air quality concentrations are specified by authorities to allow air quality practitioners to assess compliance with ambient standards (WHO, 2006).

In October 2004, the South African Bureau of Standards (SABS) published the SO_2 standards in the SANS 1929 document, while the DEAT SO_2 guidelines were published in February 2005 as Schedule 2 of the AQA (South African National Standard 1929: 2005). The SABS and the DEAT established a technical committee with three working groups which developed proposed standards for South Africa (South Africa, 2001a). The SANS 1929 proposed limits for SO_2 are the same as the DEAT guidelines, apart from the SANS 1-hour average guideline which is used when 10-minute average data are not available. This value can be applied to give an indication of air quality over a 1-hour averaging period (South African National Standard 1929:2005). In addition to the SANS 1929 document, the SANS developed the SANS 69 document detailing the framework for setting and implementing national ambient air quality standards. The SANS 69 requires that air quality objectives be set to include limit values, alert thresholds and target values, margins of tolerance, time frames for achieving compliance with limit values and permissible frequencies of exceeding limit values (South African National Standard 69: 2005). The DEAT guidelines have progressed to standards after the publication of the National Framework and include the frequency of exceedances for priority pollutants and the associated averaging periods. The DEAT ambient air quality standards have been published for public comment during October 2007, in line with the requirements of the National Framework and standard setting process which involves public participation before publishing final standards (National Framework, 2007; South Africa, 2007). The air quality standards for SO_2 have been adopted from the WHO guidelines of 2000 (WHO, 2000).

A comparison of the EU, US, UK, WHO, SANS and the DEAT guidelines is presented in Table 2.1. The WHO guidelines were subsequently revised in 2005, with the result that there is currently no 1-hour average guideline and the 24-hour average guideline has been reduced significantly to 20 $\mu g/m^3$. The rationale behind omitting the 1-hour guideline value and reducing the 24-hour average is detailed in section 1.2 of this study (WHO, 2005; 2006).

Table 2.1 Comparison of the SO_2 standards and guidelines for the EU, US, UK, WHO, SANS and the DEAT.

* This standard is adopted for the protection of vegetation and ecosystems. All of the remainder are for the protection of human health.

SO_2	**EU**	**US**	**UK**	**WHO**	**SANS**	**DEAT**
Instantaneous	none	none	none	none	none	500 µg/m^3
10 minute average	none	none	none	500 µg/m^3	500 µg/m^3	500 µg/m^3
15 minute average	none	none	266 µg/m^3 (not to be exceeded more than 35 times per year)	none	none	none
1-hour average	350 µg/m^3 (not to be exceeded more than 24 times per year)	none	350 µg/m^3 Not to be exceeded more than 24 times per year	none	350 µg/m^3	none
3-hour average	none	1310 µg/m^3 (not to be exceeded more than once per year)	none	none	none	none
24-hour average	125 µg/m^3 (not to be exceeded more than 3 times per year)	365 µg/m^3 (not to be exceeded more than once per year)	125 µg/m^3 (not to be exceeded more than 3 times per year)	20 µg/m^3	125 µg/m^3	125 µg/m^3
annual average	20 µg/m^3	79 µg/m^3	* 20 µg/m^3	none	50 µg/m^3	50 µg/m^3
References	European Union, 2004	European Union, 2004	UK National Air Quality Archive Air Quality Standards	WHO 2005;2006	South African National Standards 1929:2005	South Africa, 2001b

2.2.2.2 Air Quality Management Plan (AQMP)

The AQA requires local authorities to include an AQMP into their Integrated Development Plan and the content thereof is listed in Section 16 of the AQA. The AQMP should identify and reduce pollutants that may have a negative effect on human health by addressing industrial and fossil fuel emissions and any point or non-point source emissions within the municipal area. An annual report on the implementation of the AQMP must be compiled by the local authority and submitted to the DEAT with 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 (South Africa, 2005b). In addition to local air pollution problems, the AQMP should consider trans-boundary air pollution as well as international agreements such as the Montreal Protocol and the Stockholm Convention on Persistent Organic Pollutants (National Framework, 2007).

2.2.2.3 Concluding Remarks

Having outlined the legislative background to air quality management in South Africa, and provided the context for air pollution dispersion modelling, it is now appropriate to examine air pollution dispersion models in more detail.

2.3 Urban Air Pollution Dispersion Models

Urban air pollution dispersion models simulate the natural physics and chemistry of the atmosphere and make use of source emissions data and meteorological data to predict air pollutant concentrations at specific receptors in the ambient environment (Douglas, 1982). The United States Environmental Protection Agency (USEPA) has compiled a guideline document on air quality models that are used for regulatory purposes and recommends that the choice of an appropriate model should depend on the meteorological and topographical conditions of the modelling domain; the level and extent of information required in the final results; the technical competence of the model user; the resources available for the purposes of the study; and the validity of the input data (United States Environmental Protection Agency, 2003). Air quality predictions are continually being improved and studies by Carmichael *et al.* (2007) reported that atmospheric chemical observations will be a significant part of air quality predictions in the future, requiring increased communication between the weather forecasting and the modelling communities (Carmichael *et al*., 2007).

2.3.1 Types of Urban Air Pollution Models

Dispersion modeling has progressed from one-dimensional simulations to multi-dimensional simulations involving complex atmospheric chemistry. The models range from simple models, which are termed screening models, to complex models called refined models. The screening models present the worst case meteorological conditions to assess impacts of specific sources. These are simple diffusion models that assume the transport and diffusion of pollutants are the main processes that affect the concentration of pollutants with uniform wind speed and state of the atmosphere over the modelling domain. Examples of simple models include box models and the Atmospheric Turbulence and Diffusion Laboratory (ATDL) model (Ames *et al*., 2002; Zib, 1977). Refined models include chemical transformation processes and detailed input data. In addition, refined models assess the control strategies in place for emissions through various emissions scenarios, for example, the AERMOD model (United States Environmental Protection

Agency, 2005). AERMOD can be used for complex modelling scenarios such as the dispersion of vehicle emissions on roads (Venkatram *et al*., 2007).

Models can be further distinguished based on mathematical treatment of atmospheric phenomena. The treatment of emissions in a turbulent fluid can be described as Eulerian or Lagrangian (UNESCO, 1995). The Eulerian model is treated as a multi-box model, where the atmosphere in the modelling domain is divided into a grid of boxes and the flow of pollutants in the box is mixed vertically only and not horizontally (Johnson, 1976). The Lagrangian box approach allows for horizontal movement of the columns of air following the average wind speed and direction. The Eulerian box does not move horizontally according to the wind speed and direction (UNESCO, 1995).

2.3.1.1 Gaussian Diffusion Models

The Gaussian model assumes that the turbulent flow of the atmosphere is homogenous in the vertical and horizontal directions. The Gaussian model assumes that pollutants are distributed in the vertical and horizontal dimensions according to the mean and standard deviation of a normal distribution (Zib, 1977; Beychok, 1994).

- **Gaussian Plume Model**

The steady-state, straight-line, Gaussian plume model is based on the assumption that meteorological conditions are homogeneous across the modelling domain. It assumes that pollutants move in a straight line without curving as shown in Figure 2.1. The changes in wind speed and direction are not accounted for due to the assumption that the plume has a steady-state nature. The shortest averaging period for Gaussian plume models is 1-hour. The assumption of a homogeneous wind field limits the Gaussian plume model’s ability to model over a large domain as meteorology is expected to change over large distances (BCME, 2006; Earth Tech, 2000a; Beychok, 1994; Holmes and Morawska, 2006).

Gaussian plume models predict downwind concentrations by incorporating information such as stack height, stack exit velocity and stack exit diameter to estimate the height of the plume or plume rise. They use atmospheric conditions such as mixing height, wind speed, wind direction, atmospheric stability and terrain to estimate pollutant dispersion. In general, Gaussian plume models remain insensitive to terrain specifications as long as the downwind terrain remains below the height of the centerline of the plume and below the stack height (Scott *et al*., 2003)

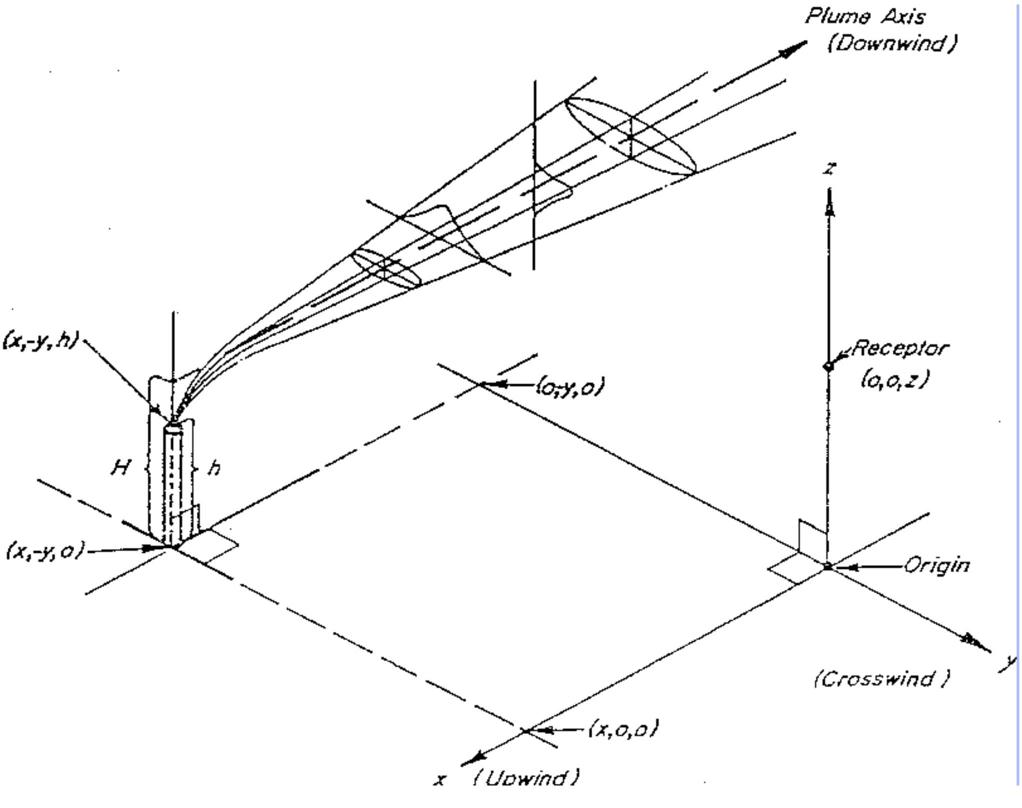


Figure 2.1 Gaussian plume distributions of pollutants from a stack source (Earth Tech, 2005)

Pollution concentrations based on a Gaussian plume model are predicted according to the following equation:

$$\chi_{(x,y,z)} = \frac{Q}{2\pi\sigma_y\sigma_z U}\exp\left[-\frac{y^2}{2\sigma_y{}^2}\right]\left\{\exp\left[-\frac{(z-H_e)^2}{2\sigma_z{}^2}\right]+\exp\left[-\frac{(z+H_e)^2}{2\sigma_z{}^2}\right]\right\}$$

where,

$\chi_{(x,y,z)}$	is the concentration (µg/m^3) at distance x downwind, distance y crosswind, and at height z above the ground
U	is wind speed (m/s)
$\sigma_y\sigma_z$	is standard deviations of lateral and vertical concentrations (i.e. dispersion parameters)
Q	is the emission rate (g/s)
H_e	is the effective stack height (m)

(Beychok, 1994)

Examples of Gaussian plume models include AEROMOD and the Industrial Source Complex short term model (ISCST) and long term model (ISCLT). AERMOD is a near field steady state Gaussian plume model that includes treatment of surface and elevated sources over simple and complex terrain. It is able to model multiple sources of different types including point, area and volume sources. In the stable boundary layer the distribution is assumed to be Gaussian in both the horizontal and vertical directions (Holmes and Morawska, 2006).

- **Gaussian Puff Model**

The Gaussian puff model, as shown in Figure 2.2, interprets the movement of pollutants as a series of puffs rather than as a plume moving in a straight line. The Gaussian puff model can thus compute complex flow situations because it allows meteorological conditions to fluctuate across the modelling domain. A typical example of a puff model is Calpuff, which is a multi-layer non-steady state Langrangian puff dispersion model that can model both gases and particulates from point, line, volume and area. It is able to simulate dispersion under calm or low wind conditions (Barna and Gimson, 2002). Calpuff can be used in complex terrain with complex meteorology and can simulate both spatial and temporal variations in meteorology down to scales of a few hundred meters. However, Calpuff does not perform well under conditions of extreme turbulence and the shortest averaging period is limited to a 1-hour average (BCME, 2006; Earth Tech, 2000a; Godfrey and Clarkson, 1998; Holmes and Morawska, 2006). A comparison between the Gaussian plume and puff models is summarized in the SANS 1929 document in Appendix 1.

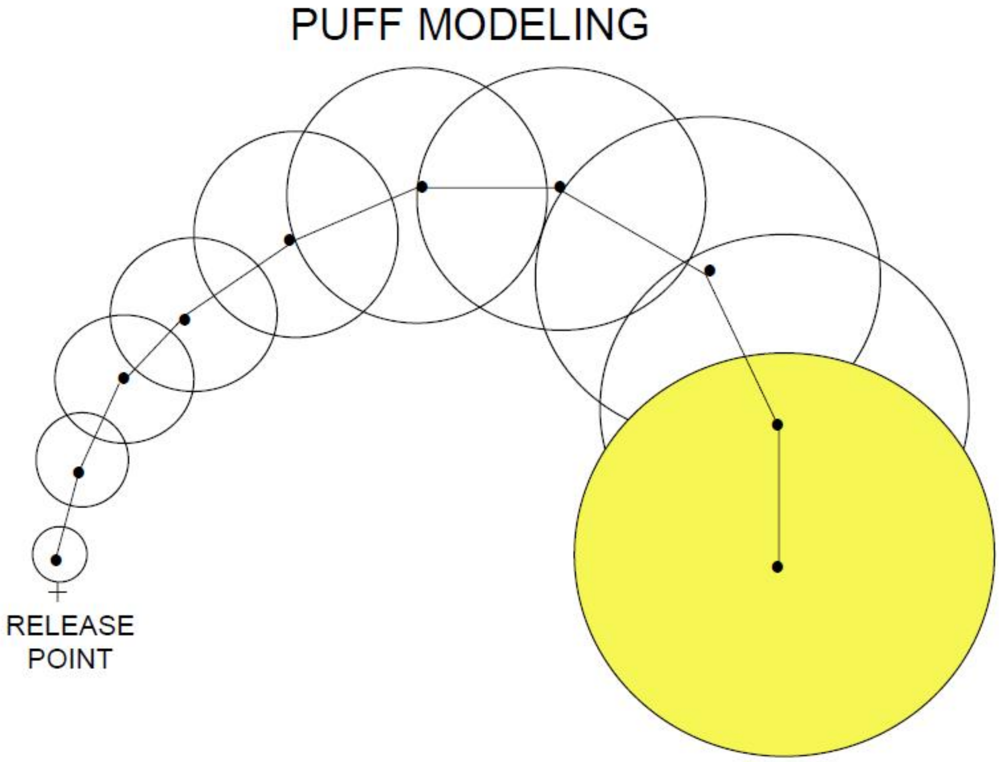


Figure 2.2 Gaussian puff distribution of pollutants from a point source (Earth Tech, 2005)

The basic equation for the contribution of a puff at a receptor is as follows:

$$C = \frac{Q}{2\pi\sigma_x\sigma_y} \, g \, \exp\left[-d_a^2/\left(2\sigma_x^2\right)\right] \exp\left[-d_c^2/\left(2\sigma_y^2\right)\right]$$

$$g = \frac{2}{(2\pi)^{1/2}\sigma_z} \sum_{n=-\infty}^{\infty} \exp\left[-\left(H_e + 2nh\right)^2/\left(2\sigma_z^2\right)\right]$$

where,	C	is the ground-level concentration (g/m^3),
	Q	is the pollutant mass (g) in the puff,
	σ_x	is the standard deviation (m) of the Gaussian distribution in the along-wind direction,
	σ_y	is the standard deviation (m) of the Gaussian distribution in the cross-wind direction,
	σ_z	is the standard deviation (m) of the Gaussian distribution in the vertical direction,
	d_a	is the distance (m) from the puff center to the receptor in the along-wind direction,
	d_c	is the distance (m) from the puff center to the receptor in the cross-wind direction,
	g	is the vertical term (m) of the Gaussian equation,
	H	is the effective height (m) above the ground of the puff center, and
	h	is the mixed-layer height (m).

(Earth Tech, 2000a)

2.3.2 Uncertainties in Air Dispersion Modelling

The interpretation of air dispersion modelling simulations should take into account the uncertainties associated with the results due to the complex and unstable nature of the atmosphere. The input data used in the modelling comprises meteorological data and emissions data. Meteorological data are generally obtained from measurements at a single point and do not necessarily represent the entire modelling domain. Variations over the domain may occur as a result of uneven topography or the influence of land and sea surface temperatures. In addition, the margin of error in the meteorological monitoring equipment is not taken into account when interpreting the meteorological data. In the case of emissions data, the data that can be used in modelling consists of measured or calculated emissions data. In combustion processes the fuel composition as well as the process of combustion may fluctuate from time to time. Fugitive emissions may not be measured and accounted for in an emissions inventory and can be omitted from modelling input data (Douglas, 1982; UNESCO, 1995; Stern, 1976)

Emissions arising from a source are influenced by aerodynamic conditions and plume rise characteristics. The aerodynamic movement of emissions from a source will be influenced by obstacles in their path, for example, buildings, and this might result in changes to the maximum ground level concentrations at specific receptors. Plume rise depends on ambient wind speeds as well as atmospheric stability between the stack exit point and the maximum height reached by air pollutants. Due to the unstable nature of the atmosphere from 10-1000 m, the buoyancy and momentum of plumes and puffs will be altered as they leave the source and react with the surrounding environment (Douglas, 1982; UNESCO, 1995).

Air pollutant transport will be influenced by the vertical wind shear that is caused by the change in wind speed with an increase in height. Furthermore, horizontal variation in wind speed occurs due to varying surface temperatures, uneven topography, and buildings that act as obstacles. The measurement of wind speed is done at a constant height in the atmosphere therefore vertical and horizontal changes in wind speeds may not be accounted for in the model calculations. The mixing depth and stability of the atmosphere depends on surface heating by solar radiation which may not be uniform throughout the modelling domain. In the case of dispersion coefficients, the Pasquill-Gifford dispersion coefficients which are commonly used to calculate plume transport, have been validated for ground-level pollutant releases that occur within 1 km of an emission source and do not account for the mixing depth limitations under unstable conditions and over long distances from a source (Douglas, 1982; UNESCO, 1995; Stern, 1976; United States Environmental

Protection Agency, 2000b). In the case of new buildings or revised emissions rates the wind flow and turbulence must be considered where buildings are located. The dispersion of fugitive and low level emission sources can be affected by buildings in the vicinity of air pollution sources (Riddle *et al*., 2004).

Due to the uncertainties in dispersion modelling, model validation against a set of standard criteria is necessary in order to assess its accuracy. A set standard of evaluation procedures and performance criteria have not yet been developed. The current method of evaluating models is through comparison with measured ambient data and the comparison of different models for the same modelling exercises (Elbir, 2003). During the evaluation of air dispersion modelling results, the background concentrations of the pollutants must be taken into consideration. The background concentrations of polluted areas are not easily obtained due to the lack of measured data available for these areas prior to the air pollution sources (Abdul-Wahab *et al*., 2002).

2.4 Air Pollution Potential

Air pollution potential (APP) is defined as the likelihood of pollutant accumulation in the atmosphere during specific meteorological conditions (Preston-Whyte and Diab, 1980; Diab, 1978a; Diab,1978b). Meteorological conditions that influence the ambient concentration of pollutants in the uMhlathuze area are both synoptic scale and meso-scale circulations.

2.4.1 Synoptic Scale Circulations

Preston-Whyte and Tyson (1988) have identified the major categories of synoptic scale circulations that affect South Africa (Fig. 2.3). Scott and Diab (2000) further singled out three synoptic categories that have an influence on APP. The first of these is the established high pressure system that is characterized by light north-easterly winds and subsiding air creating low mixing depths. Furthermore, surface inversions may occur at night due to surface radiational cooling under the clear sky conditions which increases the APP.

As the high pressure system moves eastwards, the low pressure system approaches South Africa leading to pre-frontal conditions in Figure 2.4. The pre-frontal synoptic condition increases APP by decreasing mixing depths. The third synoptic category, the post-frontal stage, is accompanied by an increase in wind speeds and the dissipation of the subsidence inversion (Diab *et al*., 1991; Diab, 1978a; Diab, 1978b).

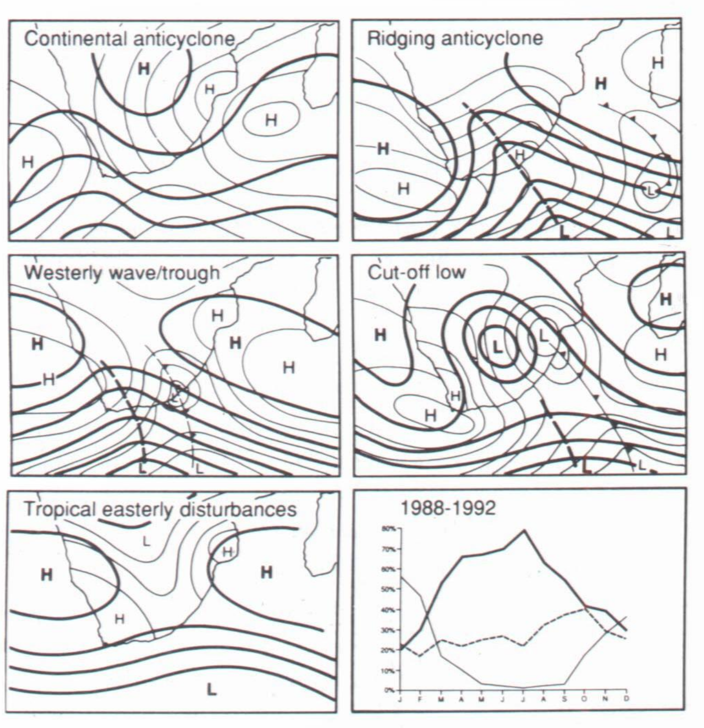


Figure 2.3 Major synoptic circulation types affecting Southern Africa and their monthly frequencies of occurrence over a five year period (Preston-Whyte and Tyson, 1988)

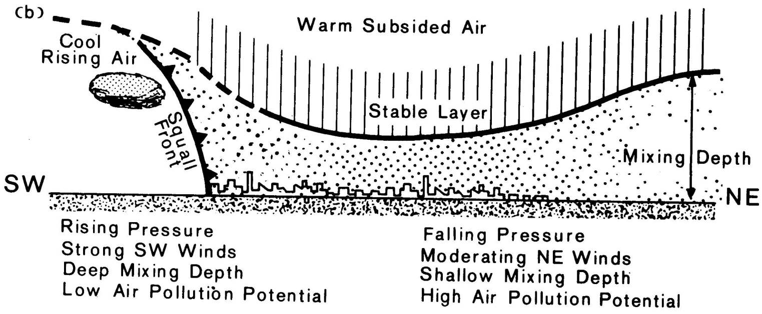


Figure 2.4 Fluctuations in Air Pollution Potential with the passage of a frontal disturbance (Preston-Whyte and Diab, 1980)

2.4.2 Meso-scale Circulations

Along the coast, the transport of pollution is influenced by both land-sea breezes and topographically-induced winds. Sea breezes are well developed in the summer months, whereas land breezes, moving from the land to sea at night, are dominant during the winter months. Topographically-induced winds, particularly the mountain-plain wind system, are well developed in KwaZulu-Natal as a result of the deeply incised river valleys. During the day the wind flows from the cool plains to the warmer mountains and at night the wind flows from the cooler mountains to the warmer plains. These winds are dependent on clear fine weather and therefore best occur during an established high pressure system (Tyson and Preston-Whyte, 1971). Pollutant transport occurs when the mountain-plain winds transport air pollutants from the interior to the coast. The wind is deflected as its travels parallel to the coast and could be re-circulated back to shore by a seas breeze or plain–mountain wind (Liebenburg, 1998). The re-circulation of these pollutants will occur over a few days until the passing of a frontal system which will upset the topographically-induced winds pattern (Scott and Diab, 2000).

CHAPTER 3

METHODOLOGICAL FRAMEWORK

3.1 Introduction

In this chapter a description of the Calpuff and TAPM (The Air Pollution Model) models used in this study is given, as well as a description of the receptor network, the emissions inventory, meteorological data and the modelling scenarios. The use of TAPM was necessary in this study due to the lack of measured surface and upper air data available for the uMhlathuze area. TAPM was used to generate meteorological surface and upper air data sets for uMhlathuze which were used as input data in one of the Calpuff suite of models, namely Calmet. The Calpuff suite of models comprises Calmet, Calpuff and Calpost. The Calmet model was used to process the surface and upper air data files from TAPM. The Calmet data set, together with the SO_2 emissions data, was used in the Calpuff model and processed through Calpost to generate SO_2 ambient concentrations over uMhlathuze. In order to view the ambient SO_2 concentrations on the map of uMhlathuze, a software tool called Surfer was used to generate isolines of SO_2 concentrations.

The results of previous modelling studies conducted in uMhlathuze are compared to the results of this study. The three recent modelling studies that were conducted in the uMhlathuze area are the Air Quality Specialist Study for the Proposed TATA Steel project that was conducted by the CSIR Environmentek in 2004 and updated in 2005, hereafter referred to as the CSIR (2004) and CSIR (2005) projects (CSIR 2004;2005); and the Review of the Spatial Development Framework for the City of uMhlathuze by Airshed Planning Professionals in 2006, hereafter referred to as the Airshed (2006) project (Airshed 2006a)

3.2 The Air Pollution Model (TAPM)

3.2.1 General Description

The Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) meteorological processor, TAPM is a model that predicts 3-dimensional meteorology as well as air pollution concentrations. The model is available from CSIRO at http://www.cmar.csiro.au/research/tapm/index.html. TAPM uses databases of global terrain height, vegetation and soil type datasets, a sea surface temperature dataset and synoptic scale meteorological datasets (Fig. 3.1). The global terrain height, vegetation and soil type datasets are available on a longitude and latitude grid at 30 second grid spacing, while the sea surface temperature and synoptic scale meteorological datasets are available on a longitude and latitude grid of 1 degree. The global terrain height, vegetation and soil type datasets, sea surface temperature datasets were obtained from the Australian governmental agencies and are accessible to the public, while the synoptic scale meteorological data are obtained from the Australian Bureau of Meteorology (Hurley, 2002). The built-in feature of terrain, land-use and synoptic circulation data for any region implies that the only data that are required from the user are the emissions data. Hurley *et al.* (2005) reported that the meteorological results showed that TAPM performed well in coastal, inland and complex terrain, and in sub-tropical to mid-latitude conditions. It must be noted, however, that the maximum simulation period for TAPM is one year (Hurley *et al.,* 2005).

The meteorological feature of TAPM uses large scale synoptic meteorological fields to predict local-scale flow, such as sea breezes and terrain-induced circulations. In the evaluation study undertaken by Luhar and Hurley (2003), they reported that TAPM produces better concentration results when measured surface data such as wind are assimilated into the model; however, the results do not vary significantly when no measured wind data are available for the area modelled. They concluded that TAPM predicted the local meteorology well, but under-predicted during night-time stable conditions and slightly over-predicted under daytime convective conditions. TAPM can be used to predict site specific meteorological data where no data are available, as well as incorporate available measured data to assimilate model runs. Using measured surface data to predict local meteorology in a region is termed nudging. The evaluation study by Luhar and Hurley (2003) further revealed that TAPM concentration results are compatible with the results produced by models such as ADMS3, AERMOD and ISCST3, which do not generate their own meteorology data (Luhar and Hurley,2003)

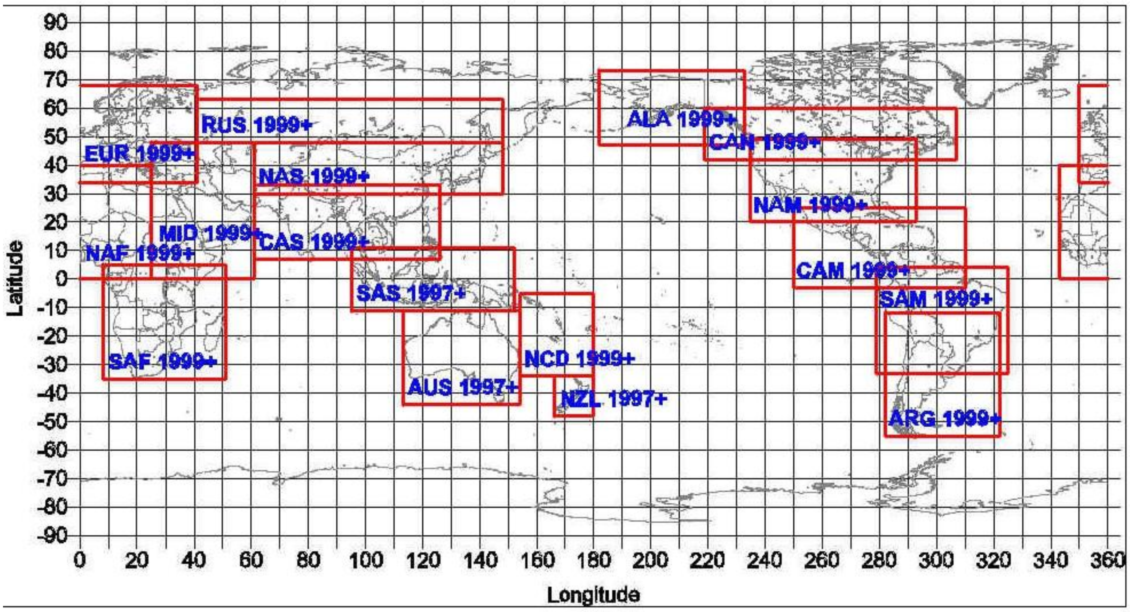


Figure 3.1 Map showing regions where meteorological analyses are available for TAPM (http://www.cmar.csiro.au/research/tapm/index.html)

3.2.2 Rationale for using the TAPM Model

TAPM was used in this study as a tool to predict upper air meteorology above the study area of uMhlathuze. Upper air data provide information such as the extent of the mixing layer in the modelling domain which is not measured in the uMhlathuze Municipality. The use of TAPM overcomes the lack of measured upper air data available within South Africa. Surface meteorological data were obtained from the South African Weather Service (SAWS) station located at the Richards Bay Airport. The measured surface data such as wind speed and wind direction were used as input files into TAPM to nudge the predicted upper air data in line with the measured surface data.

A study was conducted in Richards Bay to validate TAPM’s predicted surface meteorology for the period 2000 to 2001. The predicted surface wind and temperature data from TAPM were compared against the measured surface data from a meteorological station in Richards Bay. It was concluded that the TAPM model predictions were enhanced when assimilating the measured surface data from the Richards Bay meteorological station. The TAPM predictions were also acceptable where no measured surface data were used to influence the model (Rughunandan *et al,* 2008). TAPM has been used successfully in South Africa by the CSIR in air quality specialist studies in the uMhlathuze Municipality, as well as in countries such as Uruguay (CSIR, 2004; 2005; 2006).

Although TAPM is capable of predicting air pollution concentrations, it was not used for this purpose in this study as it does not have the capabilities of the Calpuff model. Its limitations are listed in Section 3.2.3 below.

3.2.3 Limitations of TAPM

TAPM is time consuming and requires more expertise and resources to run than Gaussian models. It has a limited run length of one year which restricts the use of TAPM for this study which incorporates three years of meteorological data (Hurley *et al.*, 2005). The modelling domain is restricted to 1000 km by 1000 km as TAPM does not consider the curvature of the earth and assumes a uniform horizontal modelling domain. This restriction affects the accuracy of TAPM in representing extreme weather conditions. Meteorological conditions such as wind, temperature and humidity at heights over 5000 m are not represented accurately. It also assumes that cloud processes occur in a single grid spacing of 3 km or less and does not allow for large scale cloud processes linked with extreme weather conditions. Although TAPM can be used for uneven terrain, it cannot represent discontinuities in terrain height, for example cliffs (Hurley, 2005a; 2005b). TAPM has not been used to undertake air pollution dispersion modelling for regulatory purposes in Richards Bay. In addition, TAPM is not on the list of preferred USEPA models that can be used for regulatory purposes (United States Environmental Protection Agency, 2005).

3.3 Calpuff Model

3.3.1 General Description

The Calpuff modelling system is an integrated modelling system consisting of a meteorological model (Calmet), a non-steady-state Lagrangian puff dispersion model (Calpuff) and a post-processing module (Calpost). It is computer based model and the requirements are outlined in Appendix 2. Calpuff uses dispersion equations based on a Gaussian distribution of pollutants across the puff and simulates the spatial and temporal effect of meteorological phenomena on air pollutant movement (United States Environmental Protection Agency, 2005). The Calpuff model system is also considered accurate for distances in the 50 to 300 km range (United States Environmental Protection Agency, 2003).

The Lagrangian principle assumes that emissions travel as a series of puffs. The puffs can be modelled in areas with complex terrain, low and calm wind speeds and for transport over water in coastal areas. Calpuff makes provision for point, area, line, and volume sources which enables cumulative impact assessments to be conducted in areas with multiple emission sources (Earth Tech, 2000a). Calpuff is however limited to the shortest timescale of 1-hour averages due to being influenced by turbulence (Holmes and Morawska, 2006). The puffs emitted from a stack point are modelled separately as each puff changes with the wind direction and speed from hour to hour. The concentration of pollutants is calculated as each puff passes over a receptor point (Zhou *et al*., 2003). Due to its capability of integrating puffs the model saves time while maintaining its accuracy (Song *et al*., 2006).

The Calpuff model is an internationally approved model that is used by the USEPA for regulatory purposes (United States Environmental Protection Agency, 2005). The Calpuff model has gained regulatory approval for air dispersion modelling of medium to long-range transport of pollutants (Heydenrych *et al.*, 2005). Due to the capability of Calpuff to evaluate both short and long range pollutant transport, the impacts of pollutants can be measured around an industry’s fence line to the nearest populated areas situated kilometres away.

Calmet is a meteorological model that generates 3-dimensional wind fields. Calmet requires geophysical data including gridded fields of terrain elevation and land use categories. The Calmet model uses atmospheric temperature, wind speed, wind direction, cloud cover, relative humidity, and atmospheric pressure as input data while Calpost processes the Calmet output files for plotting on modelling domain maps (Earth Tech, 2000b).

3.3.2 Rationale for using the Calpuff Model

The Calpuff model is one of the most widely used USEPA models that produces satisfactory results for regulatory purposes. It is freely available from the USEPA and operates with a user friendly windows interface with on-line help. There is an input parameter error-checking screen that lists all the errors detected by the Calpuff Graphical User Interface before and after the model runs are undertaken (Earth Tech, 2000a). The validation studies conducted for the Calpuff model are detailed in the USEPA guideline documents (United States Environmental Protection Agency, 2003; 2000b; 2005). Calpuff has been used for regulatory purposes for example, to evaluate the emission reduction measures at an old fossil-fuel power plant in the US state of Illinois due to its capabilities of long range transport and to handle complex 3-dimensional wind fields. Calpuff was also used to estimate primary and secondary particulate matter concentrations from the power plant. Calpuff was selected as the model for the study due to its USEPA regulatory use (Levy *et al.*, 2002). In addition, Calpuff was selected for use in Richards Bay due to its capability to model line sources which are characteristic of the two aluminium smelters in Richards Bay namely, Bayside and Hillside (United States Environmental Protection Agency, 2005).

In recent studies conducted by the CSIR (CSIR, 2004; 2005) and Airshed Planning Professionals study (Airshed, 2006a); the Hazard Area Wiz Kit (HAWK) dispersion model was used to simulate SO_2 concentrations in the uMhlathuze Municipality. The HAWK model was developed in South Africa by an environmental consultancy company and has similar capabilities to that of Calpuff. The HAWK model is a Lagrangian puff model that can also simulate SO_2 emissions from multiple sources, can operate under calm winds and over complex terrain, with a grid resolution varying from 50 m to 500 m. The averaging periods of HAWK includes 10-minutes; 1-hour; 24-hour and annual average periods, which differs from Calpuff which does not produce a 10-minute average concentration (CSIR, 2004; 2005 and Airshed, 2006a). The use of Calpuff will be a valuable comparison with other model runs in the uMhlathuze Municipal area.

Although the HAWK model is not approved for regulatory purposes, it was used in the CSIR (2004), CSIR (2005) and the Airshed (2006) studies due to it being the locally preferred model for all dispersion modelling exercises by the RBCAA. Additionally, the HAWK model has been validated twice by the model developer in the Richards Bay area (CSIR, 2004; 2005). The two validation reports referred to in the CSIR studies were peer reviewed in 2005 by Professor Eugene Cairncross. It was found that there were significant differences between the HAWK modelled results and measured results in Richards Bay. Further, the validation studies were viewed as biased due to them being carried out by the developers of the HAWK model (Cairncross, 2005a; 2005b). These findings again justify the use of an alternate model, namely Calpuff.

3.3.3 Modelling Options Selected

The simulation period for the study was from 2002 to 2004, with meteorological data processed for the same period. A receptor elevation of 1 m above ground level was selected as this falls within a range acceptable for the measurement of ground level pollutant concentrations. Five modelling scenarios were selected for this study. Scenario 1 was the baseline or control scenario comprising current SO_2 emissions data; Scenario 2 was the worst case scenario comprising Registration Certificate or permitted emissions data. The permitted emissions were thereafter reduced by 25%, 50% and 75% across all sources to assess ambient SO_2 concentrations around sensitive receptors and are called Scenarios 3 to 5 respectively. The averaging times selected were 1-hour, 24-hour and annual averaging periods.

3.4 Receptor Network

The modelling domain is the area in which the concentration and movement of pollutants will be predicted (BCME, 2006). The modelling domain over uMhlathuze covered a 50 km by 50 km grid, which incorporated the entire municipal area of uMhlathuze and a total of 2500 receptors in 1 km grid spacing. The receptor network of particular focus in this study was selected based on the populated areas within uMhlathuze Municipality that may be sensitive to SO_2. A total of 9 sensitive receptors was chosen as shown in Figure 3.2. The receptors chosen are Esikhaweni, Felixton, Alton, Meerensee, Industrial Cluster, Central Business District (CBD), Arboretum, Veldenvlei and Empangeni. The residential areas are Esikhaweni, Felixton, Meerensee, Arboretum, Veldenvlei and Empangeni, with the business and industrial areas at Alton, the Industrial Cluster and the CBD. These 9 areas represent places where people are likely to spend at least an 8-hour working day or more.

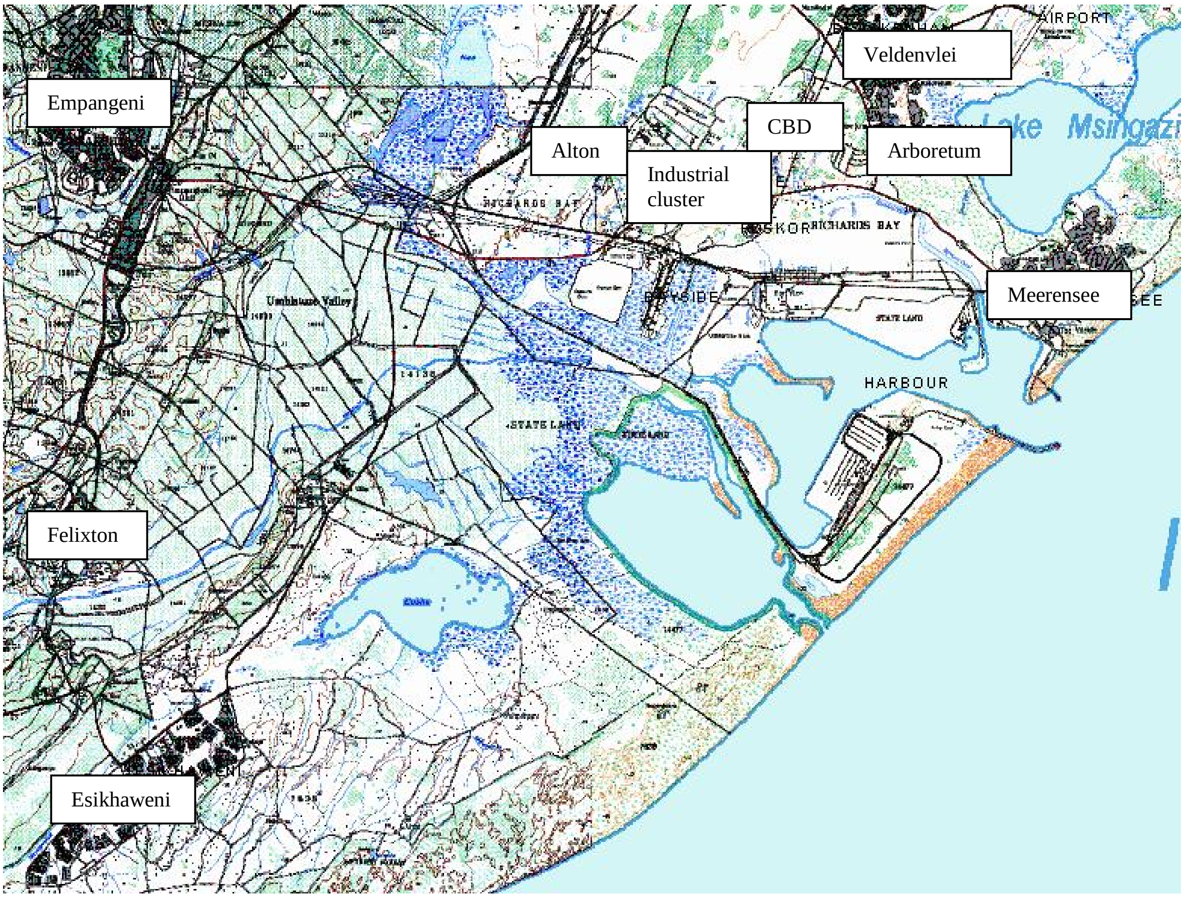


Figure 3.2 Map of uMhlathuze area showing the 9 chosen receptors for the study (map obtained from the CSIR, Durban)

3.5 Sources of Data and Data Description

3.5.1 Emission Inventory

The emission inventory for the uMhlathuze Municipality is compiled and updated annually by the RBCAA together with the uMhlathuze Municipality. The RBCAA emissions inventory was audited by COEX Environmental Planners in 2004 (RBCAA COEX, 2004). The audited actual emission rates were used in this study, which can also be obtained from the air quality specialist study for the proposed TATA Steel plant undertaken by the CSIR in 2005 (CSIR, 2005). The RBCAA emission inventory excluded the Tongaat-Hulett plant with no specific reason provided in the report. However, the Tongaat-Hulett plant has been included in this study with the permitted emission rates obtained from the CSIR air quality specialist study conducted in 2004 (CSIR, 2004). Appendix 3 presents the emission rates per source modelled and Table 3.1 includes the emissions inventory data for the control scenario and permitted scenarios. All other source parameters were kept constant.

The emission inventory used for this study does not include SO_2 emissions from motor vehicles, domestic fuel burning, ships in the harbour, the local airport, emissions from rail transport, cane burning, veld fires or other small industries that are not defined as scheduled processes under APPA. It was assumed that SO_2 emissions from all other sources do not significantly contribute to the total SO_2 emission load in the municipal area as compared with that of heavy industry. This assumption is endorsed by the Airshed (2006) project which stated that industry contributes 99.5% of the total SO_2 emission load in the uMhlathuze Municipal area (Airshed, 2006a). This study has therefore focused on scheduled process industries as the largest source of SO_2 emissions in the uMhlathuze Municipality.

The emissions inventory used by the Airshed (2006) study included the RBCAA emissions inventory as well as biomass burning and vehicle emissions estimates. The CSIR (2004) and CSIR (2005) studies included the emissions inventory from the RBCAA as well as the proposed Tata Steel plant, where the SO_2 emissions were estimated at 1.12 tons per annum (t/a). The emission contribution from Tata Steel was not included in this study due to its focus on existing industries at the time and not proposed industries in the uMhlathuze area.

All major SO_2 emitting industries in uMhlathuze were included in the control scenario and amounted to 40 point sources and 7 line sources. The line and point sources are present at the Hillside and Bayside aluminium smelters while the remaining point sources exist for the rest of the industries in the emissions inventory. The stack parameters included stack base height in meters, stack diameter in meters, stack gas temperature in degrees Kelvin, gas exit velocity in meters per second, and stack locations in UTM format.

The emission data used for the control scenario were based on actual annual SO_2 emissions from existing industries and it must be noted that these figures may vary from one year to the next as they are based on production requirements of an industry and emission control measures that may be implemented by an industry. The worst case scenario of ambient SO_2 concentrations in the uMhlathuze area was modelled by using permitted values for SO_2. The permitted values for SO_2 are regarded as the highest allowable level of SO_2 that an industry is permitted to release at any given time, except during upset or emergency conditions. Based on the results produced in the worst case scenario, the permitted emission values from all sources were reduced by 25%, 50% and 75%. The Airshed (2006) study focused on actual and permitted emissions scenarios; while the CSIR (2004) and CSIR (2005) focused only on the actual SO_2 emission scenario.

Table 3.1 Emissions Inventory for uMhlathuze Municipality for the period 2004-2005

Emission Source	**Actual SO_2 emission in tons per annum (t/a)**	**Actual SO_2 emission in grams per second (g/s)**	**Permitted SO_2 emission in tons per annum (t/a)**	**Permitted SO_2 emission in grams per second (g/s)**
Hillside	10561	335	16881	535
Bayside	3832	122	6298	200
Mondi Richards Bay	4337	138	4708	149
Foskor	2401	76	6326	201
Mondi Felixton	1096	35	934	30
RBM	375	12	1397	44
AECI	3	0.10	1.50	0.05
Ticor	251	8	1444	46
Tongaat Hullets	314	10	315	10
Total emissions	**23170**	**735**	**38306**	**1215**

(CSIR, 2004; 2005; RBCAA COEX, 2004)

3.5.2 Meteorological Data

The three years of surface meteorological data from 2002 to 2004 used in this study were obtained from the South African Weather Services (SAWS) station at the Richards Bay Airport. The surface data included hourly values of relative humidity, rainfall, ambient temperature, ambient pressure, and wind speed and wind direction. The upper air data for a 3-year period was generated by CSIRO TAPM model. The upper air data included mixing heights, ambient temperatures and atmospheric pressure and solar radiation.

The Airshed (2006) study obtained surface meteorological data from the stations managed by the RBCAA namely, Bayside; Hillside; Arboretum; RBM1; RBM2 and Wildenweide and the SAWS. The meteorological parameters used in the HAWK model thus consisted of pressure, wind speed, wind direction, temperature, precipitation, solar radiation, and humidity. The source of the upper air data is not mentioned. Meteorological data for a period of one year, namely 2004, were used for the dispersion simulations (Airshed, 2006a). In the study conducted by the CSIR (2004) and CSIR (2005), the surface meteorological data were obtained from the RBCAA monitoring network and the SAWS, while the upper air data were obtained from the CSIRO TAPM model. The surface meteorological data set was generated for the period 2000 to 2002 using wind direction, wind speed, atmospheric pressure, rainfall, solar radiation, and relative humidity. The stability and mixing heights were calculated from temperature profiles and wind patterns measured at a 70 m tower at Bayside Aluminum (CSIR, 2004; 2005).

The USEPA recommends that a period of five consecutive years of meteorological data be used for regulatory air dispersion modelling in order to cater for the worst case meteorological conditions that could occur within a period of five years. Alternatively, if such data are not readily available then a period of one year of meteorological data can be used provided it is site specific (United States Environmental Protection Agency, 2000a).

CHAPTER 4

MODEL RESULTS AND DISCUSSION

4.1 Introduction

The results are based on outputs from the Calpuff suite of models used in this study. Maximum values for 1-hour, 24-hour and annual averaging periods were extracted for each of the five scenarios and the maps depicting isolines of SO_2 concentrations over the study domain produced. Time series analyses have been conducted for the 9 sensitive receptors showing the number of times the maximum 1-hour and 24-hour air quality standards are exceeded in a three year period.

The predicted results are compared with results of previous studies conducted in the area. These include the Air Quality Specialist Study for the Proposed TATA Steel project that was conducted by the CSIR in 2004 and updated in 2005 (CSIR, 2004; 2005); the Review of the Spatial Development Framework for the City of uMhlathuze by Airshed Planning Professionals in 2006 (Airshed, 2006a) and the annual reports of the RBCAA (RBCAA, 2002; 2003; 2004; 2005).

4.2 Scenario 1: Control Run

The baseline or control scenario is derived from the actual SO_2 emissions values as presented in the emission inventory in Appendix 3, with a summary of the sources in Table 4.1. The emission inventory in the CSIR (2004) study specified emission rates per individual stack for all major industries in the uMhlathuze Municipality. In a subsequent report, the emission inventory was updated according to the RBCAA COEX (2004) report.

This study includes information from both the CSIR (2004) report, as well as the updated emission rates used in the CSIR (2005) study.

4.2.1 Maximum 1-hour Concentrations

The isoline map in Figure 4.1 shows that the area of highest SO_2 concentration is in the industrial cluster of Alton, Hillside Aluminium (to be referred to as Hillside), Foskor Richards Bay (to be referred to as Foskor) and Bayside Aluminium (to be referred to as Bayside), with a maximum hourly average of 2520 $\mu g/m^3$. The area of highest SO_2 concentration is elongated in a north-easterly/south-westerly direction according to the prevailing wind pattern in Richards Bay. The area to the north of Felixton also emerges as an area of high concentrations (up to 2000 $\mu g/m^3$) due to the presence of Mondi Felixton and Tongaat-Hulett. The exceedance of the hourly standard of 350 $\mu g/m^3$ extends over virtually the entire study domain, with the exception of a small area in the south-west corner.

A similar pattern was noted in the CSIR (2005) study which showed highest SO_2 concentrations greater than 1000 $\mu g/m^3$ around the Aluminium smelters (Hillside and Bayside) and the paper mill (Mondi Richards Bay) (CSIR, 2005). The Airshed (2006) study showed a maximum hourly average of 1600 $\mu g/m^3$ around the industrial cluster. Table 4.2 is a comparison of the maximum 1-hour average results from this study with those of previous studies. The results of the current study are greater than the other two and it is likely that the higher SO_2 emissions used in this study lead to the increase in the results. The increase of 1410 t/a of SO_2 in this study compared to the Airshed study produced a 63% increase in the maximum concentration of SO_2. It must be noted that due to the close proximity of the major industries to one another in the Industrial Cluster, the highest concentrations might fall directly over the emissions sources; however the according to the definition of ambient air in the AQA the concentration of pollutants that the public can be exposed to lies outside an industry's Occupational Health and Safety zone (South Africa, 2005b). In most cases this zone falls just outside an industry fence line and in the case of uMhlathuze municipality, the main highway (John Ross R24 Highway) runs between the Hillside Aluminium and Foskor plants (http://www.demarcation.org.za/).

The frequency of exceedances of the 1-hour standard of 350 μg/m^3 over the 3-year period at the 9 selected receptors appears in Table 4.3, with 1216 exceedances occurring in the industrial cluster. The Airshed (2006) and CSIR (2005) studies did not report on the number of exceedances of the SANS 1929 or DEAT ambient standards. According to the SANS 1929 standard, the permissible frequency for exceeding the 1-hour limit values per year is still to be determined, while the October 2007 discussion document published by DEAT allows for 88 exceedances per year of the 1-hour standard. Although the SAAAQS have been legislated the number of permissible exceedances have not been finalized at the time of this study. Hence the EU and UK standards for the allowable number of exceedances will be compared in the following scenarios for this study. The EU and UK standards allow for 24 exceedances of the 350 μg/m^3 hourly standard per year (South African National Standard 1929: 2005 : European Union, 2004; South Africa, 2007).

Table 4.1 Summary of SO_2 sources for scenario 1 in tons per annum (t/a) (CSIR 2004; 2005 and Airshed 2006a)

Emission Source	SO_2 emission rates (t/a) used in this study in line with the RBCAA COEX figures used in the CSIR (2005) study	SO_2 emission rates (t/a) used in the Airshed (2006) study from the RBCAA COEX report, but not specified per industry (Airshed, 2006a)	SO_2 emission figures (t/a) used in the CSIR (2005) report obtained from the RBCAA COEX report (CSIR, 2005)
Hillside	10561	Included	10561
Bayside	3832	Included	3832
Mondi Richards Bay	4337	Included	4337
Foskor Richards Bay	2401	Included	2401
Mondi Felixton	1096	Included	513[2]
RBM	375	Included	375
AECI	3	Included	3
Ticor	251	Included	251
Tongaat-Huletts	315[3]	Not included	Not included
Tata Steel	Not included[4]	Not included	1.12
Vehicle Emissions	Not included	Included	Not included
Total emissions	**23170**	**21760** [1]	**22274**

1. The Airshed (2006) study reported that the RBCAA COEX emission rates were used in their study, however the 21760 t/a is significantly less than the RBCAA COEX figures. Airshed reported that some of the emissions rates were updated independently during the course of their study (Personal Communication, 2007).

2. The CSIR (2005) report recorded the Mondi Felixton actual emissions as 513 t/a in an independent review of the emissions inventory, while the RBCAA COEX report recorded this as 1096 t/a in the RBCAA review

3. The CSIR (2004) report included Tongaat-Hullet in its emission inventory, while the updated report in 2005 excluded the Tongaat-Hullet plant. The updated inventory was obtained from the RBCAA COEX 2004 report which did not specify a reason for excluding the Tongaat-Hulett SO_2 emissions. This study has included the Tongaat-Hulett plant which is currently operational.

4. Tata Steel was not operational at the time of conducting this modelling study

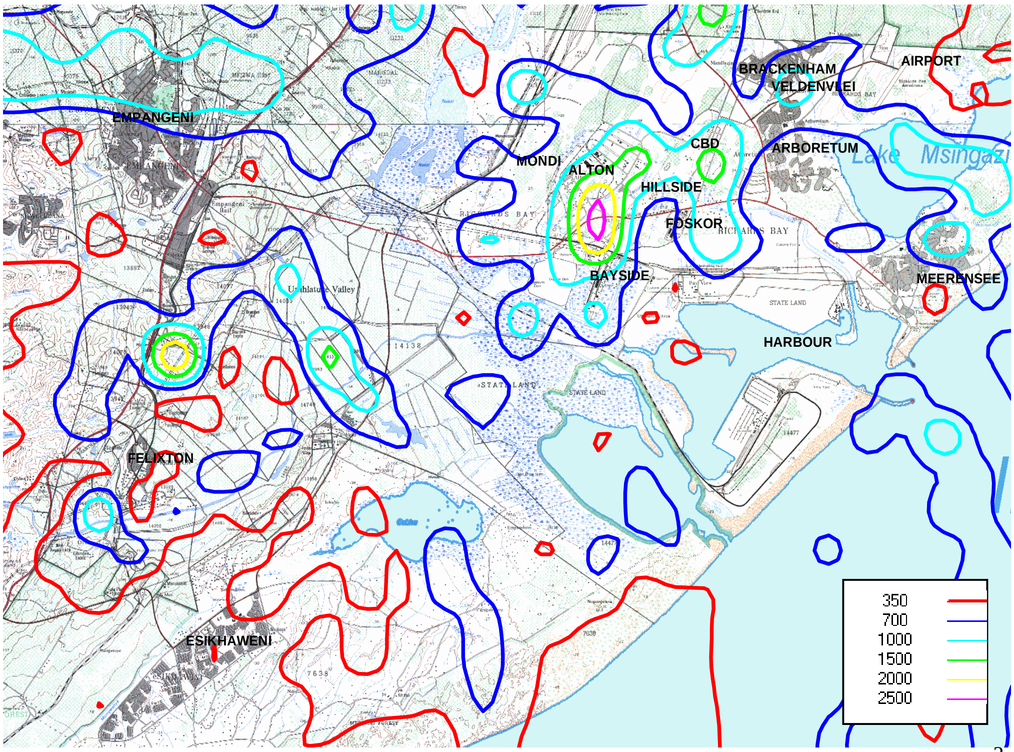


Figure 4.1 Scenario 1: Maximum 1-hour average SO_2 concentrations in µg/m^3

Table 4.2 Comparison of the maximum 1-hour average concentration (µg/m^3) of current and previous studies and the total SO_2 emissions used for modelling

	CSIR (2004) and CSIR (2005)	Airshed (2006)	Current Study
Total SO_2 emissions (t/a)	22274	21760	23170
Maximum 1-hour average (µg/m^3)	>1000	1600	2520

Table 4.3 Maximum 1-hour average concentrations (µg/m^3) and the frequency of exceedances at the receptors for scenario 1

Receptors	Maximum 1-Hour Average Concentration (µg/m^3)	Number of Exceedances
Esikhaweni	348	0
Felixton	409	3
Alton	1240	360
Industrial Cluster	2520*	1216
Meerensee	773	11
CBD	1690	18
Arboretum	569	15
Veldenvlei	1180	11
Empangeni	1190	4

* 2520 µg/m^3 occurred in August 2002

4.2.2 Maximum 24-hour Concentrations

The position of the highest 24-hour SO_2 concentration shown in Figure 4.2 occurs in the industrial cluster and displays a north/south oriented dispersion pattern. The area exceeding the DEAT 24-hour standard of 125 $\mu g/m^3$ is smaller than the area exceeding the 1-hour standard. The CSIR (2005) study for the cumulative impact of SO_2 shows concentrations of SO_2 higher than 200 $\mu g/m^3$ in the vicinity of the aluminium smelters and the paper mill; with the Airshed (2006) study producing results up to 350 $\mu g/m^3$ in the industrial cluster as shown in Table 4.4. Again, values produced by the current modelling study are relatively higher than the previous studies.

The frequency of exceedances of the 24-hour average standard is highest at the industrial cluster and is limited to the CBD as shown in Table 4.5 and Figure 4.2. There are 226 exceedances of the 24-hour average standard over 3 years in this study, compared to the 3 exceedances per annum allowed by the EU and UK and the 4 allowable exceedances per annum proposed by the DEAT 24-hour standard. The residential areas are not impacted upon provided industries operate under normal conditions, however, under emergency, upset or abnormal conditions the 24-hour average standard may be exceeded in these areas as well. Upset and emergency conditions were not modelled in this study due to lack of emissions data for these conditions.

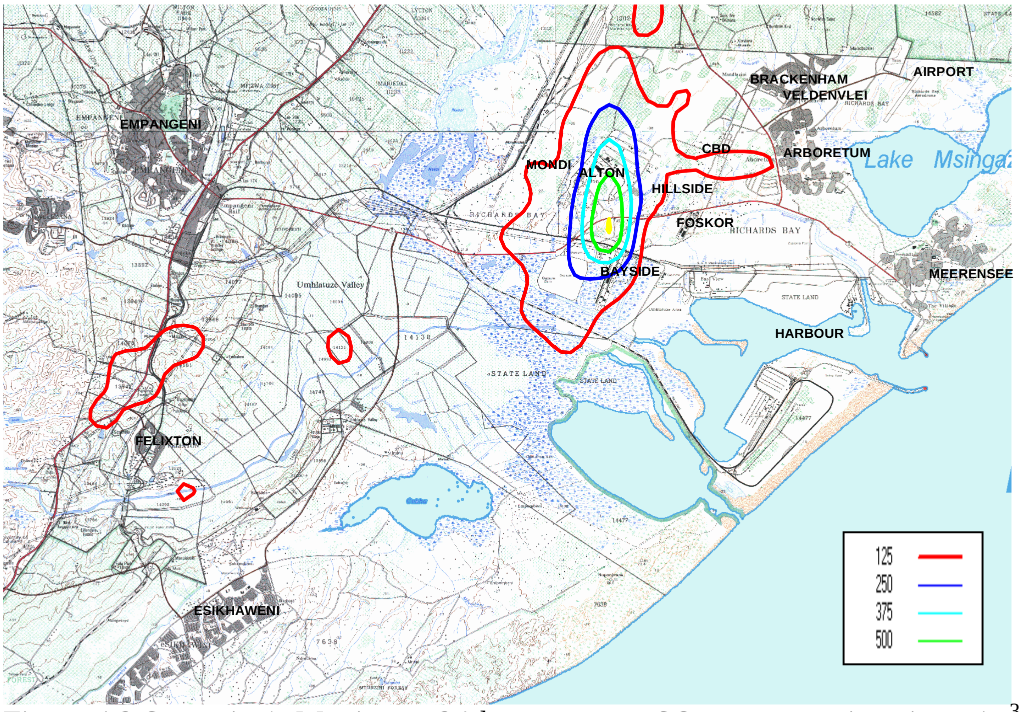


Figure 4.2 Scenario 1: Maximum 24-hour average SO_2 concentrations in µg/m^3

Table 4.4 Comparison of the maximum 24-hour average concentration (µg/m^3) of current and previous studies for scenario 1

	CSIR (2005)	Airshed (2006)	Current Study
Total SO_2 emissions (t/a)	22274	21760	23170
Maximum 24-hour average (µg/m^3)	>200	350	590

Table 4.5 Maximum 24-hour average concentration (µg/m^3) and the frequency of exceedances at the receptors for scenario 1

Receptors	Maximum 24-Hour Average Concentration (µg/m^3)	Number of Exceedances
Esikhaweni	42	0
Felixton	68	0
Alton	478	86
Industrial Cluster	590*	226
Meerensee	67	0
CBD	140	1
Arboretum	73	0
Veldenvlei	65	0
Empangeni	91	0

*590 µg/m^3 occurred in September 2004

4.2.3 Annual Average Concentrations

The annual average standard of 50 µg/m^3 is exceeded over the industrial cluster only, with values below 50 µg/m^3 over the residential and business areas in uMhlathuze (Fig. 4.3). The annual average results from three years of meteorological data resulted in 102 µg/m^3 in the year 2002, 74 µg/m^3 in 2003 and 83 µg/m^3 in 2004, giving a three year average of 86 µg/m^3. The Airshed (2006) study recorded an annual average of 40 µg/m^3 for the 2004 meteorological data set used, while the CSIR (2004) and CSIR (2005) studies did not model an annual average as highlighted in Table 4.6. The 3-year meteorological data set produced three annual average exceedances for this study.

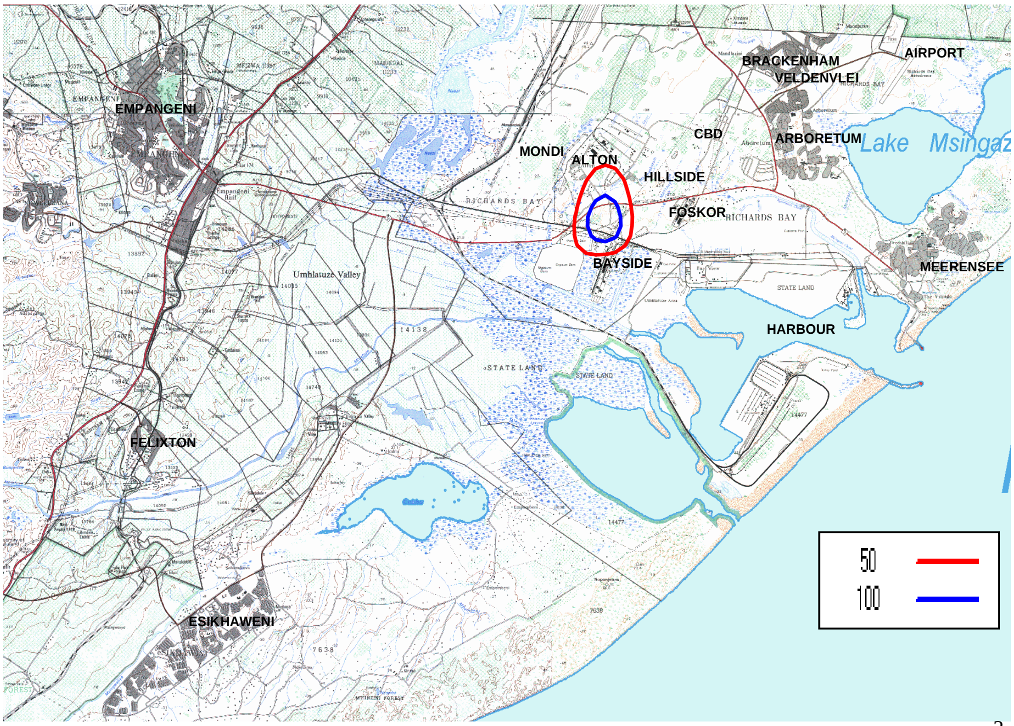


Figure 4.3 Scenario 1: Maximum annual average SO_2 concentrations in µg/m^3

Table 4.6 Comparison of the annual average concentration (µg/m^3) of current and previous studies for scenario 1

	CSIR (2004) and (2005)	Airshed (2006)	Current Study
Total SO_2 emission (t/a)	22274	21760	23170
Annual Average (µg/m^3)	Not modeled	40	86

4.3 Scenario 2: Worst Case with Permitted SO_2 Values

The worst case scenario is based on the permitted SO_2 emission values as presented in the emissions inventory in Appendix 3 with a summary of the sources in Table 4.7. It is assumed that all permit values recorded in the CSIR (2004) report have remained unchanged for all major industries. A further assumption is that the Airshed (2006) study has used the same permitted emission rates. The RBCAA COEX (2004) report did not contain permitted SO_2 values (CSIR, 2004; 2005, RBCAA COEX, 2004).

Table 4.7 Summary of permitted SO_2 sources for scenario 2

Emission Source	SO_2 emission used in this study (t/a)	Airshed (2006) (t/a)	CSIR (2004) and (2005) (t/a)
Hillside	16881	16881	A permitted scenario was not modelled
Bayside	6298	6298	
Mondi Richards Bay	4708	4708	
Foskor	6326	6326	
Mondi Felixton	934 *	934	
RBM	1397	1397	
AECI	1.5 *	1.5	
Ticor	1444	1444	
Tongaat Hullets	315	Not included	
Tata Steel	Not included	Not included	
Vehicle Emissions	Not included	Not included	
Total emissions	**38306**	**37990**	

* Actual emission values exceed permitted amounts for Mondi Felixton and AECI

4.3.1 Maximum 1-hour concentrations

The predicted SO_2 concentrations over the entire uMhlathuze Municipal area in the case of all industries operating at the maximum permitted emissions rates is greater than 1000 $\mu g/m^3$. The residential areas of Arboretum, Veldenvlei and Brakenham which are close to the SO_2 emitting industries are likely to be impacted on, with predicted maximum SO_2 concentrations over 1500 $\mu g/m^3$. The maximum SO_2 concentration predicted in the industrial cluster was 4207 µg/m^3 as shown in Figure 4.4. The concentration at all receptors exceeded the 1-hour standard of 350 µg/m^3. The Airshed (2006) study recorded a maximum 1-hour average of 3750 µg/m^3 in the case of all industries operating at the permitted emission rates as shown in Table 4.8. Considering that this study used an additional 316 t/a of SO_2 emissions , the result of 4207 µg/m^3 is comparable with the 3750 µg/m^3 obtained by the Airshed study and gives credibility to the results. Exceedances of the 1-hour standard occurred 3747 times over the 3-year period in the industrial cluster, and over 100 times in the residential areas of Arboretum and Veldenvlei as shown in Table 4.9.

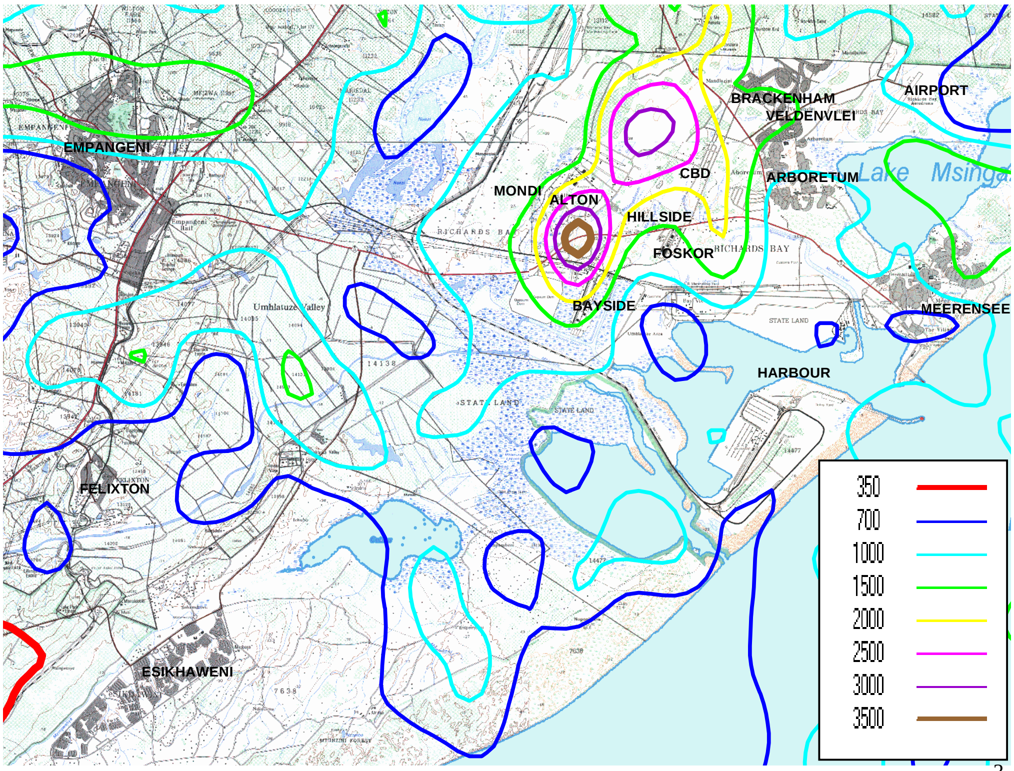


Figure 4.4 Scenario 2: Maximum 1-hour average SO_2 concentrations in µg/m^3

A comparison of the control and worst case scenarios reveals that the SO_2 concentrations in the area to the north of Felixton have decreased in concentration when comparing Figure 4.1 and 4.4. This is due to a decrease in SO_2 emissions from Mondi Felixton by 169 t/a as shown in Tables 4.1 and 4.7. The effect of Mondi Felixton operating above its permitted limit of SO_2 is reflected in the predicted SO_2 concentrations.

Table 4.8 Comparison of the maximum 1-hour average SO_2 concentration (µg/m$^{3)}$ of current and previous studies for scenario 2

	CSIR (2004) and (2005)	Airshed (2006)	Current Study
Total permitted SO_2 emission (t/a)	Not modelled	37990	38306
Maximum 1-Hour average (µg/m^3)	Not modelled	3750	4207

Table 4.9 Maximum 1-hour average SO_2 concentration (µg/m^3) and the frequency of exceedances at the receptors for scenario 2

Receptors	Maximum 1-Hour Average Concentration (µg/m^3)	Number of Exceedances
Esikhaweni	564	4
Felixton	651	5
Alton	1783	1513
Industrial Cluster	4207*	3747
Meerensee	1406	39
CBD	2642	119
Arboretum	1403	119
Veldenvlei	1908	127
Empangeni	1943	29

*4207 µg/m^3 occurred in August 2002

4.3.2 Maximum 24-hour concentrations

In comparison to the 24-hour maximum concentrations predicted using actual emissions, the permitted scenario shows a greater area exceeding the 24-hour average standard of 125 µg/m^3 (Fig. 4.5). The daily standard is exceeded over a large area encompassing Richards Bay and Empangeni and extending further into the harbour and towards the coastline. The Airshed (2006) study produced a result of 985 µg/m^3 for the maximum 24-hour average shown in Table 4.10, which is very similar to the results obtained in this study. The similarity in results could be attributed to the meteorological dataset used in both studies since the maximum 24-hour average result in this study occurred in the month of September 2004 and Airshed (2006) used the 2004 meteorological dataset in their study.

The number of times the 24-hour standard was exceeded at each selected receptor is shown in Table 4.11. The number of exceedances of the daily standard at the residential areas is less than or equal to three over the 3-year period, which is acceptable by EU and UK standards. In comparison with the control run which produced 226 24-hour average exceedances in the industrial cluster, the permitted emission scenario produced 567 24-hour average exceedances in the same area.

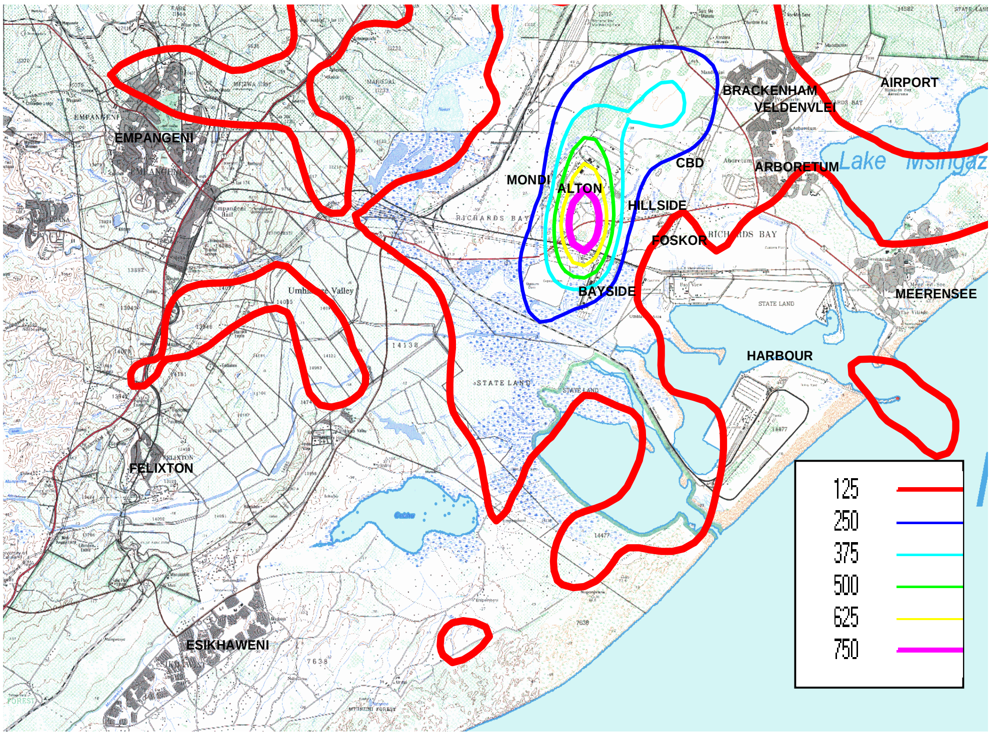


Figure 4.5 Scenario 2: Maximum 24-hour average SO_2 concentrations in µg/m^3

Table 4.10 Comparison of the maximum 24-hour SO_2 average concentration (µg/m^3) of current and previous studies for scenario 2

	CSIR (2005)	Airshed (2006)	Current Study
Total permitted SO_2 emission (t/a)	Not modelled	37990	38306
Maximum 24-Hour average (µg/m^3)	Not modelled	985	966

Table 4.11 Maximum 24-hour average SO_2 concentration (µg/m^3) and the frequency of exceedances at the receptors for scenario 2

Receptors	Maximum 24-Hour Average Concentration (µg/m^3)	Number of Exceedances
Esikhaweni	59	0
Felixton	64	0
Alton	752	157
Industrial Cluster	966*	567
Meerensee	99	0
CBD	220	7
Arboretum	152	3
Veldenvlei	142	1
Empangeni	145	1

*996 µg/m^3 occurred in September 2004

4.3.3 Annual Average Concentrations

Exceedances of the annual standard of 50 µg/m^3 occur only in the industrial cluster. In comparison with the annual concentrations in the control run, the permitted scenario impacts a slightly larger area (Fig. 4.6). The three years of meteorological data used has predicted an annual average concentration of 187 µg/m^3 in the year 2002, 138 µg/m^3 in 2003 and 152 µg/m^3 in 2004 with an average of 159 µg/m^3 over a three year period. The Airshed (2006) study shows a maximum annual average of 85 µg/m^3. This can be attributed to the higher SO_2 emission data used in this study which is 316 t/a more than the Airshed study, as well as to varying meteorological data. In general, the meteorological conditions during the year 2002 produced higher SO_2 concentrations than in the following two years.

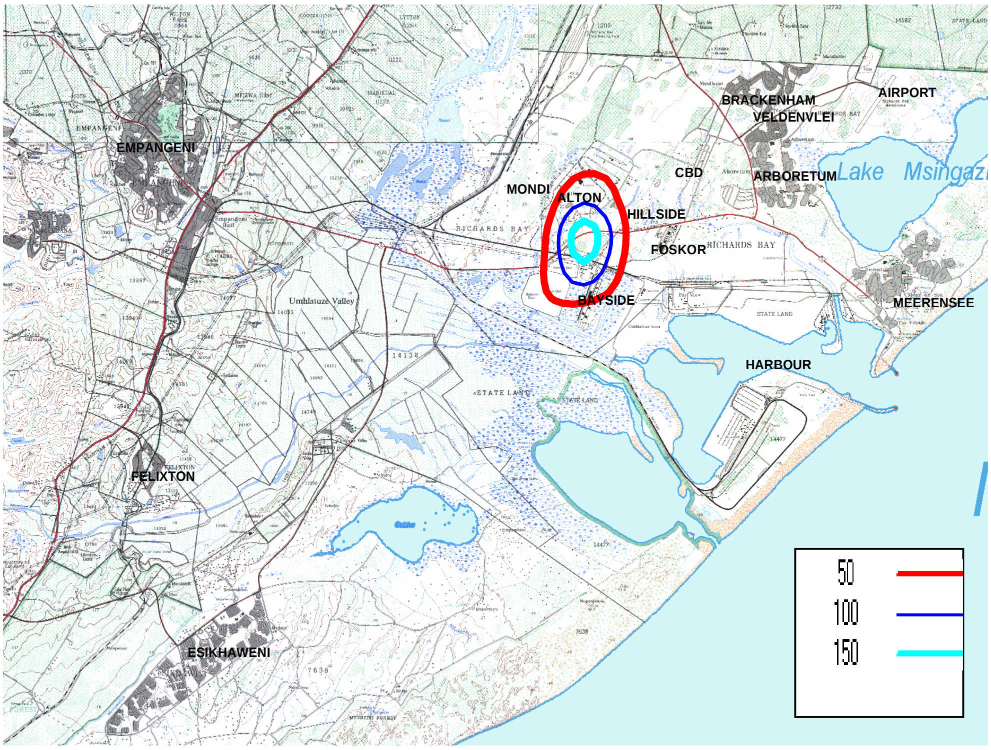


Figure 4.6 Scenario 2: Maximum annual average SO_2 concentrations in µg/m^3

Table 4.12 Comparison of the annual average SO_2 concentration (µg/m^3) of current and previous studies for scenario 2

	CSIR (2004) and (2005)	Airshed (2006)	Current Study
Total permitted SO_2 emissions (t/a)	Not modelled	37990	38306
Annual average (µg/m^3)	Not modelled	85	159

4.4 Scenario 3: Permitted Values reduced by 25%

In view of the exceedances experienced in the control run and the permitted run, it is likely that under the AQA, some reduction in emissions will be required. Hence in the future scenarios modelled, the permitted emissions were reduced. This scenario predicts the ambient concentration of SO_2 in uMhlathuze when the permitted values of SO_2 from all industries are reduced by 25%. All other parameters were kept constant. Previous studies in the uMhlathuze area did not predict emission reduction scenarios and therefore cannot be compared in the following scenarios. The Airshed (2006) study predicted a future scenario by adding the SO_2 emissions from the proposed Tata Steel and Pulp United industries that were planned for Richards Bay, while the CSIR studies added the Tata Steel industry to the future scenario (Airshed, 2006a; CSIR, 2005).

Table 4.13 Summary of SO_2 sources for scenario 3

Emission Source	25% reduction of permitted SO_2 emissions used in this study (t/a)
Hillside	12661
Bayside	4723
Mondi Richards Bay	3531
Foskor	4745
Mondi Felixton	701
RBM	1048
AECI	1
Ticor	1083
Tongaat Hullets	237
Total emissions	28730

4.4.1 Maximum 1-hour Concentrations

A 25% reduction of permitted emissions from all industries still results in ambient SO_2 concentrations exceeding the 350 $\mu g/m^3$ 1-hour standard and a concentration exceeding 700 $\mu g/m^3$ over most of the uMhlathuze area as shown in Figure 4.7. In the control run a maximum 1-hour average SO_2 concentration of 2520 $\mu g/m^3$ was predicted at the industrial cluster area, and the reduction of permitted emissions by 25% produces a concentration of 3172 $\mu g/m^3$ in the same area. These results imply that industries are operating below 25% of the legislated limits. The number of exceedances of the 1-hour average standard in Table 4.14 compared to the control run is higher at all receptors, except Mondi Felixton where the actual emissions from Mondi Felixton were higher than the permitted emissions. The number of exceedances at Alton and the Industrial cluster is above the EU limit of 24 1-hour average exceedances per year.

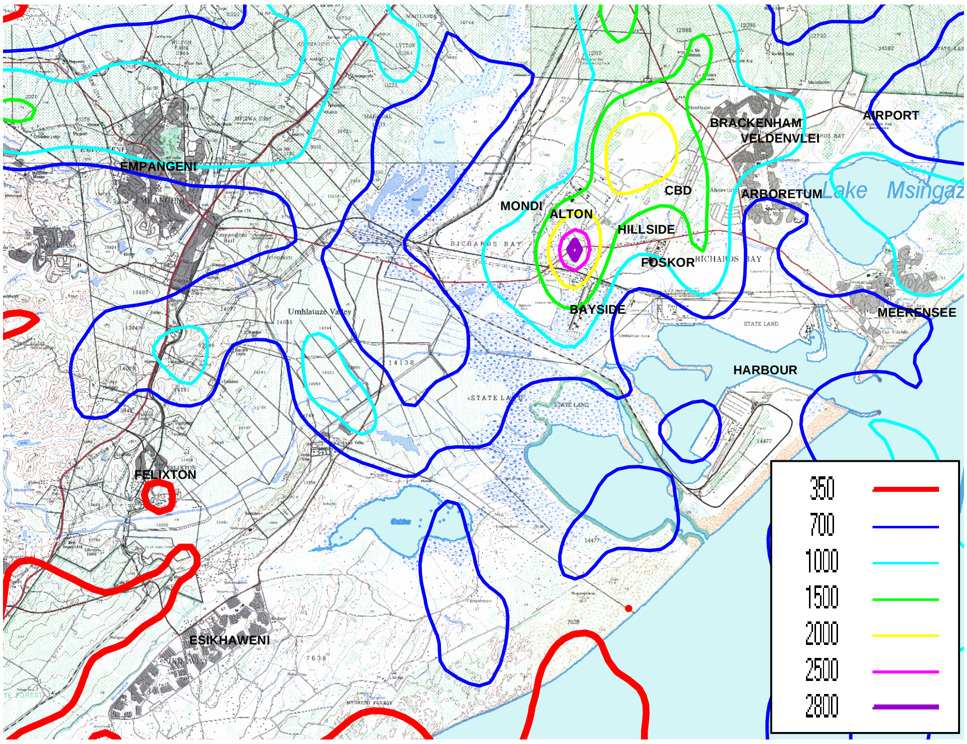


Figure 4.7 Scenario 3: Maximum 1-hour average SO_2 concentrations in µg/m^3

Table 4.14 Maximum 1-hour average SO_2 concentration (µg/m^3) and the frequency of exceedances at the receptors for scenario 3

Receptors	Maximum 1-Hour Average Concentration (µg/m^3)	Number of Exceedances
Esikhaweni	475	2
Felixton	536	2
Alton	1356	1053
Industrial Cluster	3172	2863
Meerensee	1072	16
CBD	2002	55
Arboretum	1062	67
Veldenvlei	1482	75
Empangeni	1514	11

4.4.2 Maximum 24-hour Concentrations

Figure 4.8 illustrates that a reduction of emissions by 25% of the permitted emissions produces a maximum 24-hour average concentration of 725 µg/m^3 in the industrial cluster, with 394 exceedances of the 125 µg/m^3 24-hour average standard in the same area (Table 4.15). The maximum daily average concentration obtained in the control run was 590 μg/m^3 with 226 exceedances of the daily standard occurring at the industrial cluster, again emphasizing that industries are operating below 25% of the permitted levels. The isoline of the 125 μg/m^3 24-hour average limit shown in Figure 4.8 encroaches on the residential areas of Brackenham, Veldenvlei and Arboretum, but there are no exceedances at the receptors in these areas. The number of exceedances at Alton and the industrial cluster are above the EU limit of 3 24-hour average exceedances allowed per year.

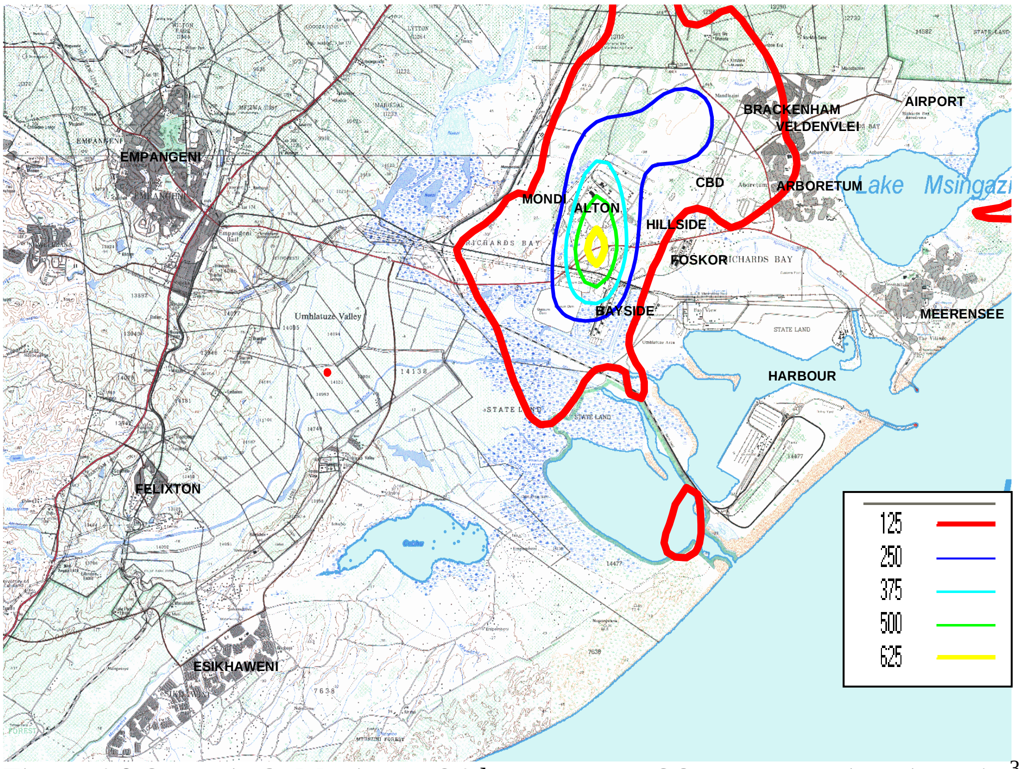


Figure 4.8 Scenario 3: Maximum 24-hour average SO_2 concentrations in μg/m^3

4.4.3 Annual Average Concentrations

The area in excess of the annual average standard of 50 μg/m^3 is restricted to the industrial cluster area (Fig. 4.9), with no exceedances of the standard in the residential or business areas. The control run maximum annual average over three years was 86 μg/m^3 which is lower than the 120 μg/m^3 predicted in this scenario for reasons discussed in Section 4.3.3.

Table 4.15 Maximum 24-hour average SO_2 concentration (µg/m^3) and the frequency of exceedances at the receptors for scenario 3

Receptors	Maximum 24-Hour Average Concentration (µg/m^3)	Number of Exceedances
Esikhaweni	48	0
Felixton	48	0
Alton	76	115
Industrial Cluster	725	394
Meerensee	566	0
CBD	166	2
Arboretum	122	0
Veldenvlei	114	0
Empangeni	112	0

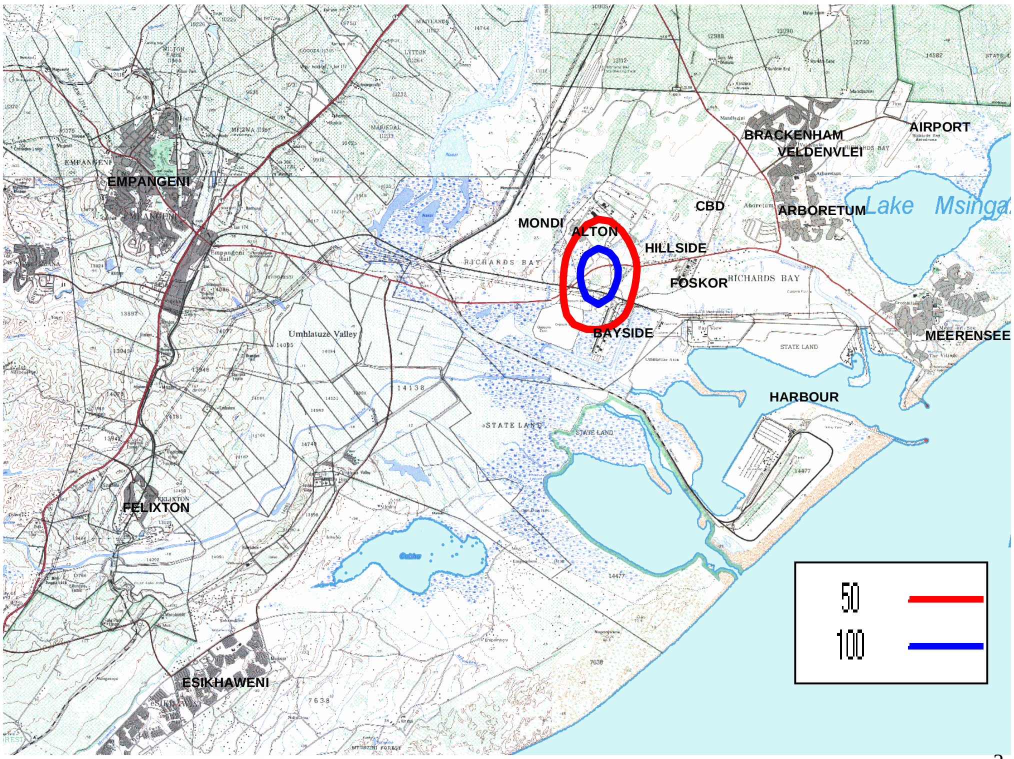


Figure 4.9 Scenario 3: Maximum annual average SO_2 concentrations in µg/m^3

4.5 Scenario 4: Permitted Values reduced by 50%

This scenario predicts the concentrations of SO_2 when permitted limits of SO_2 from all industries are reduced by 50% and all other parameters are kept constant (Table 4.16).

Table 4.16 Summary of SO_2 sources for scenario 4

Emission Source	50% reduction of permitted SO2 emissions used in this study (t/a)
Hillside	8441
Bayside	3149
Mondi Richards Bay	2354
Foskor	3163
Mondi Felixton	467
RBM	699
AECI	0.75
Ticor	722
Tongaat Hullets	158
Total emissions	19153

4.5.1 Maximum 1-hour Concentrations

After a 50% reduction of the permitted values from all industries, there is a smaller area of impact when compared to the 25% reduction of permitted emissions (Fig. 4.10). However, the residential and business areas remain within the 700 $\mu g/m^3$ isoline, which is above the 1-hour standard value of 350 $\mu g/m^3$.

A maximum 1-hour average of 2115 $\mu g/m^3$ occurs in the industrial cluster as shown in Table 4.17, which is closer to the control run result of 2520 $\mu g/m^{3.}$ The number of exceedances of the 1-hour standard at the industrial cluster, the CBD, Arboretum and Veldenvlei is higher for this scenario (50% reduction in permitted emissions) than the corresponding results of the control run depicted in Table 4.5. Thus far, the results obtained for this scenario are closer to the results obtained in the control scenario, implying that the industries are currently operating at approximately 50% of their permitted limits. The number of exceedances in the industrial areas is above the EU limit of 24 1-hour average exceedances allowed per year.

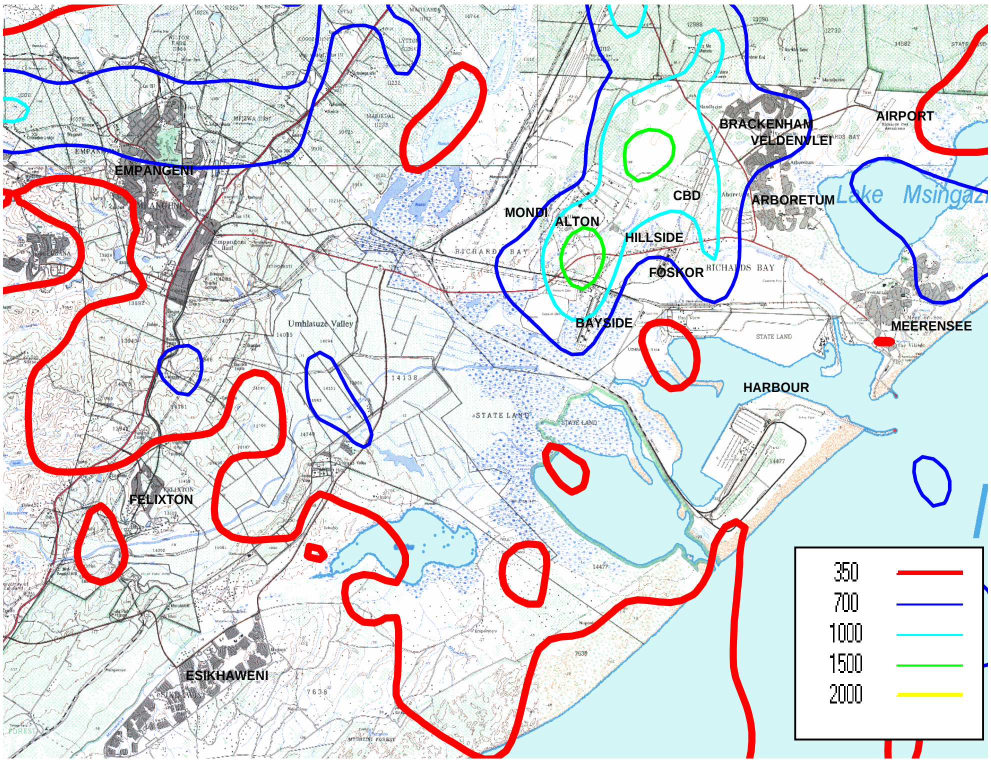


Figure 4.10 Scenario 4: Maximum 1-hour average SO_2 concentrations in µg/m^3

Table 4.17 Maximum 1-hour average SO_2 concentration (µg/m^3) and the frequency of exceedances at the receptors for scenario 4

Receptors	Maximum 1-Hour Average Concentration (µg/m^3)	Number of Exceedances
Esikhaweni	316	0
Felixton	357	1
Alton	904	344
Industrial Cluster	2115	1463
Meerensee	715	4
CBD	1335	20
Arboretum	708	16
Veldenvlei	988	20
Empangeni	1010	2

4.5.2 Maximum 24-hour Concentrations

The area encompassed by the 125 µg/m^3 SO_2 isoline is restricted to the industrial areas and does not have a significant impact on the residential areas as shown in Figure 4.11. The control run predicted a maximum result of 590 µg/m^3 in the industrial cluster area and is higher than the maximum of 483 µg/m^3 predicted in this 24-hour average run. The number of exceedances is above the EU limit of 3 24-hour average exceedances allowed per year in the industrial areas but not in the residential areas (Table 4.18).

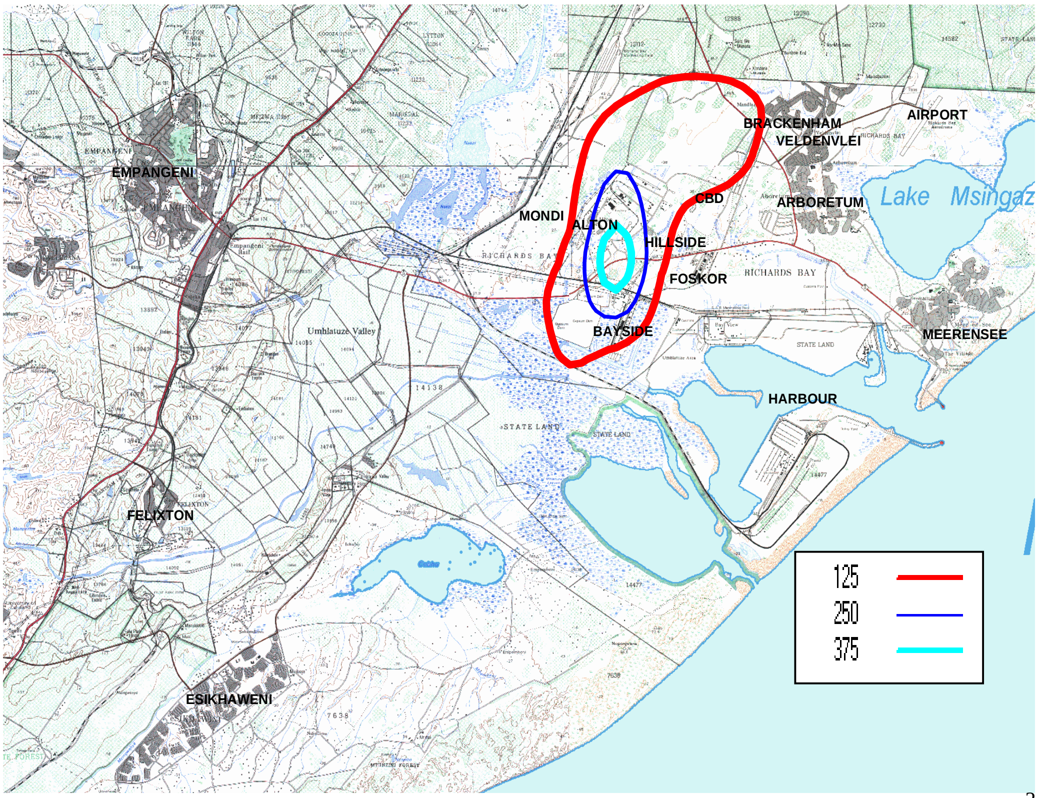


Figure 4.11 Scenario 4: Maximum 24-hour average SO_2 concentrations in µg/m^3

Table 4.18 Maximum 24-hour average SO_2 concentration (µg/m^3) and the frequency of exceedances at the receptors for scenario 4

Receptors	Maximum 24-Hour Average Concentration (µg/m^3)	Number of Exceedances
Esikhaweni	32	0
Felixton	32	0
Alton	377	53
Industrial Cluster	483	196
Meerensee	51	0
CBD	111	0
Arboretum	82	0
Veldenvlei	75	0

4.5.3 Annual Average Concentrations

Figure 4.12 illustrates that the area above the annual average standard of 50 µg/m^3 is restricted to the industrial cluster of Alton, Hillside, Foskor and Bayside areas, with no significant impact on the residential and business areas. Hence, a reduction in emissions by 50% predicts a minimal impact on the sensitive receptors when mean annual concentrations are considered. The maximum annual average concentration obtained is 80 µg/m^3 in comparison with 86 µg/m^3 obtained in the control run.

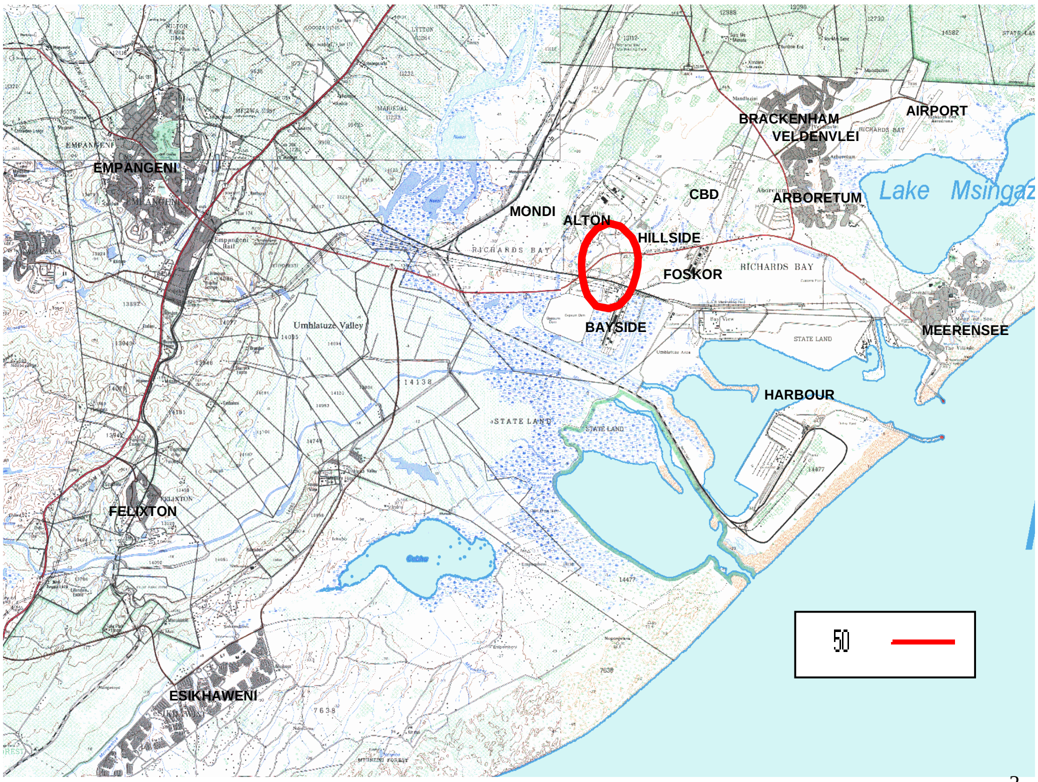


Figure 4.12 Scenario 4: Maximum annual average SO_2 concentrations in µg/m^3

4.6 Scenario 5: Permitted Values reduced by 75%

This scenario predicts the concentration of SO_2 when the permitted emission quantities from all industries are reduced by 75%.

4.6.1 Maximum 1-hour Concentrations

After a 75% reduction of the permitted SO_2 emissions, the 1-hour standard is still exceeded over the Richards Bay and Empangeni areas as shown in Figure 4.13. However, the size of the area impacted, as well as the number of exceedances (Table 4.20) is significantly reduced when compared to the control run in Table 4.5. The residential areas experience a maximum of two exceedances over a 3-year period in this scenario. The number of exceedances in the residential areas complies with the EU limit of 24 1-hour average exceedances allowed per year.

Table 4.19 Summary of SO_2 sources for scenario 5

Emission Source	75% reduction of permitted SO_2 emissions used in this study (t/a)
Hillside	4220
Bayside	1574
Mondi Richards Bay	1178
Foskor	1582
Mondi Felixton	234
RBM	349
AECI	0.38
Ticor	361
Tongaat Hullets	79
Total emissions	9577

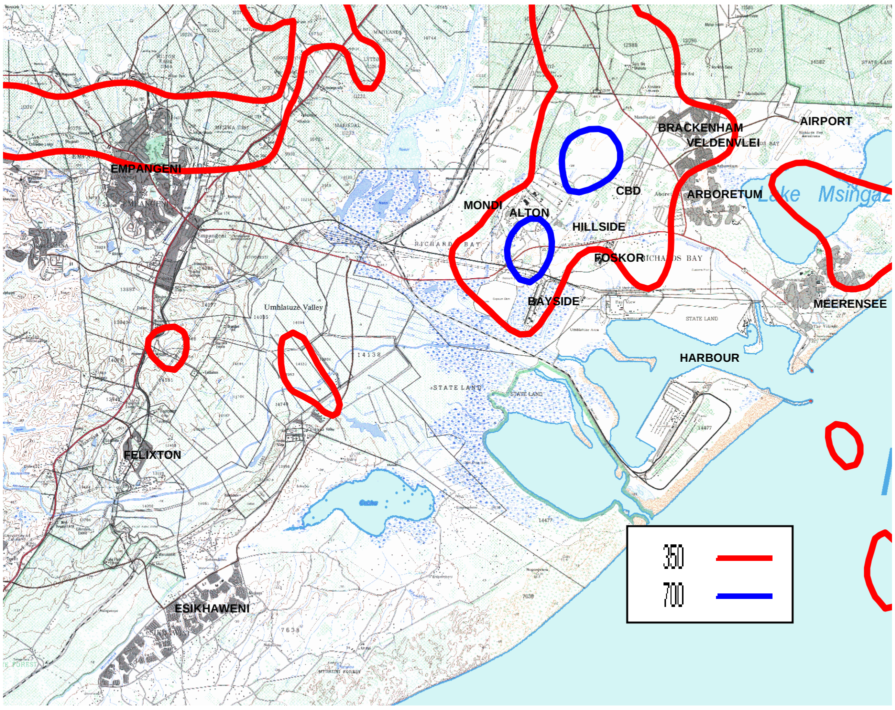


Figure 4.13 Scenario 5: Maximum 1-hour average SO_2 concentrations in µg/m^3

Table 4.20 Maximum 1-hour average SO_2 concentration (μg/m^3) and the frequency of exceedances at the receptors for scenario 5

Receptors	Maximum 1-Hour Average Concentration (μg/m^3)	Number of Exceedances
Esikhaweni	158	0
Felixton	178	0
Alton	452	3
Industrial Cluster	1057	72
Meerensee	357	1
CBD	667	2
Arboretum	354	1
Veldenvlei	494	2
Empangeni	504	1

4.6.2 Maximum 24-hour Concentrations

The area encompassed by the 24-hour average standard of 125 μg/m^3 is restricted to the industrial cluster as shown in Figure 4.14, with a maximum daily average value of 242 μg/m^3 and a total of 30 exceedances (Table 4.21). The residential areas are not impacted upon and do not exceed the daily average limit as shown in Table 4.21. The number of exceedances in the residential area complies with the EU limit of three 24-hour average exceedances allowed per year.

4.6.3 Annual Average Concentrations

The maximum annual average concentration does not exceed the annual average standard of 50 μg/m^3 anywhere over the study area and reaches a maximum annual average of 40 μg/m^3 in the industrial cluster area.

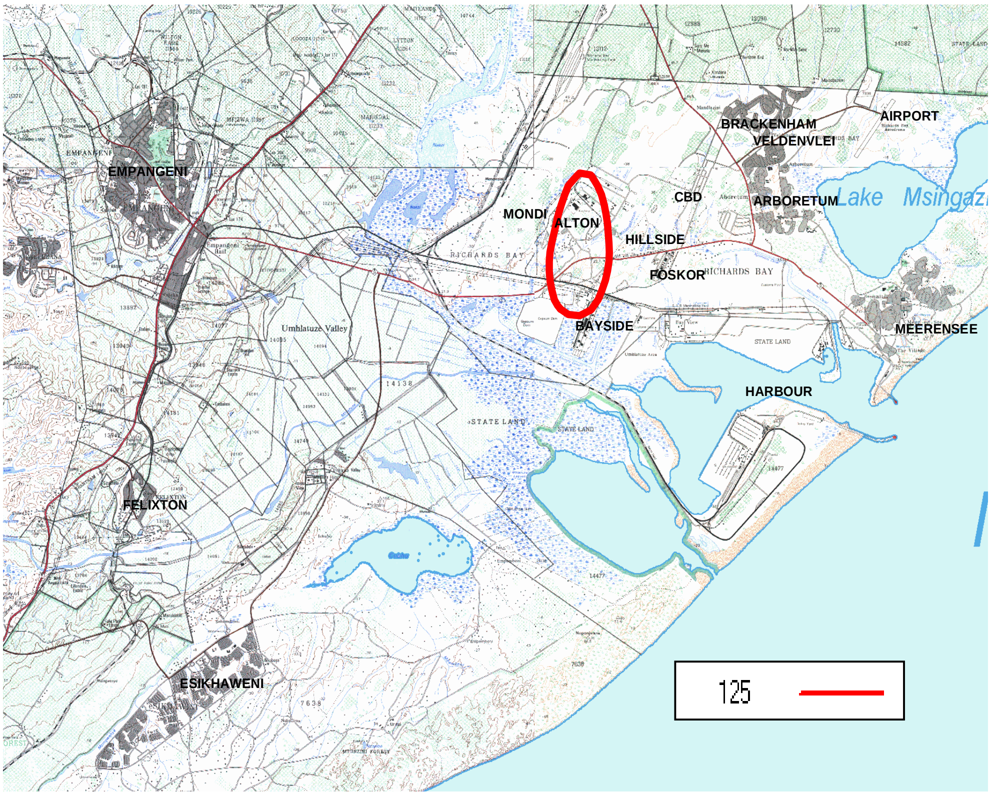


Figure 4.14 Scenario 5: Maximum 24-hour average SO_2 concentrations in µg/m^3

Table 4.21 Maximum 24-hour average SO_2 concentration (µg/m^3) and the frequency of exceedances at the receptors for scenario 5

Receptors	Maximum 24-Hour Average Concentration (µg/m^3)	Number of Exceedances
Esikhaweni	16	0
Felixton	16	0
Alton	189	3
Industrial Cluster	242	30
Meerensee	25	0
CBD	55	0
Arboretum	41	0
Veldenvlei	37	0
Empangeni	38	0

4.7 Summary of Model Results

The control run using the actual emissions data produced high concentrations of SO_2 that exceeded the 1-hour standard of 350 µg/m^3 over most of the study area. The 24-hour standard is exceeded over the industrial cluster, while the annual average is exceeded over

Hillside, Bayside and Foskor. These results showed higher SO_2 concentrations than previous studies conducted in uMhlathuze due to larger SO_2 emissions used in this study. There is a difference of 1410 t/a of SO_2 from the Airshed (2006) study and 896 t/a from the CSIR (2005) study in the control run. In addition, different meteorological data sets were used for the three studies with the Airshed (2006) study using 2004 meteorological data and the CSIR (2005) study, a 3-year dataset from 2000 to 2002. This study used the 2002 to 2004 meteorological dataset. Over and above the different meteorological data sets used, the HAWK model was used in the previous studies, while the Calpuff model was used in this study.

The use of the permitted emission values for the worst case scenario produced higher SO_2 concentrations over the study area than the control run due to the higher emission values used. This implies that all industries are operating below their permitted limits, except for AECI and Mondi Felixton. The maximum 1-hour average standard was exceeded over the entire study area with the 24-hour standard exceedances extending into the residential areas of Brackenham, Veldenvlei and Arboretum. The annual average was exceeded over the industrial cluster. The RBCAA COEX (2004) report did not contain permitted SO_2 values, therefore these values were derived from the permit values recorded in the CSIR (2004) report based on the assumption that they have remained unchanged for all major industries and have been used in the Airshed (2006) study.

There is close correlation between the Airshed (2006) results obtained with the HAWK model and the Calpuff model used in this study for the permitted scenario. The 1-hour maximum results were 4207 $\mu g/m^3$ in this study and 3750 $\mu g/m^3$ in the Airshed (2006) study. The higher result can be attributed to the difference of 316 t/a that was included in this study from the Tongaat-Hulett plant. A comparison of the control run and worst case scenarios reveals that the SO_2 concentrations in the area to the north of Felixton have decreased from 2000 $\mu g/m^3$ in the control run to 1500 $\mu g/m^3$ in the permitted scenario. This is due to a decrease in SO_2 emissions from Mondi Felixton by 169 t/a as shown in Tables 4.1 and 4.7 and shows the effect of Mondi Felixton operating above its permitted limit.

The Airshed (2006) study produced a result of 985 $\mu g/m^3$ for the maximum 24-hour average, which is very similar to the 966 $\mu g/m^3$ result obtained in the permitted scenario for this study. The similarity in results could be attributed to the 2004 meteorological dataset used in both studies where the maximum 24-hour average result in this study occurred in the month of September 2004. The number of exceedances of the daily standard at the residential areas is less than or equal to three over the 3-year period, which is acceptable by EU and UK standards. The maximum annual average of 159 $\mu g/m^3$ was produced over a 3-year period from this study, while the Airshed (2006) study shows a maximum annual average of 85 $\mu g/m^3$ for a 1-year period. This can be attributed to the higher SO_2 emission data used in this study, as well as to varying meteorological data. In general, the meteorological conditions during the year 2002 produced higher SO_2 concentrations than in the following two years.

In view of the exceedances experienced in the control run, it is likely that under the AQA, some reduction in emissions will be required by major industries. Hence future scenarios reduced emissions rather than increased them. This scenario predicts the ambient concentration of SO_2 in uMhlathuze when the permitted values of SO_2 from all industries are reduced by 25%. All other parameters were kept constant. Previous studies in the uMhlathuze area did not predict emission reduction scenarios and therefore cannot be compared in the following scenarios. The reduction of the permitted limits by 25% resulted in concentrations just below the permitted scenario at 3172 µg/m^3 for the maximum 1-hour average run. The 24-hour and annual average isolines are encroaching on the areas depicted in the permitted 24-hour and annual average scenarios.

The reduction of permitted emissions by 50% produces SO_2 concentrations closest to the control run results for the 1-hour, 24-hour and annual average scenarios. The emission reduction scenarios modeled revealed that the industries are likely to be operating at 50% of their permitted limits. The reduction in 75% of the permitted emissions shows that the 1-hour standard is exceeded over the Richards Bay and Empangeni area, but the area impacted on is significantly smaller than the reduction in 50% of the permitted SO_2 emissions. The 24-hour maximum concentrations are restricted to the Alton and Hillside areas with no exceedance of the annual average standard. Table 4.22 presents a summary of the above results.

Table 4.22 Comparison of the maximum average SO_2 concentrations (µg/m^3) for the five scenarios modeled

Scenarios	Maximum 1-Hour Averages in µg/m^3 (Limit of 350 µg/m^3)	Maximum 24-Hour Averages in µg/m^3 (Limit of 125 µg/m^3)	Annual Averages in µg/m^3 (Limit of 50 µg/m^3)
Control run	2520	590	86
Permit Emissions	4207	966	159
25% reduction of permit emissions	3172	725	120
50% reduction of permit emissions	2115	483	80
75% reduction of permit emissions	1057	242	40

4.8 Comparison of the Modelled and Ambient Monitoring Results

The RBCAA monitoring network has five ambient stations which are described in more detail in the RBCAA monthly and annual reports that can be accessed via the RBCAA website (www.rbcaa.co.za) and are depicted in the map shown in Figure 4.15. The number of exceedances during the period 2002 to 2005 is shown in Table 4.23. Exceedances occurred at the Scorpio station (between Hillside and Foskor); the Caravan Station (in the CBD) and the Arboretum station in the residential area of Arboretum. In comparison to the control run in this study, which represents the actual or baseline emissions scenario, the number of exceedances of the maximum hourly and daily averages is significantly higher than those based on the RBCAA measured results. The Airshed (2006) and CSIR (2004, 2005) modelling studies conducted in the uMhlathuze area also predicted higher concentrations over Richards Bay than the measured SO_2 concentrations obtained by the RBCAA monitoring network (CSIR, 2005; Airshed, 2006a; RBCAA, 2005).

There were 13 exceedances of the 1-hour average standard measured by the RBCAA in 2005 and 7 of these exceedances occurred in the CBD area (RBCAA, 2005). By comparison, in the modelled control run, there were 18 exceedances of the 1-hour average standard at the receptor in the CBD area, which is approximately three times that of the measured results. The 24-hour average exceedances in the control run produced one exceedance of the 125 $\mu g/m^3$ standard in the CBD area, corresponding well with the single exceedance of the daily average for the RBCAA measured results. It has generally been observed that with an averaging period of 24-hours, a close correlation occurs between the results from this study and the Airshed (2006) study for the permitted 24-hour scenario, and the number of SO_2 exceedances measured by the RBCAA over the 24-hour period at the CBD station.

Table 4.23 RBCAA exceedances of the applicable South African SO_2 standards from the year 2002 to 2005 (RBCAA 2002; 2003; 2004; 2005)

Exceedance Averaging Period	2002	2003	2004	2005
10 minute Average	18	10	37	16
1-hour Average	Not reported	Not reported	Not reported	13
24-hour Average	1	None	3	1
Annual Average	None	None	None	None

Figure 4.15 Map of RBCAA ambient monitoring stations (CSIR, 2005)

4.9 Implications for Air Quality Management

Ambient air is defined in the AQA as air that is not regulated by the Occupational Health and Safety Act (No. 85 of 1993) (OHS Act, 2004). This definition suggests that any air outside a workplace is considered ambient air. This description is unclear as it does not stipulate a specific boundary between the air in the workplace and air in public places. Boundaries such as the fence line of an industry represent the extent of the workplace however, air pollution cannot be contained within the fence line of an industry, unless the industry is completely enclosed. The USEPA Clean Air Act of 1990 briefly explains ambient air as outdoor air and this definition is maintained in the document published on South Africa’s energy future (United States Environmental Protection Agency, 2007; Davidson and Winkler, 2003). The SANS 69 defines ambient air as outdoor air that excludes workplaces (South African National Standard 69:2005). Based on these definitions, any area outside an enclosed building is considered ambient air and when compared to the AQA, it implies that personnel of a South African industry working outside enclosed buildings are exposed to levels of pollutants that are harmful to human health whether this is within the boundaries of an industry fence line or not. The implications for industry to comply with ambient air quality standards in the current interpretation of the AQA implies that ambient air quality beyond the boundary of an industry must comply with ambient air quality standards.

The control run result in this study shows that all areas around the periphery of the major SO_2 emitting industries have maxima above the 1-hour average standard of 350 $\mu g/m^3$ and are therefore non-compliant with the 1-hour standard. The control run represents the actual SO_2 emissions scenario and predicts that sensitive receptors in the residential areas of Richards Bay and Empangeni may experience negative health effects related to exposure to SO_2. In the case of all industries releasing their maximum permitted SO_2 quantities, the 1-hour average standard will be exceeded over the entire uMhlathuze area. Although this scenario is unlikely to occur, it highlights the inconsistency of industry complying with point source permit limits but exceeding ambient guidelines at the same time.

The industries in the Empangeni area comply with the 1-hour average standard in the immediate areas surrounding their fence line if a there is a 75% reduction in permitted limits of SO_2 by all major industries. However, the ambient areas surrounding industries in Richards Bay namely Hillside, Bayside, Mondi Richards Bay and Foskor, are likely to have maxima that exceed the 1-hour average standard. The 24-hour average standard of 125 $\mu g/m^3$ is exceeded in the Richards Bay area when using the permitted emissions data, but is limited to the industrial cluster when permitted values are decreased by 50%. A 75% reduction in SO_2 is necessary to limit the SO_2 pollutant to the industrial cluster without approaching the neighboring residential areas.

Based on the AQA’s aim to regulate ambient air, the scenarios in this study indicate that all major industries need to implement emission reduction measures in order to comply with ambient air quality standards across their fence lines. However, number of allowable SO_2 exceedances of the 1-hour, 24-hour or annual averages have not yet been finalized The EU and UK standards allow 24 exceedances of the maximum 1-hour average standard and 3 exceedances of the maximum 24-hour average standard per annum. In comparison with the EU exceedance limits, the SO_2 exceedances in the control run comply with EU limits in the residential areas but not in the industrial area. A reduction in the permitted levels of SO_2 of more than 50% is required to comply with the EU exceedance limits in all residential areas, except in the industrial cluster which still exceeds the EU limits even after a reduction of 75% of the permitted industry limits.

The AQA details that municipalities are responsible for point source monitoring; ambient monitoring; establishing local emission limits for priority pollutants; compiling AQMPs and issuing AELs to polluters (South Africa, 2005b). The municipality is consequently responsible for ensuring that the discrepancies between point source emissions and ambient air quality compliance are dealt with in the AEL process of all major industries.

The USEPA strategy to ensure compliance to the ambient air quality standards is through designating polluted areas as non-attainment areas in which there is strict regulation of emitters in these areas (Greenstone M, 2004). The designation of areas into high priority air pollution management areas is dealt with in the DEAT National Framework. The DEAT National Framework details the implementation of the ambient air quality standards based on five classes of air quality impact zones. The zones include target levels which are expected to form 80% of the national air quality standards; alert levels which may be 90% of the national air quality standards and transition levels which may specify the number of years within which ambient standards need to be complied with. The Class 1 areas comply with ambient standards and do not exceed the target levels; the Class 2 areas remain within the alert levels; Class 3 areas remain within the ambient air quality standards but are at risk of exceeding the ambient standards and ambient monitoring is necessary; Class 4 areas exceed ambient standards and will require ambient air quality monitoring and review of the atmospheric emissions license conditions of polluters; Class 5 areas also exceed ambient standards and must be immediately declared as national or provincial priority areas (National Framework, 2007; South African National Standard 69:2005).

In line with the DEAT National Framework classification system, the City of uMhlathuze is likely to fall under a Class 4 zone where ambient concentrations of SO_2 can pose a threat to the health and well-being of people and needs air quality management action plans that have specific timeframes for compliance to the ambient standards. The air quality officer in charge of the municipal area is required to execute the action plans incorporated in the air quality management plan for the municipality by reviewing and enforcing the conditions of AEL's of listed activities (National Framework, 2007). The local municipality has thus far established an ambient monitoring network with the Richards Bay Clean Air Association and conducted an air quality impact assessment of current and permitted SO_2 emissions; however the municipality does not have an air quality management plan incorporating emissions reduction initiatives within uMhlathuze Municipality. The air quality management plans proposed by the municipality through its draft 2007/2008 Integrated Development Plan, includes plans to site future light industries that have little to no air emissions between heavy industry and sensitive areas to act as buffer zones; to investigate the accommodation of all future industry types in Empangeni; and further highlights the high levels of fluoride emissions present in Richards Bay (uMhlathuze Municipality Draft IDP, 2007). The modeled results in this study indicate that there should be more than 75% reduction of the cumulative SO_2 quantity in the uMhlathuze area to comply with the SAAAQS. The measures required for the reduction of SO_2 involve the implementation of emission reduction plans by the major SO_2 emitters.

The National Framework highlights that the air quality impact of an industry will be assessed before an AEL is granted and implies that each industry is required to undertake an air quality specialist study to determine its individual impact on the ambient air quality. The air quality specialist study should include air dispersion modelling to assess the ambient SO_2 concentrations; a health risk assessment based on the results of the dispersion modelling; and mitigation measures necessary to comply with ambient standards via the use of the BPEO (National Framework, 2007). In countries like the United Kingdom (UK) local authorities are required to implement Air Quality Action Plans for areas exceeding ambient air quality standards. These plans must include measures for reducing pollutants to an acceptable level (Beattie *et al*., 2002).

The responsibility of industries is outlined in NEMA section 28 which requires polluters to control and prevent pollution by implementing air pollution prevention plans which can include: installation of air pollution control equipment; upgrading of current equipment; revised maintenance procedures; employee training programmes on air pollution control; revised operating procedures; reviewing process control systems; mitigation systems to limit accidental releases; and a comprehensive air quality management plan (Davis, 2000).

The local authorities in Europe and the UK have implemented limit values for priority pollutants with margins of tolerance for areas that have to reduce pollutant concentrations. The air quality management system incorporates air quality monitoring strategies with sampling methods and quality control procedures that are required. The local authorities need to submit air quality action plans if limit values are exceeded. In order to capacitate the local authorities, the national government provides resources such as guideline documents, internet based information such as monitoring data and an e-mail help desk. Access to air quality information by the public has been undertaken through publishing air quality reports, air quality information leaflets, local newspaper articles, sustainability reports, internet sites and televisions and radio broadcasts. A priority for the different levels of government is the distribution of this information across the government departments in order to allow sufficient communication to decision-makers (Beattie *et al*., 2001). The establishment of cooperative management groups is also essential to address issues collectively as government, non-governmental organizations and industries (Beattie *et al*., 2002).

CHAPTER 5

CONCLUSION

5.1 Summary

This study focused on the contribution of air dispersion modelling to air quality management in the uMlathuze Municipality using SO_2 as an indicator pollutant. The Calpuff model was used for the five scenarios modeled. These varied according to emissions input data and included actual emissions data, permitted emissions data and then a reduction of the permitted emissions data by 25%, 50% and 75%. The results of the Calpuff model were compared to other recent modelling studies conducted in the area and with the South African Ambient Air Quality Standards for SO_2.

The dispersion modelling involved the use of TAPM to extract upper air data. The Calmet model was used to process the meteorological data files from TAPM and these output files, together with the SO_2 emission data were used in the Calpuff model and processed through Calpost. A software tool called Surfer was used to view the ambient SO_2 concentrations on the map of uMhlathuze. Results obtained from two other modelling studies, namely the Airshed and CSIR modelling studies were compared to this study.

The modelled current maximum SO_2 concentrations in the City of uMhlathuze are above the SAAAQS for the 1-hour average in both the residential and industrial areas, and above the 24-hour and annual average standards in the industrial areas. The modelled results for permitted SO_2 emissions from industry emphasize the possibility of higher levels of SO_2 than the current concentrations. The emissions reduction scenarios showed that compliance with ambient standards entailed a 75% reduction of the permitted limits of SO_2 from all major industries. It will be the responsibility of the municipality to drive emissions reduction plans through its AQMP.

The results of this study were compared to the Airshed (2006), CSIR (2004) and the CSIR, (2005) studies which used the HAWK model to assess the ambient concentrations of SO_2. The results are compatible and variations can be attributed to the differences in the SO_2 emissions input used in the modelling exercises. This study produced higher SO_2 concentrations in the control scenario due to the larger SO_2 emissions used. A direct comparison of the results can be made with the Airshed (2006) study in terms of the permitted levels of SO_2. Based on the assumption that the permitted levels of SO_2 for all major industries in the uMhlathuze area have not changed since 2004, there is close correlation between the permitted emission scenario of this study and the Airshed (2006) study.

5.2 Recommendations

- The emissions inventory of the RBCAA must be revised to include the Tongaat-Hulett plant, motor vehicles, domestic fuel burning, ships in the harbour, the local airport, emissions from rail transport, cane burning, veld fires; other small industries within the municipal area that are not defined as scheduled process under APPA; and any other SO_2 emission sources. Other potential sources may be natural sources that include marshes, swamps, and vegetation (Villasenor, 2003). A comprehensive emission inventory will allow for cumulative impact assessments and gain a representative SO_2 emission result in future studies. SO_2 is used as an indicator pollutant which implies that the high levels of SO_2 may be related to high levels of other pollutants emitted by industries in the same area and these should be investigated by the local authority;

- The studies using the HAWK model for decision making purposes should be compared with other models besides Calpuff in order to gain a more representative illustration of the ambient air pollutant concentrations in the uMhlathuze area. The models currently used in South Africa that may be used in the uMhlathuze area is the ADMS (Atmospheric Dispersion Model System) that is used in the City of Johannesburg (Scorgie *et al.,* 2003);
- Emission reduction measures need to be implemented by existing heavy industry in the uMhlatuze area based on the results of this study as well as the results of previous studies (Airshed, 2006a; CSIR, 2004, 2005). The municipality should request AQMPs from all industries detailing their emission reduction measures for SO_2;
- The Vaal Triangle has been declared a priority area based on exceedances of the ambient levels of pollutants which the Minister believes may cause significant negative impacts in the area. According to the definition set out by the National Framework (2007), uMhlathuze Municipality is categorised as a Class 4 area which is defined as areas that exceed ambient standards and require ambient air quality monitoring and review of the atmospheric emissions license conditions of polluters (South African, 2006b; National Framework, 2007);
- The RBCAA air quality monitoring system should become a part of the South African Air Quality Information System (SAAQIS) to enable the ambient monitoring data to become accessible to the public for undertaking and validating future modelling studies (CSIR NILU, n.d; National Framework, 2007);
- The definition of ambient air in the AQA is vague as it does not delineate the area that falls out of the occupational health and safety zone and conversely, the definition of the air regulated by the OHSAct is not explicit (OHSAct, 2004). In order to assess

compliance with ambient standards, the DEAT need to define the ambient atmosphere together with the publication of the DEAT national ambient air quality standards;

- The municipality needs to consider the impact of background sources of SO_2 and other priority pollutants when assessing compliance with ambient standards (Elbir , 2003);
- The locations of the monitoring stations should be sufficiently representative to assess the spatial and temporal distribution of SO_2. The RBCAA stations are currently situated only in Richards Bay and the impacts in Empangeni and Felixton are not measured. The local authority AQMP should aim at ensuring that the ambient air quality standards are met throughout the municipal area and should implement control strategies to prevent air pollution incidents (Chen *et al.*, 2006; Nguyen and Kim, 2006);
- The WHO has proposed a new 24-hour guideline for SO_2 of 20 $\mu g/m^3$ and recommends a gradual decrease in SO_2 guidelines/standards for compliance assessments from 125 $\mu g/m^3$ to 50 $\mu g/m^3$ to 20 $\mu g/m^3$. The Municipality needs to consider this new guideline in the setting of its own ambient air quality limits (WHO, 2005);
- Concern over the health impacts of air pollutants is growing in the uMhlathuze Municipality according to the trend in air quality complaints. It may be necessary to undertake epidemiological studies to determine the health risks posed to humans by noxious gases in the area (Kampa and Castanas, 2007). The relationship between air pollution exposure and ill health can be investigated via an air pollution index system which is based on the relative risk of increased daily mortality and short term exposure to common air pollutants such as SO_2. One of the systems that can be used for the South African context is the Dynamic Air Pollution Prediction System (DAPPS) developed in South Africa (Zunckel *et al.*, 2006).

Air quality in South Africa can only be managed through integrated abatement strategies for source-based emissions control and cost-effective solutions to meet ambient standards that are necessary for the protection of all living organisms (Borrego *et al.*, 2002).

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http://www.weathersa.co.za

http://www.ipcc.ch/

Appendix 1

A comparison of Gaussian plume and Gaussian puff models

Mode	Advantages	Disadvantages	Availability	Suitability for regulatory purposes
Gaussian Plume	Used by many regulatory agencies worldwide. Relatively easy to use. Can incorporate: • plume rise due to momentum and buoyancy; • diffusion; • deposition; • plume reflection from ground and top of the mixing height; • stack-top downwash and building wake effects; • various averaging periods; • the calculation of spatial distribution of ground level pollutant concentrations and deposition rates; • the calculation of pollutant concentration isopleths; and • intermittent releases. Uses well tested and documented dispersion parameters.	Cannot readily incorporate: • realistic wind fields; • instantaneous releases; • complex terrain and associated thermal effects; • low wind speeds; • changing dispersion characteristics with height; • Dispersion in layered atmospheres; and • chemical reactions and removal processes. Needs expert meteorological understanding if used for convective boundary layer calculations. Often overly conservative	Some good examples are available as download files and commercial schemes are available	High for multi-source situations and air quality management planning in noncomplex terrain and for short to medium ranges

	Fairly good to moderate data intensity. Short and medium ranges			
Gaussian Puff	Can incorporate: • realistic wind field simulations including low wind conditions; • various averaging periods; • the calculation of spatial distribution of ground level pollutant concentrations and deposition rates; • the calculation of pollutant concentration isopleths; and • complex terrain. Complex terrain, including street canyon and urban boundary layer effects. Uses well tested and documented chemical transformation mechanisms. Input of emissions for a range of diverse source types. Medium and regional scale.	Often very data intensive. Requires detailed metrological data. Requires specialist meteorological expertise to prepare meteorological input data required.	ome good examples are available as download files and commercial schemes are available	Low for non-complex terrain and short to moderate range applications. High for multi-source situations and air quality management planning in complex terrain environments. High for regional assessments VOC, NOx and CO, as well as means for generating meteorological data governing transport and dispersion of ozone and its precursors.

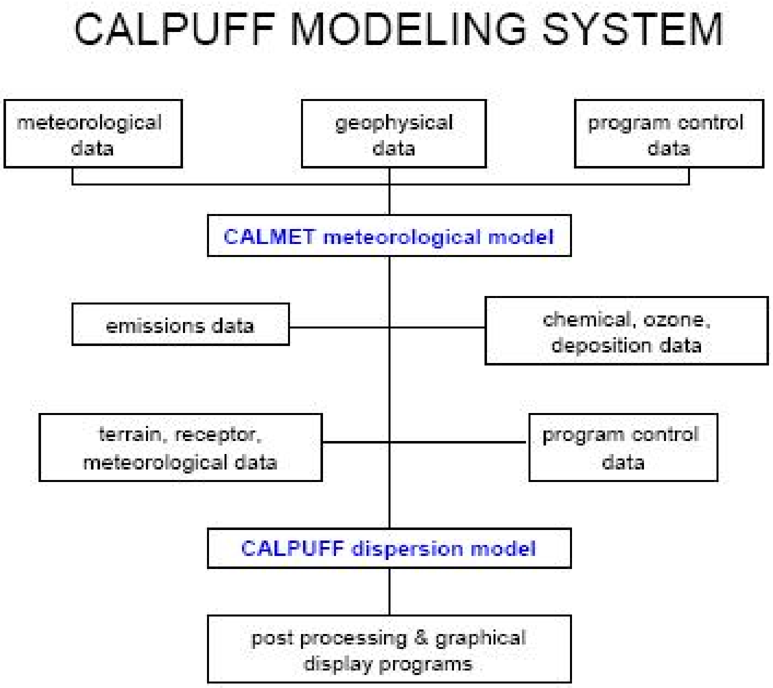
(South African National Standards 1929:2005)

APPENDIX 2

Calpuff Modelling System

Calpuff Characteristics and Computer Requirements

The Calpuff dispersion model was developed by Sigma Research Corporation with the original development of Calpuff and Calmet sponsored by the California Air Resources Board. Calpuff is a transport and dispersion model that the USEPA has proposed as a guideline model for regulatory applications involving long range transport and scenarios involving non-steady state effects. Calpuff operates with a windows based interface with the requirements for typical studies are at least 32 megabytes of memory with more memory required for simulations involving a large number of sources. Calpuff requires 300 kilobytes of memory for a test run with a 10 X 10 horizontal grid, 5 vertical layers and a maximum of 100 puffs. The run time varies and depends on the number of sources in relation to the grid size. A larger number of sources and a larger grid size will have a longer run time. A detailed account of the Calpuff modelling system and operation can be studied in the Earth Tech users guide accessible at http://www.src.com/calpuff/calpuff1.htm (Earth Tech, 2000a).



Calpuff Modelling System (Earth Tech, 2000a)

Appendix 3

Emission Rates of Point and Line Sources for the period 2004-2005

Source Name	**Actual SO_2 Values (g/s)**	**Permitted SO_2 Values (g/s)**
AECI boiler	0.1	0.05
Hillside GTC 1	49	70
Hillside GTC 2	49	70
Hillside GTC 3	49	70
Hillside GTC 4	49	70
Hillside GTC 5	49	70
Hillside FTC	56	80
Hillside FTC2	19	32
Hillside Cast House	8	18
Mondi RB incinerator	8	8
Mondi RB power boiler	94	102
Mondi RB recovery boiler	36	39
Mondi Felix Babcock	7	6
Mondi Felix JT boiler	13	11
Mondi Felix Tosi boilers	15	13
Mondi Felix Oil burner	0.27	0.23
Foskor acid plants	76	200
Foskor Boiler	0.26	0.68
RBM Smokers	0.02	0.03
RBM Char plant	10	42
RBM MSP (Drier)	0.84	1.22
RBM Miscellaneous	0.75	1.08
Tongaat Boiler	10	10
Bayside Primary No 1	10	20
Bayside Primary No 2	10	20
Bayside Primary No 3	10	20
Bayside bake furnace	13	24
Bayside dry scrubber GTC1	59	81
Ticor	0	0.001
Ticor	0	0.001
Ticor	0.001	0.005
Ticor	0	0
Ticor	0.09	0.50
Ticor	0.09	0.50
Ticor	0.002	0.011
Ticor	0.002	0.011
Ticor	0.16	0.92
Ticor	6	36
Ticor	0.69	4
Ticor	0.69	4
Ticor	0	0.001

Source Name	**Actual Values SO_2 (g/s)**	**Permitted Values SO_2 (g/s)**
Hillside Potroom A	2	10
Hillside Potroom B	2	10
Hillside Potroom C	2	10
Hillside Potroom D	2	10
Hillside Potroom E	0.76	9
Hillside Potroom F	0.76	9
Bayside Potroom B & C	17	28
Bayside Potroom A roof	1	8

(CSIR, 2004; 2005; RBCAA COEX, 2004)