MAURITIUS RESEARCH COUNCIL

ASSESSMENT OF IMPACT OF POLLUTION SOURCES ON AIR QUALITY THROUGH MONITORING AND MODELLING

Final Report

December 2007

MAURITIUS RESEARCH COUNCIL

Address:

Level 6, Ebène Heights,
34, Cybercity,
Ebène 72201,
Mauritius.

Telephone: (230) 465 1235
Fax: (230) 465 1239
Email: mrc@intnet.mu
Website: www.mrc.org.mu

This report is based on work supported by the Mauritius Research Council under award number MRC/RUN-0013. Any opinions, findings, recommendations and conclusions expressed herein are the author's and do not necessarily reflect those of the Council.

UNIVERSITY OF MAURITIUS
FACULTY OF ENGINEERING

Assessment of Impact of Pollution Sources on Air Quality through Monitoring and Modelling

by

Prof. T Ramjeawon
and
Mrs A Dindoyal Mahapatra

Project funded by the Mauritius Research Council

Final Report

December 2007

13

1143

ACKNOWLEDGEMENTS

First of all we would like to thank the Mauritius Research Council for funding this project. Our appreciation also goes to the Management of the University of Mauritius for their collaboration and in providing the necessary logistics.

We would like also to thank the following persons:

- Mr S Seebaluck, the Permanent Secretary of the Ministry of Environment for his collaboration and help in conducting the capacity building workshop on Air Modelling
- Dr Prasad Modak, Consultant, for running the Capacity Building Workshop successfully.
- Mr S Ramchurn – Research Assistant on this project during the period October 2000 to February 2001.
- Mr S Ramen, Technician in the CAD-CAM Computer Laboratory for his help in the modeling exercise.

Executive Summary

Industry is under increasing pressure from the regulatory authority and from the general public to control the air pollution from its boilers and particularly that of sulphur dioxide pollution. The measures taken are usually 'adhoc' in nature and there has been no proper scientific methodology to justify the nature of the pollution control interventions that need to be taken by the industry. Air modelling as a planning tool provides a scientific methodology to industries and the regulatory authority to select among the possible options such as raising stack heights, change of fuels, implementing cleaner production (CP) opportunities or installation of wet-scrubbers. The aim of this project was to use an air dispersion model for the selection of air pollution control systems for industrial boilers on the island of Mauritius. Given a number of constraints, it is recommended to start using established and simple modelling methods as the complexity of the more refined models requires a relatively long learning curve to be able to use the model correctly in the Mauritian context. The Industrial Source Complex 3 (ISC3) is recommended for that purpose.

The application of the ISCST-3 model to a single-source case study showed that for the base-case, 1-hour and 24-hour average concentrations of sulphur dioxide have a high probability of not meeting standards at the two receptors. Raising the stack height to 30m does not resolve the problem although there is a significant decrease in the concentrations of SO_2. CP options alone or change in fuel alone also are not enough to resolve the problem. The best option is raising the stack

height to 30 m and either a change of fuel and implementing CP or an investment in a wet-scrubber system.

The application of the ISCST-3 model to a multiple sources case study showed that by increasing the stack heights of all factories to 30 m the problem can be resolved cost-effectively. Implementing CP options will further decrease ambient concentrations. A source apportionment identified that one factory was responsible for 79% of the ambient level of SO_2 and will need to be closely monitored by the regulatory authority.

The regulatory authority needs to review the current standards to include a regulation on stack height as well as to enable it to mandate a change of fuel if need be. Also, there is a need for capacity building on cleaner production opportunity assessments for industrial boilers in Mauritius. An Air Quality Modelling Guideline also needs to be developed by the regulatory authority to ensure consistency in the use of dispersion models for regulatory applications in Mauritius. Recommendations are made to the Department of Environment for the application of air quality modeling in the Mauritian context.

TABLE OF CONTENTS

		Page
Acknowledgements	.....	i
Executive Summary	.....	ii
Table of Contents	.....	iv
List of Figures	.....	vii
List of Tables	.....	ix
Abbreviations	.....	xi
CHAPTER ONE:	**INTRODUCTION AND OBJECTIVES**.....	1
1.1	Background and Justification of Project.....	2
1.2	Aim and Objectives.....	6
	12.1 Aim.....	6
	1.2.2 Objectives.....	6
1.3	Project Investigators.....	6
1.4	Structure of the Report.....	6
CHAPTER TWO:	**INDUSTRIAL AIR POLLUTION IN MAURITIUS**.....	8
2.1	Sources and Types of Air Pollution in Mauritius...	9
2.2	Legislative and Institutional framework.....	11
2.3	Sulphur dioxide pollution from industrial boilers.....	19
CHAPTER THREE:	**THE ISCST3 GAUSSIAN AIR DISPERSION MODEL**.....	23
3.1	Principal of Air Quality dispersion modeling.....	24
3.2	Types of Air Quality Models	26
	3.2.1 Eulerian Models.....	26
	3.2.2 Lagrangian Models.....	28
	3.2.3 Gaussian Plume Models.....	29
3.3	Limitation of Atmospheric Dispersion Models.....	36
3.4	The Industrial Source Complex Model (ISC).....	38

3.5 Applications and comparisons of the ISCST3 Model.....

3.6 Choosing an appropriate model in the Mauritian context..... 44

CHAPTER FOUR: MATERIALS AND METHODS..... 50

4.1 Evaluation Criteria..... 51

4.2 Stack Monitoring data..... 52

4.3 Single Source case study..... 52

4.3.1 Site location and description of Industrial Source..... 52

4.3.2 Stack Characteristics and Emission Factors..... 53

4.3.3 Meteorological data..... 55

4.3.4 Assumptions..... 56

4.4 Multiple Sources case study..... 57

4.4.1 Site locations and description of industrial complex..... 57

4.4.2 Stack Characteristics and Emission Factors 59

4.4.3 Meteorological data 63

4.4.4 Assumptions 64

4.5 Modeling Scenarios 64

4.6 Cost of Pollution Control Systems..... 67

CHAPTER FIVE: RESULTS AND DISCUSSION..... 69

5.1 Predicted Concentrations of Pollutants for single source..... 70
case-study

5.2 Predicted Concentrations of Pollutants for multiple sources..... 80
case-study

5.3 Discussion..... 86

5.3.1 Comparison of Modeling results with Monitoring Data..... 86

5.3.2 Single source case-study..... 87

5.3.3 Multiple source case-study..... 89

5.3.4 General discussion..... 92

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS 93

6.1 Conclusions 94

6.2 Recommendations for Effective Air Quality Modelling in Mauritius 97

6.3 Recommendations for further research 99

REFERENCES 101

APPENDICES

APPENDIX A 106

APPENDIX B 111

APPENDIX C 113

APPENDIX D 115

APPENDIX E 131

APPENDIX F 132

APPENDIX G 135

LIST OF FIGURES

Page

Figure 3.1 Overview of the pollution modeling procedure..... 26

Figure 3.2 A typical plume from an elevated point source..... 31

Figure 4.1 Location of the single source stack in relation to Receptors..... 53

Figure 4.2 Location of the factories and stacks in relation to the 58
residential area

Figure 5.1 Ambient SO2 concentrations at Government school for a..... 72
stack height 21m & 30m for a time period of 1- hour average

Figure 5.2 Ambient SO2 concentrations at Marie Jeannie for a stack 73
height of 21m and 30m for a time period of 1 hour average

Figure 5.3– Ambient SO2 concentration for Govt. School for a stack 75
height of 21m and 30m for a time period of 24 hour average

Figure 5.4 Ambient SO2 concentration at Marie Jeannie for a stack..... 76
height of 21m and 30m for a time period of 24 hour average

Figure 5.5 Ambient SO2 concentration for Govt. School for a stack 78
height of 21m and 30m for Annual average

Figure 5.6 Ambient SO2 concentration at Marie Jeannie for a stack..... 79
height of 21m and 30m for Annual average

Figure 5.7 Graphs of time period of 1 hour average for baseline stack..... 81
height 20m, 30m and CHP

Figure 5.8 Graphs for a time period of 24 hour average for baseline..... 83
stack height 20m, 30m and CHP

Figure 5.9 Graphs of annual average for baseline stack height 20m, 30m and CHP 85

Figure 5.10 Source contribution at. Valentina Village..... 91

LIST OF TABLES

Page

Table 2.1 Main sources and types of industrial air pollutants in Mauritius..... 10

Table 2.2 Ambient Air Quality Standards in Mauritius..... 12

Table 2.3 Comparisons of standards..... 13

Table 2.4 Recommended new set of ambient air quality standards..... 15

Table 2.5 Maximum limits for stack emissions as per Mauritian standards..... 17

Table 2.6 Use of fuel in the industrial sector in 2005..... 19

Table 2.7 Characteristics of HFO used in industry..... 20

Table 2.8 Characteristics and Running cost of different fuels..... 21

Table 2.9 Estimated Emission rates of SO_2 by fuel types..... 21

Table 3.1 Commonly used Atmospheric Dispersion Models..... 32

Table 3.2 Characteristics of the two versions of ISC models..... 39

Table 4.1 Evaluation Criteria level for sulphur dioxide concentrations..... 51

Table 4.2 Description of factories in and around VIE..... 59

Table 4.3 Modelling Scenarios..... 64

Table 5.1 Predicted sulphur dioxide modelling concentrations for single source (1 hour average)..... 70

Table 5.2 Predicted sulphur dioxide Modelling concentration for single source (24 hour average)..... 74

Table 5.3 Predicted sulphur dioxide modelling concentration for single source(Annual average)..... 77

Table 5.4 Summary of results of sulphur dioxide modelling for multiple..... 80
source (1 hour average (annual average)

Table 5.5 Summary of results of sulphur dioxide modelling for multiple..... 82
source (24 hour average).

Table 5.6 Summary of results of sulphur dioxide modelling for multiple..... 84
source (annual average)

Table 5.7 Estimated cost of pollution control options for single source..... 88

Table 5.8 Total Cost of pollution control options for multiple sources..... 90

ABBREVIATIONS

AQM	Air Quality Model
CEB	Central Electricity Board
CHP	Central Heat Power
CO	Carbon Monoxide
CP	Cleaner Production
DBM	Development Bank of Mauritius
EIA	Environment Impact Assessment
GPM	Gaussian Plume Model
HCL	Hydrogen Chloride
HFO	Heavy Fuel Oil
ISC	Industrial Source Complex
ISC3	Industrial Source Complex 3
ISCLT	Industrial Source Complex Model Long- term
ISCST	Industrial Source Complex Model short-term
Km	Kilometre
Ktoe	Thousand tonne of oil equivalent
MOE	Ministry Of Environment
NOx	Oxides of Nitrogen
O_3	Ozone
Pb	Lead
PM_{10}	Particulate Matter of diameter less than 10 microns

Ppm	Parts per Million
R & D	Research and Development
R.s	Redwood Seconds
SO_2	Sulphur Dioxide
TSP	Total Suspended Solid
US	United States
USEPA	United States Environment Protection Act
VIE	Valentina Industrial Estate
WHO	World Health Organisation

CHAPTER ONE

INTRODUCTION & OBJECTIVES

CHAPTER ONE: INTRODUCTION AND OBJECTIVES

1.1 Background and Justification of Project

Air pollution threatens the human health and the gain in economic growth of any country. The island of Mauritius has undergone rapid economic development over the past thirty years. Without any endowment of natural resources, Mauritius is dependent on imported fossil fuels for its energy needs. Because of this dependence on fossil fuels and because of its economic structure, the emissions of pollutants from combustion in the industrial, transport and power generation sectors will inevitably grow as the economy develops. There is a clear link between air pollution and the use of fossil fuel in the Mauritian economy.

During the late 1980's the industrial sector (particularly the textile industry) expanded rapidly and several industrial estates were established across the island. Some of these industrial estates were located in the vicinity of residential areas mainly to take advantage of the available infrastructure and labour. Rising emissions levels caused localised air quality problems due to

- High dependence on fossil fuels and poor energy efficiency in industry
- Poor fuel quality
- Lack of regular air quality monitoring
- Lack of enforcement capacity
- Absence of air pollution Control technologies
- Insufficient application of the Cleaner Production concept

- ❖ Lack of air quality modelling expertise.

With increasing importance being attached to the quality of life as the standard of living improves, there are nowadays more and more complaints from inhabitants residing downwind of stacks of factories. Many of these complaints relate to sulphur dioxide pollution through the combustion of heavy fuel oil in industrial boilers. Industries are nowadays under increasing pressure to control their stack air emissions. The latter can be controlled through a number of options such as by raising stack heights, changing to cleaner fuels, cleaner production, and installation of pollution control equipments, or centralised heat and power systems. Because of the many options, proper air quality management downwind of factories requires an integrated approach consisting, *inter-alia*, of:

- ❖ Use of monitoring and modelling to establish an emissions inventory of key pollutants and emission sources
- ❖ Use of dispersion modelling to determine the impacts of the emissions on ambient concentrations
- ❖ Identification of technically feasible abatement options and calculation of their costs
- ❖ Estimation of the impacts of these abatement alternatives on ambient air quality and human health
- ❖ Determination of priority measures with high benefit-cost ratios

An Air Quality Model (AQM) is a useful tool that is becoming popular worldwide in predicting the possible impacts of a pollutant emitted from an industrial stack. It can be used amongst others for:

- Sitting/zoning of developmental projects,
- Deciding on buffer zones,
- Setting emission and ambient air quality standards,
- Deciding on stack heights,
- Making choice of fuel,
- Recommending air pollution control technology,
- Preparing for emergency response due to leaks/accidental release,
- Assessing impact on human life and natural resources.

Air modelling is an important management and planning tool, but which is not being effectively used either by industry or by the regulatory authority in pollution control. Its main application in Mauritius during the last decade has been in the preparation of EIA reports by foreign consultants for the installation of Electric Power Plants. The different constraints for its wider use have been as follows:

- Lack of technical know-how among local consultants and staff of the Ministry of Environment in the field of air modelling
- Unavailability of processed and representative meteorological data
- Guidelines have not yet been formulated by the regulatory authority for the use of air quality models.

This projects aims to use an air dispersion model to help in the selection of cost-effective pollution control systems for industrial boilers in Mauritius. Over the past two decades, the Industrial Source Complex (ISC) model has been the preferred model for most regulatory modelling applications around the world. This model is being replaced by the more sophisticated AERMOD model as the USEPA's preferred model for regulatory applications in the U.S. The AERMOD model is however quite complex and requires a lot more inputs (especially advanced meteorological and terrain data) that would be difficult for Mauritius to apply. Given such constraints, and as recommended in this report, the country should start using established and simple modelling methods as the complexity of the more refined models requires a relatively long learning curve to be able to use the model correctly. Simple models such as Industrial Source Complex 3 (ISC3) have a relatively good history for regulatory applications and their strengths and weaknesses are well understood. The ISC3 Models are steady-state Gaussian plume models which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial complex and which are relatively easy to use and rely on standard, inexpensive meteorological data inputs from one station.

1.2 Aim and Objectives

1.2.1 Aim

The aim of this project is to use an air dispersion model for the selection of cost-effective sulphur dioxide pollution control systems for industrial boilers on the island of Mauritius

1.2.2 Objectives

The specific objectives of this project are as follows:

- To carry out a literature review on the types of regulatory air dispersion models available and subsequently choose one suitable for the Mauritian context.
- To predict the ambient sulphur dioxide concentration in the residential areas downwind of a single industrial boiler and downwind of an industrial estate consisting of multiple industrial boilers under different modelling scenarios.
- To determine the optimum air pollution control system in each case based on a cost-benefit analysis.
- To recommend an air quality modelling guideline for the regulatory authority in Mauritius
- Organise a Capacity Building Workshop on "Air Quality Modelling"

1.3: Project Investigators

Professor Toolseeram Ramjeawon was the Principal Investigator for this project. Mrs A.Dindoyal-Mahapatra carried out her M.Phil study as part of this project during the period 2003 to 2007 and the results presented are from her M.Phil dissertation.

1.4 Structure of the Report

This report unfolds as follows:

Chapter 2 gives an overview of the types and sources of industrial pollution in Mauritius and describes the legislative and institutional framework for air pollution control. It also reviews the application of air quality models in Mauritius.

The principles, types and limitations of atmospheric dispersion modelling are presented in **Chapter 3**. The different types of Gaussian plume models are presented and a more elaborate description and types of application of the Industrial Source Complex model are given.

Chapter 4 describes the methodology adopted in this study. The stack characteristics and location stack emission factors and meteorological variables input for the model are described. The modelling scenarios and the cost of pollution control options are also presented.

Chapter 5 gives the results of the predicted concentrations under the different modelling scenarios for the two cases. The most cost-effective system is determined.

Chapter 6: It summarizes the conclusions of the study and gives recommendations on further research and on a modelling guideline for the regulatory authority in Mauritius.

Appendix F summarizes the capacity building workshop on Air Quality Modelling carried out in April 2005 .

CHAPTER TWO

INDUSTRIAL AIR POLLUTION CONTROL IN MAURITIUS

CHAPTER TWO

INDUSTRIAL AIR POLLUTION CONTROL IN MAURITIUS

2.1 Sources and Types of Air Pollution in Mauritius

Anthropogenic air pollution in Mauritius originates from large stationary sources (power plants and sugar factories), small stationary sources (stone crushing plants, industrial boilers and waste incinerators) and mobile traffic sources. Many of these sources are closely related to the consumption of fossil fuels energy. Energy consumption increased by 2.8% from 815 Ktoe in 2003 to 838 Ktoe in 2004. The largest consumers were transport and manufacturing sectors which accounted for 49% and 31% of the total energy consumption, (MOE, 2004). Appendix A gives main energy indicators imports of energy sources, fuel input, and final energy consumption by sector and type of fuel, percentage share of final energy consumption by sector for the republic of Mauritius between the year 1996- 2005. Table2.1 lists the main sources and types of industrial air pollutants in Mauritius.

Table 2.1: Main sources and types of industrial air pollutants in Mauritius

Source	Type of Emissions
1. Bagasse/Coal Power Plants in sugar factories	Particulate Matter, CO, SO_2,NO_X
2. CEB Oil Power Plants	NOx, SO_2
3. Stone Crushing Plants	Particulate Matter, dust
4. Industrial boilers	NOx, SO_2, CO, Particulate matter
5. Medical waste incinerators	NOx, SO_2, Particulate Matters, CO, HCL, hydrocarbons, Dioxins and Furans.

During the late 1980's the industrial sector in Mauritius (particularly the textile industry) expanded very rapidly. In a time of unemployment and an absence of environmental management, there was practically no opposition to the establishment and decentralization of industrial estates, even when these were located in the vicinity of residential areas. The availability of infrastructure (electricity, water, sewage system) gave no other alternative to the authorities than to locate these close to residential areas. The majority of industrial estates in Mauritius were developed with little environmental considerations given that Environmental Impact Assessments (EIAs) have only been required for industrial estates since the enactment of the Environmental Protection Act in 1991. Poor sitting of the estates and later expansion of residential and industrial sites have resulted in close proximity of residential housing to some of the industrial estate, exacerbating the impacts of industrial pollution on nearby residents. The impacts

arising from industrial estates are caused mainly due to emissions of particulate matter and sulphur dioxide form the use of heavy fuel oil for combustion that contains high percentage of sulphur, the low level of stack heights, the absence of pollution control equipment on the stacks and the absence of any buffer zone between the industries and the neighborhood population. (Modak, 2002)

2.2 Legislative and Institutional Framework

The Ministry of Environment is the principal regulatory body that looks after environmental issues. The regulatory process is operated through various instruments such as Environment Impact Assessment (EIA) and ambient emission/effluent standards. MOE regulates approvals for sittings (if EIA is applicable) and enforces the emission/effluent standards. The enforcement of these instruments and various provisions at MOE is unfortunately weak.

The Environment Protection Act of 2002 provides the framework for administration of environmental protection in Mauritius. Key areas included the creation of enforcing agencies, provisions to allow the formulation of national standards by means of regulations, policies for enforcement and environmental impact assessment.

The Environment Protection (Standards for Air) Regulations 1998 provide for maximum limits for criteria pollutants such as Total Suspended Particles (TSP), Particulate Matter of diameter less than 10 microns (PM_{10}), Sulphur Dioxide

(SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO), Lead (Pb) and Ozone as per the Second Schedule to the Environment Protection (Standards for Air) Regulations 1998 (see Table 2.2).

Table 2.2: Ambient Air Quality Standards in Mauritius (Source: MOE, 2002)

Ambient Pollutant	**Standard ($\mu g/m^3$) maximum**	**Averaging Time**	**Measurement Method***
Total suspended particles	*150* *50*	*24-hour* *Annual average*	*Hi-volume Sampler*
PM_{10}	*100*	*24-hour*	*Hi-volume Sampler*
Sulphur Dioxide	*350* *200* *50*	*1-hour* *24-hour* *Annual average*	*Fluorescence SO_2 Analyser, Colorimetry*
Nitrogen Dioxide	*200*	*24-hour*	*Sodium Arsenite, Chemiluminescence*
Carbon Monoxide	*25,000* *10,000*	*1-hour* *8-hour*	*Nondispersive Infrared Photometry*
Lead	*1.5*	*3-month average*	*Hi-volume Sampler with Atomic Absorption*
Ozone	*100*	*1-hour*	*Ozone Analyzer, Chemiluminescence*

Table 2.3 shows a comparison between worldwide ambient air quality standards and the Mauritian standards:

Table 2.3: Comparisons of standards (Source: MOE, 2002)

Summary of key parameters for Ambient Air Quality Standards of Criteria Pollutants**							
				EU[a]			
	Averaging Times	**Mauritius**	**World Bank**	**Limit**	**No of exceedances permitted per year**	**WHO (as at 2000)**	**USEPA (actual)**
NO_2	99.8th percentile of hourly averages	-	-	200	18	-	-
	1-hour average	-	-	-	-	200	-
	24-hour average	200	150	-	-	-	-
	Annual average	-	100	40	-	40	100
SO_2	10-minute	-	-	-	-	500	-
	1-hour average	350	-	-	-	-	-
	99.7th percentile of hourly averages	-	-	350	24	-	-
	24-hour average	200	150	-	-	125	375

	99.2nd percentile of hourly averages	-	-	125	3	-	-
	Annual average	50	80	20	for ecosystems	50	80
PM_{10}	24-hour average	100	150	-		no guideline but a value of risk per unit concentration	150
	90th percentile of 24-hour averages	-	-	50	35		-
	Annual average	-	50	40	-		50
CO	15-minutes	-	-	-	-	100 000	-
	30-minutes	-	-	-	-	60 000	-
	1-hour average	25 000	-	-	-	30 000	40 000
	8-hour average	10 000	-	-	-	10 000	10 000
	Running 8-hour average	-	-	10 000	-	-	-
TSP	24-hour average	150	-	-	-	-	-
	Annual average	50	-	-	-	-	-
Pb	3-month average	1.5	-	-	-	-	1.5
	Annual average	-	-	0.5	-	0.5	-
O_3	1-hour average	100	-	-	-	-	235[b]
	8-hour average	-	-	--	-	120	157[c]

** All values are in $\mu g/m^3$

a EU guidelines as per directive 96/62/EC and its daughter directive 99/30/EC

b not to be exceeded in more than one occasion per year

c 3-year average of annual 4th highest daily maximum 8-hour ozone concentration

\- Limits not specified

The following major shortcomings can be identified in the Mauritian standards:

- ❖ Absence of frequency of monitoring for the standards
- ❖ Absence of use of statistical methods in standards setting
- ❖ Standard temperature and pressure are not specified

A Technical Committee was set up by the Ministry of Environment in 2004 to review the standards. The Committee recommended a new set of ambient air quality standards as per Table 2.4. These standards have not yet been approved by Government and are expected to be enacted near the end of 2007.

Table 2.4: Recommended new set of ambient air quality standards
(Source: MOE, 2002)

Criteria Pollutant	Limit ($\mu g/m^3$)	Averaging Time	Frequency of Monitoring
TSP	50	Annual	An annual average for 104 measurements taken twice a week for a period of 24 hours at uniform intervals
	150	24-hour	24-hourly values should be met 98% of the time in a year and it should not exceed 2 consecutive days.
PM_{10}	100	24-hour	24-hourly values should be met 98% of the time in a year and it should not

			exceed 2 consecutive days.
SO_2	50	Annual	An annual average for 104 measurements taken twice a week for a period of 24 hours at uniform intervals
	150	24-hour	24-hourly values should be met 98% of the time in a year and it should not exceed 2 consecutive days.
	350	1-hour	The maximum value should never be exceeded
	500	10-minutes	The maximum value should never be exceeded
NO_2	40	Annual	An annual average for 104 measurements taken twice a week for a period of 24 hours at uniform intervals
	200	1-hour	The maximum value should never be exceeded
CO	10 000	8-hour	8-hourly values should be met 98% of the time in a year and it should not exceed 2 consecutive days.
	25 000	1-hour	The maximum value should never be exceeded
Pb	1.5	3-month	An average of at least 3 measurements per week over a period of 3 months.
O_3	100	1-hour	The maximum value should never be exceeded

Maximum limits for stack emissions of air pollutants and smoke (based on opacity) as per the Mauritian Standards are given in Table 2.5.

Table 2.5: Maximum limits for stack emissions as per Mauritian standards (Source: MOE, 2002)

Pollutant	**Applicable to**	**Standard**
(i) Smoke	All stationary fuel burning source	Ringelmann No. 2 or equivalent opacity (not to exceed more that 5 minutes in any period of one hour)
(ii) Solid particles	(a) Any trade, industry, process, industrial plant or fuel-burning equipment (b) Any existing trade, industry process or industrial plant using bagasse as fuel	200 mg/m^3 400 mg/m^3
(iii) Sulphuric acid mist or sulphur trioxide	(a) Any trade, industry or process (other than combustion processes and plants for the manufacture of sulphuric acid) (b) Any trade, industry or process in which sulphuric acid is manufactured	120 mg/m^3 as sulphur trioxide 30 000 mg/m^3 as sulphur trioxide
(iv) Fluorine compounds	Any trade, industry or process in the operation of which fluorine, hydrofluoric acid or any inorganic	100 mg/m^3 as hydrofluoric acid

	fluorine compounds are emitted	
(v) Hydrogen Chloride	Any trade, industry or process	200 mg/m^3 as hydrogen chloride
(vi) Chlorine	Any trade, industry or process	100 mg/m^3 as chlorine
(vii) Hydrogen sulphide	Any trade, industry or process	5 ppm as hydrogen sulphide gas
(viii) Nitric acid or oxides of nitrogen	Any trade, industry or process in which the manufacture of nitric acid is carried out	2 000 mg/m^3 as nitrogen dioxide
(ix) Nitric acid or oxides of nitrogen	Any trade, industry or process other than nitric acid plant	1 000 mg/m^3 as nitrogen dioxide
(x) Carbon monoxide	Any trade, industry or process	1 000 mg/m^3 as carbon monoxide

The formulation of these standards, were based mainly on the Singaporean standards in the 1990s. The following shortcomings can be identified:

- ❖ Absence of sulphur dioxide emission levels
- ❖ Absence of reference conditions.
- ❖ Absence of any regulations on stack height

The enforcement capacity from the Ministry of Environment is currently weak and there is no routine environmental monitoring programme around industrial estates that has built a database. The MOE is equipped with one mobile ambient air quality monitoring station which is used to monitor hotspots only in emergency situations.

It is to be noted that a pollution control line from the development Bank of Mauritius (DBM) Ltd is available to industries which can fund up to Rs 1.5 million at 10% interest per annum with a repayment over 4 years.

2.3 Sulphur dioxide pollution from industrial boilers

Table 2.6 shows the use of each fuel type by the industrial sector in Mauritius

Table 2.6: Use of fuel in the industrial sector in 2005
(Source: Digest of Environmental Statistics, 2005)

Primary fuel	**Tonnes**
Coal	23,162
Diesel	41,127
Fuel oil	46,763
LPG	3,904
Total	114,956

Industrial Boilers are typical of textile factories in industrial estates running on a steam pressure of around 7 bars. For capacity greater than 5 tons of steam per hour, diesel and gas are often used to fire the boilers and which are less prone to emission of air pollutants. The probability of using heavy fuel oil with high sulphur content rather than diesel or gas is greater for boilers exceeding 5 T of

steam per hour. Most boilers in factories have capacities greater than 10 tons of steam per hour.

Heavy fuel oil (HFO) 1500, 1000 and 600 R.s(Redwood seconds) are typically used in industrial boilers. HFO of a viscosity of 1000 R.S. is obtained by blending HFO 1500 R.S. with diesel. Table2.7 shows the proportions of heavy fuel oil and diesel used in the preparation of HFO of 1000 and 600 R.s respectively.

Table 2.7: Characteristics of HFO used in industry (Source: Rajcoomar, 2004)

HFO Viscosity (R.S.)	**% HFO 1500 R.S.**	**% Diesel**
1000*	*95*	*5*
600	*88*	*12*

Table 2.8 below summarizes the total running cost of the different fuels and their corresponding sulphur content.

Table 2.8: Characteristics and Running Cost for different fuels
(Source: Rajcoomar, 2004)

Type of Fuel	Sulphur Content (%wt)	Amount of fuel to produce one ton of steam	Cost of producing one ton of steam(Rupees)
HFO 1500RS	3.5	65 Lt	519
HFO 1000RS	3.33	65 LT	534
HFO 600RS	3.12	64 Lt	545
Coal	0.9	108 Kg	208
Diesel	0.24	70.5 Lt	763
LPG	0	54.8 Kg	963

Table 2.9 below shows an estimate of the SO_2 emission rate from the different types of fuels based on their level of consumption.

Table 2.9: Estimated Emission rates of SO_2 by fuel type

Type of Fuel	Sulphur Content (%wt)	Annual Fuel usage Tons/ year	SO_2 Emission Tons / year	SO_2 Emission rate g/sec
Coal	0.9	23,162	41.69	1.39
Diesel	0.24	41,127	19.74	0.626
Fuel Oil	3.5	46,763	327.34	10.38
LPG	0	3,904	0	0

No factories have installed any air pollution control equipment so far on their stack for SO_2 control. A significant source of sulphur dioxide pollution therefore comes from the combustion of heavy fuel oil with high sulphur content in industrial boilers.

During the last decade, as the standard of living of the average Mauritian increases, there have been an increasing number of complaints to the Ministry of Environment regarding pollution from industrial boilers in Mauritius. Industry is under increasing pressure from the regulatory authority and from the general public to control the air pollution from boilers. The measures taken are usually 'adhoc' in nature and there has been no proper scientific methodology to justify the nature of the pollution control interventions that need to be taken by the industry. This project aims at being a scientific approach in the form of an air dispersion model to help industries (and regulatory authority) in the selection of pollution control options.

CHAPTER THREE

THE ISCST3 GAUSSIAN AIR DISPERSION MODEL

CHAPTER THREE

THE ISCST3 GAUSSIAN AIR DISPERSION MODEL

3.1 Principle of Air Quality dispersion modelling

Atmospheric dispersion modelling is a computer-based technique used for calculating downwind concentrations of pollutants which may result from emissions to air. Atmospheric dispersion models use a series of equations to estimate air pollutant concentrations at given locations downwind of the emission source(s), taking into account emission rates, the source type (e.g. point, area, volume or line source), meteorological conditions, terrain effects, building wake effects and a range of other factors.

Dispersion modelling is usually the only way to assess the potential effect of an emission source which has not been constructed. Where the source exists, the benefits of modelling over ambient monitoring include the ability to estimate ground level concentrations at many hundreds of locations for the cost of a single set of measurements. In comparison, a monitoring program would have to be undertaken over significant period of time (ranging from months to years depending on the frequency of sample collection) and at a number of locations to provide anywhere near the same level of information about downwind pollutant concentrations. With modelling techniques it is also possible to investigate the relative contributions of individual sources to cumulative downwind

concentrations, and to predict the effects of changes in emission rates and release parameters (stack heights, etc) on downwind concentrations.

The complexity and sophistication of a dispersion modelling study can vary widely from a simple screening exercise providing an estimate of potential worst case concentrations resulting from emissions from a single source, to a detailed study of terrain and building wake effects, plume interactions and chemical reactions within the plume itself. The degree of complexity of a given modelling study should reflect the complexity of the emission source(s) and surrounding area and the potential for significant off-site effects.

Dispersion modelling was developed in the 1950s for predicting background pollutant concentrations from chimneys. Since then, the science of dispersion modelling has rapidly developed and, although many models are still based on the classic algorithms, the calculations have been eased through software. Figure 3.1 below gives a brief outlook of the atmospheric dispersion model.

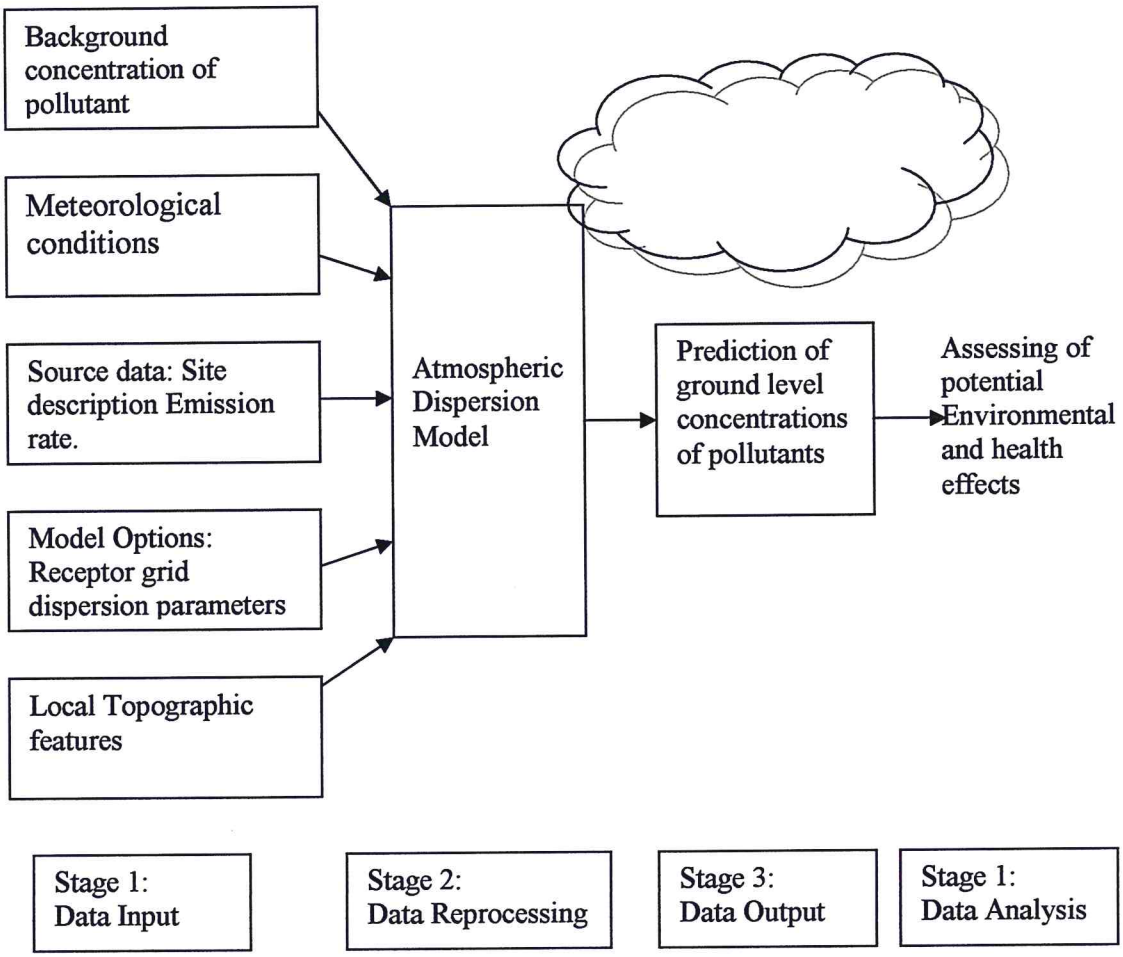


Figure 3.1: Overview of the pollution modelling procedure
(Source: MOE, New-Zealand, 2002)

3.2 Types of Air Quality Models

3.2.1 Eulerian Models:

The Danish Eulerian model is a large air pollution model for studying different phenomena connected with transport of air pollutants in the atmosphere. All important physical processes (advection, diffusion, deposition, emissions and chemical reactions) are represented in the mathematical formulation of the model. All important chemical species (sulphur pollutants, nitrogen pollutants, ammonia-

ammonium, ozone, as well as many radicals and hydrocarbons) can be studied by the model. The Eulerian models are commonly used for the simulation of large scale and long range inter-regional transport of pollutants. The transport, diffusion, transformation, and deposition of pollutant emissions in each cell are described by a set of mathematical expressions in a fixed coordinate system. These equations can then be solved either by analytical methods providing exact solutions or by numerical methods providing approximate solutions. There are several types of Eulerian models, which have been developed. The most common ones are as follows:

- **Single Box Model**

  The Single Box Model is the simplest form of atmospheric dispersion models, which can be used to estimate pollutant concentration from an area source. The single box model is used for both inert and reactive pollutants. In general the box model can be used to obtain order-of-magnitude estimates of ambient pollution levels. The limitation of the model is that it cannot account for the changes in wind speeds and directions with height.

- **Slug Model**

  The slug model is used as an improvement of the single box model, especially during stagnation episodes.

- **Multi-box Model**

  In this model the variation of the average concentration in a box with time is determined by pollutant flux through the sides of the box and the

pollutant emissions from all sources inside the box. The major limitations of this multi box approach are that it neglects horizontal diffusion and assumes instantaneous mixing. It is, however, a computationally fast method and may provide satisfactory, cost-effective answers, especially in regions where detailed meteorological and emission information is not available (Bedassy, 2005)

3.2.2 Lagrangian Models

The basic concept of Lagrangian models is the observation of individual particles, which is why these models are also referred to as Lagrangian particle dispersion models. In the case of atmospheric dispersion the term *particle* denotes any air pollutant or any buoyant substance in the air. The models use winds and fluctuation caused by turbulence to predict the pathways of individual particles or air volumes in each time step. For this reason, these models are also referred to as trajectory models. Particles or air volumes, respectively, may be released from any number of locations. The type of source, e.g. point or line source has no influence. Lagrangian trajectory models are appropriate for the description of dispersion in complex meteorological situations or heavily structured topography. Deposition effects can be considered each time a particle trajectory touches the ground.

The different types of Lagrangian models include the following:

Lagrangian Box Model

The Lagrangian box model is often used for photochemical modelling. In this case, the model provides average time-varying concentration estimates along the box trajectory. The major shortcoming of the approach is the assumption that wind speed and directions are constant throughout. As compared to the Eulerian box model the Lagrangian box model can save computational cost as they perform computations of chemical and photochemical reactions on a smaller number of moving cells instead of at each fixed grid cell of Eulerian models.

❖ **Segmented Plume and Puff Models**

These models have been developed in order to treat time-varying transport conditions, which is, change in wind speed and direction with time. In the segmented plume approach, the plume is broken up into independent elements. This model is used only for windy conditions that are wind speeds greater than 1 m /s. theoretically, the puff model can simulate calm or low wind conditions.

3.2.3 Gaussian Plume Models

The most commonly used model for the dispersion of gaseous air pollutants is the Gaussian model, which have been developed by Pasquill. The gases dispersed in the atmosphere are assumed to exhibit ideal gas behavior. The principles on which the model is based are as follows:

- ❖ The predominant force in pollution transport is the wind and pollutants move predominantly downwind.
- ❖ The greatest concentration of pollutant molecules is along the plume centre line.

- ❖ Molecules diffuse spontaneously from regions of high concentration to regions of lower concentration.
- ❖ The pollutant is emitted continuously, and the emission and dispersion process is at steady state.

The Gaussian plume formula provides a better representation of reality if conditions do not change rapidly within the hour being modeled that is conditions are reasonably steady and do not deviate significantly from the average values for the hour being modeled. The Gaussian representation of dispersion described above is simplistic and as such, should only be applied to a limited range of conditions.

The Gaussian plume models should be used only to model:

- ❖ Inert pollutants
- ❖ Pollutants that behave like gases that is deposition is not significant
- ❖ Time periods of 1 –hour or greater
- ❖ Effects in the range from a few hundred metres to no more than 10m
- ❖ Non-complex terrain
- ❖ Situations where steady-state meteorological conditions are applicable.

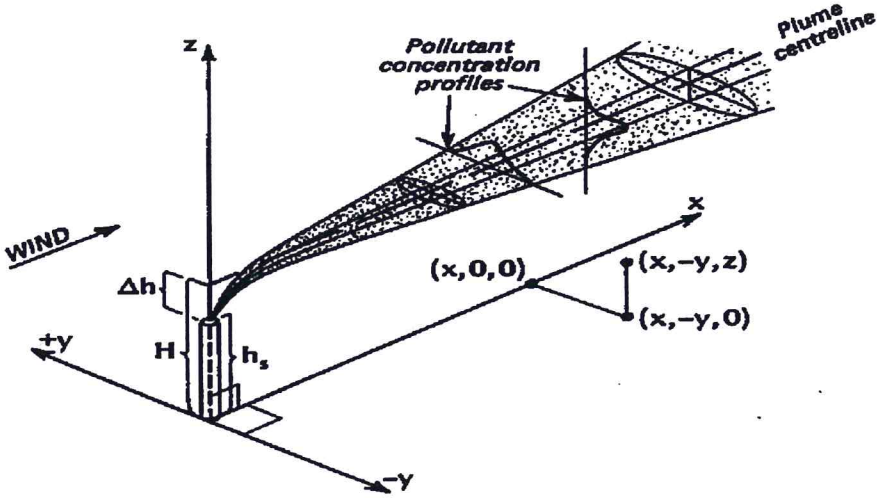


Fig 3.2 **A typical plume from an elevated point source.**

Note the plume rise (?h), and the normal (Gaussian) distribution of pollutant concentrations in tl horizontal and vertical (after Oke, 1987).

The ground level concentrations of SO_2 from the stack at different downwind distances and at relevant atmospheric stability were predicted using the Gaussian Normal Model described by Garg (1999):

$$C_x = \frac{Q}{\pi u \sigma_z \sigma_y} e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z^2}\right)}$$

Where:

C_x = Concentration of pollutant (SO_2) in g/m^3

Q = pollutant emission rate (g/s)

H = Effective height of stack (m) (or height of stack + Plume rise)

σ_z = Plume's standard deviation in vertical direction (m)

σ_y = Plume's standard deviation in cross-wind direction (m)

u = mean wind velocity (m/s)

x and y = downwind and cross-wind horizontal distances, respectively (m)

A large number of atmospheric dispersion models based on the Gaussian model have been developed, each designed to meet a specific application or need. A list of the dispersion models commonly used around the world along with their main features is given in Table 3-1. Many of these models have been developed by US regulatory authorities for use as regulatory models. The most widely used of a new generation of models in the UK, ADMS, has been the principal model used by the UK Environment Agency since 1995.Ambient air quality impact modelling is rapidly gaining importance as a tool for regulatory programs. As such, current computer models are in a state of flux, with developers working to increase software accuracy and efficiency.

Table3.1: Commonly Used Atmospheric Dispersion Models

MODEL	DESCRIPTION
AERMOD	The next generation ISC model, released in December 1998.AERMOD is a suite of models (includes met pre-processor and terrain processor) to incorporate both simple and complex terrain, surface, elevated sources and irregularly shaped area sources. (Incorporates PRIME building downwash calculations). Recommended to replace ISC. Soon to be recommended as the model of choice by the US EPA.US EPA and the American Meteorological society Aermod is a Gaussian steady-state model which was developed with the main intention of superseding ISCST3. It contains improved algorithms for convective boundary

	layers and includes more sophisticated dispersion theory as well as more advanced terrain adjustment scheme. However the model does not include either wet or dry deposition. Another drawback is that AERMOD requires too many input data that have to be processed in a special manner and Mauritius meteorological service is not yet equipped with these softwares.
ISCST	Industrial Source Complex Short-Term. A steady state Gaussian plume model which can be used to calculate short-term pollutant concentrations from a combination of point, area and/or volume sources. Note: In June 1999, the latest version of ISCST3 was modified to incorporate a new set of algorithms for advanced treatment of building downwash calculations. This model is known as ISC-PRIME, and is expected to be given regulatory status soon. Developed under contract for the US EPA.
AUSPLUME	A steady state Gaussian plume model which can be used to Calculate short-term pollutant concentrations from a combination of point, area and/or volume sources. (Based on the ISCST model).
CALINE	Californian Line Model. Calculates ambient concentrations of vehicle pollutants near highways, major roads, intersections and parking lots. Developed under contract for the US EPA.
CALPUFF	Multi-layer, multi-species non-steady-state puff dispersion model. Includes algorithms for longer range effects (such as pollutant

	removal due to wet scavenging and dry deposition, chemical transformation, and visibility effects of particulate matter concentrations).Developed under contract for the US EPA .CALPUFF is a multi-layer, multi-species non-steady –state Gaussian puff model which is able to stimulate the effects of time and space-varying meteorological conditions on pollutant transport.
CTDM, CTSCREEN	Complex Terrain Dispersion Model. A multiple source model Used for calculating ground level concentrations in complex terrain situations. CTSCREEN utilises screening met data. Developed under contract for the US EPA CTDMPLUS is a US EPA regulatory model developed specially for tall point-sources in areas of complex terrain. CTDMPLUS is a steady-state plume model that contains algorithms that enable a more physically realistic description of vertical dispersion and air flow around complex terrain features. However it is not frequently used any more due to its specialized meteorological requirements and its applicability only to tall point sources.
ISCLT	Industrial Source Complex Long-Term. A steady state Gaussian plume model which can be used to calculate long-term (e.g. 1 month, 3 month or annual averages) pollutant concentrations from a combination of point, area and/or volume sources. Developed under contract for the US EPA.

SCREEN	A screening model developed to analyze dispersion from a stack, flare or area source in simple and complex terrain. Developed under contract for the US EPA.
UK ADMS	*(Atmospheric Dispersion Modelling system) is* an advanced model for calculating concentrations of pollutants emitted both continuously from point, line, volume and area sources, and discretely from point sources. The model includes algorithms which take account of the following: effects of main site building; complex terrain; wet deposition, gravitational settling and dry deposition; short term fluctuations in concentration; chemical reactions; radioactive decay and gamma-dose; plume rise as a function of distance; jets and directional releases; averaging time ranging from very short to annual; condensed plume visibility; meteorological preprocessor. ADMS is actually a suite of models that may be used for screening, point sources or up to large urban scale airshed modelling. Contains up to date boundary layer treatment for more realistic predictions of high stacks under convective conditions. Model available for purchase in sections at varying (and considerable) sums. Unofficially recommended by the UK Environment Agency. Cambridge Environmental Research Consultants.

While ADMS and AERMOD both use atmospheric boundary scaling (h for the boundary layer depth and LMo for the Monin-Obukhov length) which considers the vertical structure of the atmospheric boundary layer, ISC and ISC-Prime use. A Pasquill stability category approach, ignoring the difference in dispersion characteristics at different heights in the boundary layer is used.

3.3 Limitation of Atmospheric Dispersion Models

Even the most sophisticated atmospheric dispersion model cannot predict the precise location, magnitude and timing of ground level concentrations with 100% accuracy. However, most model used today (especially the USEPA approved models) have been through a thorough model evaluation process and the modelling results are reasonably accurate, provided appropriate input data and model are used. Errors are introduced into results by the inherent uncertainty associated with the physics and formulation use to model dispersion, and by imprecise input parameters, such as emission and meteorological data.

Modelling techniques have a number of limitations however, and these need to be considered when interpreting the results of a modelling study. Steady-state Gaussian models, which are the most widely used models, are subject to the following assumptions and constraints:

- ❖ Winds within the modelling domain are assumed to be constant in velocity and direction both spatially (i.e. throughout the entire area being modeled) and for each hour being modeled.

- Dispersion in the downwind direction is assumed to be negligible relative to the wind transport.
- It is assumed that diffusion patterns are probabilistic and can be described exactly by Gaussian distribution. This means the plume expands in a conical fashion as it travels downwind, whereas the ideal "coning" plume is only one of many observed plume behaviours.
- The basic Gaussian models cannot handle complex terrain features such as valleys, mountains or shoreline regimes.
- Plume dispersion models have no "memory" of previous hour's emissions and therefore are not able to account for build-up and stagnation of pollutants in valleys and within building wakes.
- Gaussian models cannot account for calm (>0.5 m/s wind speed) conditions.

Many of these limitations have recently been addressed through the development of non-steady-state puff dispersion models such as CALPUFF. This model simulates the emissions as a series of "puffs" and allows for:

- Variable and curved trajectories;
- Variable meteorological conditions throughout the modelling domain (due to terrain features for example);
- The retaining of information on previous hours emissions; and
- Modelling under calm and low wind speed conditions.

However, as would be expected, the increased complexity of puff models means that their meteorological data requirements are far more onerous than those typically required for steady state models. As a result, puff models are not widely used and their use is likely to be limited in the near future to large and complex modelling investigations.

3.4 The Industrial Source Complex Model (ISC)

Industrial Source Complex (ISC) Model is a steady-state Gaussian plume model which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial complex. This versatile model is preferred by the EPA because of the many features that enable the user to estimate concentrations from nearly any type of source emitting non-reactive pollutants. The ISC code originally developed in the 1970's and modified numerous times since it had become impossible to reliably modify, debug or maintain. Restructuring and reprogramming the ISC models that began in April 1989, and was completed in March 1992. The ISC2 models were developed as replacements for and not updates to the previous versions of the models. The ISC3 models are based on revisions to the algorithms contained in the ISC2 models. (Schnelle, 1999).

The Industrial Source Complex (ISC) Dispersion Model is specifically designed for use in assessing the air quality impact of both traditional and non-traditional emissions from large source complexes. The model contains the following technical options: (1) concentration averaging times ranging from 1 hour to 1

year; (2) physical separation of multiple sources; (3) variation with height of wind speed; (4) plume rise due to buoyancy and/or momentum as a function of downwind distance; (5) differences in terrain elevation of receptors; (6) aerodynamic building wake effects (downwash); (7) gravitational settling and dry deposition of particulates; (8) curvilinear and elevated line sources with variable emission rates; (9) variable area source configurations; and (10) wind-blown emission.

There are two versions of ISC, a short-term model (ISCST) and a long-term model (ISCLT). The models differ in the averaging times available for calculation, available terrain and deposition options, and the format of input meteorological data.

Table 3.2: Characteristics of the two versions of ISC models

	Basic Gaussian Equation	**Meteorology**	**Wet Deposition option**	**Complex Terrain Option**
ISCST	Uses GPM equation	Hourly discrete met data	Available	Available
ISCLT	Uses GPM eq (with modifications for incorporation of STAR summaries	Met data in form of STAR summaries	Not available	Not available

The Industrial Source Complex Short Term model (ISCST3) provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex. The basis of the model is the straight-line, steady-state Gaussian plume equation, which is used with some modifications to model simple point source emissions from stacks, emissions from stacks that experience the effects of aerodynamic downwash due to nearby buildings, isolated vents, multiple vents, storage piles, conveyor belts, and the like. The ISC Short Term model accepts hourly meteorological data records to define the conditions for plume rise, transport, diffusion, and deposition. The model estimates the concentration or deposition value for each source and receptor combination for each hour of input meteorology, and calculates user-selected short-term averages. For deposition values, either the dry deposition flux, the wet deposition flux, or the total deposition flux may be estimated. The total deposition flux is simply the sum of the dry and wet deposition fluxes at a particular receptor location. The user also has the option of selecting averages for the entire period of input meteorology.

3.5 Applications and comparisons of the ISCST3 MODEL

There have been relatively few model inter-comparison studies since the introduction of the second generation of models (AERMOD and ADMS3). Most studies have been concerned with the comparison of single models with field data. Some of these statistics deal with the impacts of industrialized complexes.

The Industrial Source Complex Short Term (ISCST-3) model has been used by Rama Krishna et al (2005) to study the impact of an industrial complex, located at Jeedimetla in the outskirts of Hyderabad city, India, on the ambient air quality. The results show that the model-predicted concentrations are in good agreement with observed values and the model performance is found to be satisfactory.

Fushimi et al (2005) developed a source apportionment method based on an atmospheric dispersion model and multiple linear regression analysis (MLR) in conjunction with ambient concentrations simultaneously measured at points in a grid network. They used the Industrial Source Complex model (ISC) in the method applied to the case of benzene in the vicinity of an l Industrial Complex in Japan. These results support the reliability to achieve reasonable source apportionments among industries.

Abdul-Wahabl(2003) work dealt specifically with the use of the Industrial Source Complex Short Term (ISCST) model for predicting S02 concentrations around a refinery in Oman. The second objective was to evaluate the ISCST model by comparing the calculated and measured concentrations. The modelling results were validated against measured data during the study period. The comparison, based on the monthly average measurements, showed that the model underestimates the observed SO_2 concentrations.

Sivacoumar et al (2001) estimated the impact of NO(X) emissions resulting from various air pollution sources, viz. industries, vehicles and domestic, around a steel

complex using Industrial Source Complex Short-Term Gaussian dispersion model. The model performance was found good with an accuracy of about 68%.

Andretta et al (2004) used the Industrial Source Complex (ISC) for the estimation of the concentration of industrial pollutants in a wide area near an important Italian industrial complex. The Gaussian model results present an acceptable agreement with respect to air quality network data, in particular as to the air quality environmental norms purposes.

The UK Environment Agency funded a study of the relationship between different models (R&D Technical Report, 2003). The main conclusion is that there are significant differences between the outputs of the models but that these do not follow any consistent pattern. It was not practicable to provide overall recommendations on the use of one or the other model and each specific application must be considered on its own merits. Advanced models represented by ADMS and AERMOD provide significant advantages over older models particularly in their treatment of the boundary layer and complex terrain. However the results demonstrate that the new generation models are still in a state of development, especially with regard to their sensitivity to process meteorological data to provide the boundary layer parameters required for dispersion calculations.

Patil(2005) compared ISC-3 with ADMS-3 within an industrial region in north-east of Mumbai . They observed that computed concentrations of pollutants are

most of the time higher from ISCST-3 than ADMS-3 model predictions. But both models give the same trends in concentration variation for all the seasons.

Schroeder, A.J. (2004) presents a comparison of the pollutant concentration predictions from the AERMOD and ISC (ISCST3 and ISC-PRIME) air dispersion models in the context of fugitive storage tank emissions at a bulk petroleum storage terminal. Data are presented that shows that ISC consistently predicts higher overall and higher maximum pollutant concentrations when compared with AERMOD in this particular situation.

To assess the validity of the model for application to tall stack, buoyant sources, Brower et al (1996) conducted an evaluation of the AERMOD using a power plant field data. The performance measures showed a general tendency of AERMOD to under predict the observed SO2 concentrations, especially the highest and lowest values

Kumar et al (1999) evaluated the short-term and long-term versions of Industrial Source Complex Models (ISCST3 and ISCLT3) for estimating long-term concentrations using sulfur dioxide data from emission inventory of Lucas County, Ohio for the year 1990. The ISCST3 and ISCLT3 models were used to predict monthly and quarterly averages of sulfur dioxide concentrations. Both the ISCST3 and ISCLT3 models predicted concentrations that are lower than the observed concentrations. The concentrations predicted by the ISCST3 model were closer to the observed concentrations when compared with the concentrations obtained using the ISCLT3 model. The study suggested that the ISCST3 model is

better for estimating long-term concentrations of sulfur dioxide as compared to the ISCLT3 model.

Long (2004) conducted a modelling study of SO_2 emissions from several wholly owned and affiliated power generating facilities and one additional large industrial facility to determine the combined impacts of these facilities using both the Industrial Source Complex (ISC3) and AERMOD models. The modelling study was conducted using both ISC3 and AERMOD due to the pending change in the preferred Gaussian model by USEPA. The results of this side-by-side comparison indicated that AERMOD generated lower peak ambient concentrations than did ISC3; however, the peak and high-second-high values between the two models were not paired in time or space.

3.6 Choosing an Appropriate Model in the Mauritian context

The most significant factors that determine the quality and accuracy of the results of a modelling exercise are:

- ❖ The suitability of the model for the task
- ❖ The availability of the accurate source information
- ❖ The availability of accurate meteorology data.

The most appropriate model for a given application depends on a number of factors. For very simple, quick modelling investigations, the SCREEN model may be more appropriate. This model can only simulate a release from one emission

source, and uses theoretical meteorological scenarios in predicting downwind concentrations.

If, however, the application involves dense gas releases, highly complex terrain (where the maximum terrain elevation exceeds the height of the release point), or a short-term "puff" release, then a more specialised model would be required. There are also specialised models for particular applications such as the CALINE model, which is used to model emissions from highways and major roads. These models require a high level of expertise and experience to use.

The proposed philosophy for any air quality modelling can be summarized as follows:

- Use models based on well established science
- The modelling approach must be clear and unambiguous and the modelling process must be clearly defined and transparent to government, industry, individuals and communities.
- Monitoring should be an integral part of the modelling approach
- Use an approach similar to that taken by the USEPA which is limited to two tiers: screening and refined modelling
- Use established and simple modelling methods as the complexity of the more refined models requires a relatively long learning curve to be able to use the model correctly. Simple models such as Industrial Source

Complex 3 (ISC3) have a relatively good history for regulatory applications and their strengths and weaknesses are well understood.

A model requires two inputs: information on the source (release velocity, emission rate), and meteorology (wind speed and direction). However, to conduct a dispersion modelling analysis, a user usually enters data in the following four major categories: meteorological conditions, such as wind speed, wind direction, stability class, temperature and mixing height; emissions parameters, such as source location, source height, stack diameter, gas exit velocity, gas exit temperature and emission rate; terrain elevations; and building parameters, such as location, height and width.

In order to model particulate deposition using the latest algorithms included in Version 3 of ISCST, two additional parameters are required: the Monin Obukhov length and the surface friction velocity. These additional parameters relate to the amount of turbulence occurring within the surface boundary layer website.

Generally, three different types of meteorological (met) data sets may be used in modelling studies.

1. Screening met data: A compilation of hypothetical met conditions suitable for determining potential worst case short-term (1 hour or less) concentrations.

Screening met data is used for a first pass or worse case approach to the estimation of downwind concentrations. Screening data sets are routinely issued with models or can be compiled specially for a particular application. The use of screening data however, is limited in its ability to estimate averaging times greater than one hour and it does not allow the frequency of peak concentrations to be assessed.

Generally, screening data sets use a single wind direction and concentrations are determined downwind of the source(s) along a single wind line. If multiple sources are being modeled, care should be taken to select the origin and the wind direction which give maximum overlapping of the plumes.

2. Sequential met data: A sequential hour-by-hour data set compiled from met measurements collected at or near the site of at least a 1 year period. Sequential meteorological data (often referred to as "real" met data) used in modelling should be as representative as possible of conditions at the site in question. In many instances, all the met data required will not be available for the site itself, and some, or all, of the data will need to be drawn from records from a weather station operated some distance away (at a nearby airport for example). If data from another location is to be used, then an assessment must be made of whether the data is likely to be representative of conditions at the site. Differences in the local and regional topography, land use (e.g. open farmland versus a built-up

industrial area), and coastal effects need to be considered. The United Kingdom Bureau of Meteorology specifies that ideally 10 year's, or a minimum of 4 year's met data are required for good representative modelling. The United States EPA requires a minimum of 5 year's representative met data or, if not available then one year's data. The purpose of having more than one year's data is to ensure that annual changes such as El Nino or La Nina are not overlooked and that short-term variations do not play a disproportionate role in estimating downwind concentrations. The paucity of good representative met data in Mauritius however, means that often it is difficult to obtain even one year's met data. Of necessity therefore, this is considered the minimum necessary for modelling. The Plaisance Meteorological station in Mauritius is the only Met station in Mauritius that has one year's met data available.

3. Frequency met data: A frequency distribution of meteorological occurrences suitable for determining long term (seasonal or annual) averages. ISCLT uses frequency data (referred to as STAR data) to calculate long term average pollutant concentrations. STAR data is a tabulated summary of wind speed and wind direction frequencies occurring under each of the six Pasquill Stability Classes.

Over the past 15-20 years, the Industrial Source Complex (ISC) model has been the preferred model for most regulatory modelling applications around the world. This model is being replaced by the more sophisticated AERMOD model as the USEPA's preferred model for regulatory applications in the U.S. The AERMOD

model is however quite complex and requires a lot more inputs (especially advanced meteorological and terrein data) that would be difficult for Mauritius to apply. Given the limitations regarding the availability of met data, for most applications, a steady state Gaussian dispersion model such as ISCST is suitable. This model enables a number of different source configurations to be assessed and can incorporate simple terrain and building wake effects. The ISC3 Models are steady-state Gaussian plume models which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial complex. The models are easy to use and rely on standard, inexpensive meteorological data inputs from one station.

There is a movement towards more sophisticated and more accurate models but this movement is not without its drawbacks, most notable the requirement for much more robust meteorological data to improve the accuracy of model predictions.

CHAPTER FOUR

MATERIALS & METHODS

CHAPTER FOUR

MATERIALS & METHODS

4.1 Evaluation Criteria

An evaluation criteria need to be selected to assess the modeled ambient air sulphur dioxide concentrations. This criterion needs to take into account the background concentrations as well as the national standard. Based on available ambient air monitoring data for background sulphur dioxide concentrations, the evaluation criteria was set at 75% of the ambient air standards for sulphur dioxide (See Table 4.1).

Table 4.1: Evaluation Criteria level for sulphur dioxide concentrations.

Pollutant	Evaluation Criteria(µg/m3)	Standard Ambient air concentration set by MOE (µg/m3)	Time average Measured
Sulphur dioxide	260	350	1-Hour
	110	150	24-Hour
	50	50	Annual

4.2 Stack Monitoring Data

An Air Pollution Monitoring Unit exists in the Faculty of Engineering of the University of Mauritius which provides stack monitoring consultancy services to the industry. The unit has specialized on spot facilities to measure the stack emissions. All data collected from industries are considered confidential. However typical stack exist velocities and efflux temperatures have been provided to the author of this report and there have been assumed in the modelling scenarios.

4.3 Single Source case –study

4.3.1 Site Location and Description of Industrial Source

Following a number of pollution incidents around Alcodis ethanol distillery situated in the south of the island, the factory was taken for the single-source case- study. Alcodis Ltd is an alcohol distillery producing about 80,000 litres of alcohol. A Heavy Fuel Oil (HFO) fired boiler is used for steam production and the emissions are through a single stack. Figure 4.1 shows the location of the stack with respect to the residential area. Two sensitive receptor points in the vicinity of the stack are as follows:

- Rose Belle North Government School – the school is found around 400 metres from the site.
- Marie Jeannie- this residential area is found around 350 metres from Alcodis and it is taken as the second receptor point.

These two receptors have been chosen based on past pollution incidents and complaints to the Ministry of Environment.

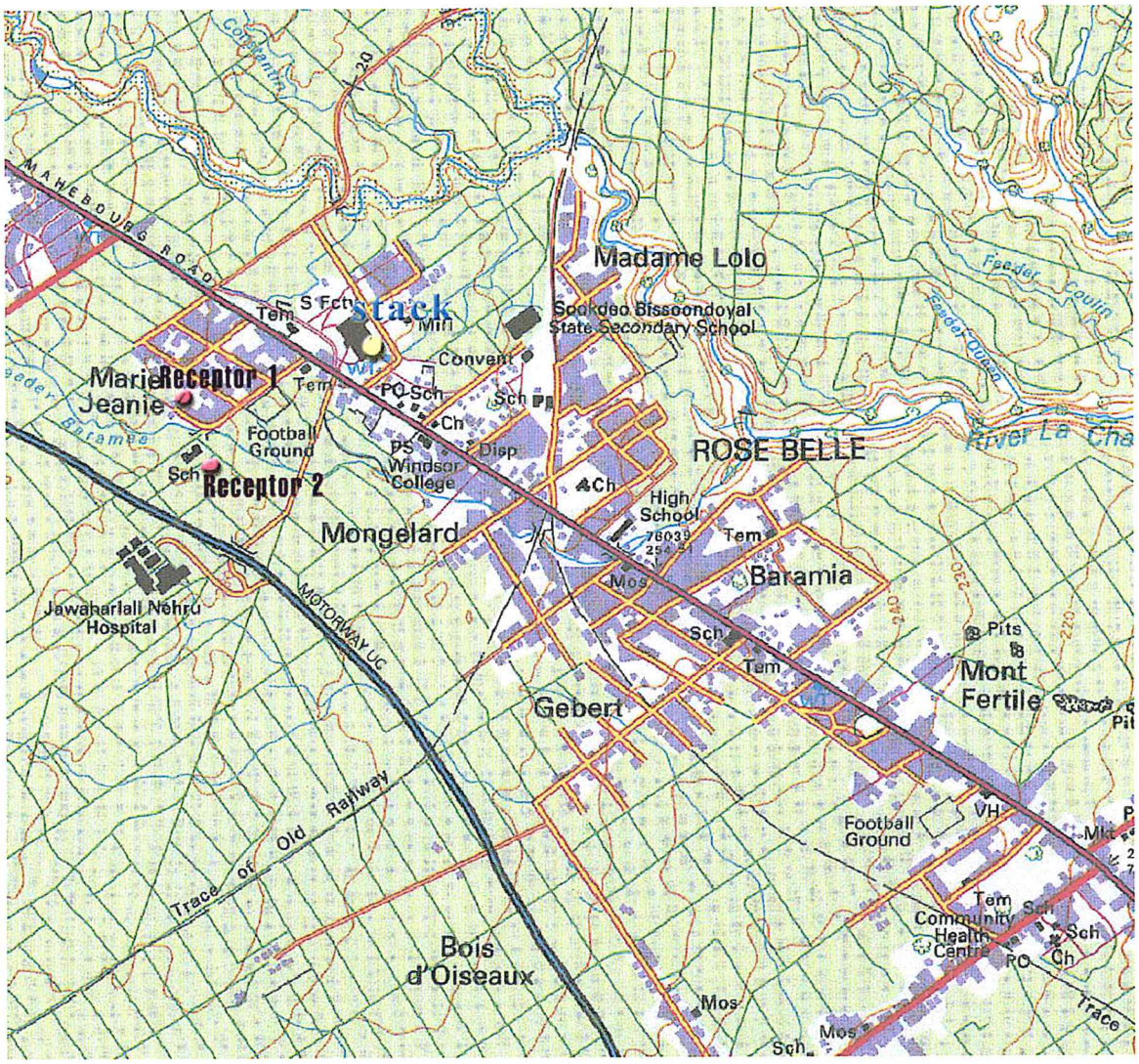


Figure 4.1: Location of single – source stack in relation to receptors

4.3.2 Stack Characteristics and Emission Factors

The stack characteristics and emission factors are as follows:

1. Stack diameter= 0.955m.
2. Stack height = 21m
3. Exit velocity = 6 m/s

4. Emission rate = 19.46 g/s

5. Efflux temperature = 100^0c

Therefore the emission rate was calculated as follows:

HFO fuel consumption of factory= 1 ton/hour= 0.278g/s

Since the fuel contain 3.5 % 0f sulphur; Mass of sulphur burnt = 3.5 / 100 * 0.278 = 9.73 g/s

From the stoichiometric equation of the conversion of S into $S0_2$

9.73g of sulphur will give (64/32) *9.73 = 19.46 g/s of $S0_2$

Therefore the emission rate = 19.46 g/s

The flue gas flow rate has been calculated using the following theoretical equation which can be used to estimate the flue gas flow rate induced by draft of a flue gas stack. The equation assumes that the molar mass of the flue gas and the outside air are equal and the frictional resistance and heat losses are negligible. (wikipedia, 2007)

$$Q = CA\sqrt{2gH\left(\frac{T_i - T_0}{T_i}\right)}$$

Q= 0.65 * 0.716*√ [(2* 9.81 *21)* (373-298) /373]

= 4.22 m^3/s

Therefore V = 6 m/s

Where:

Q = flue gas flow rate, m^3/s

A = cross-sectional area of chimney, m2 (assuming it has a constant cross-section)

C = discharge coefficient (usually taken to be from 0.65 to 0.70)

g = gravitational acceleration at sea level, 9.807 m/s^2

H = height of chimney, m

T_i = absolute average temperature of the flue gas in the stack, K

T_o = absolute outside air temperature, K

The calculated exit velocity is the efflux temperature used in this study and is in accordance with on –site measurements made by the factory occasionally through the monitoring service of the University of Mauritius.

4.3.3 **Meteorological Data**

One year (2002) of hourly sequential meteorological data has been used from Plaisance weather station, situated approximately 15 Km south of the project site. Plaisance is the closest weather station that records sufficient meteorological variables over a one – year period suitable for creating a data set as input to the dispersion model. Monthly means of maximum temperature, minimum temperature and the daily average taken as the mean of the maximum and

minimum temperature for the Plaisance Station for a period of over 15 years are given in appendix B.

A wind rose for the station showing the percentage frequencies of wind direction and speed is given in Appendix C. Wind speeds at the site are generally moderate and the winds shows a predominantly easterly direction. The one hour meteorological data collected during 2002 were processed and made in a proper format to be fed in the ISC software.

4.3.4 **Assumptions**

While running the model, various assumptions had to be made, these include:

1. The topography of the area is such that including it will not result in significantly higher concentrations than modelling without terrain.
2. The meteorological data for the region is approximately the same as that of Plaisance region.
3. There is no building downwash around the factory. This is a valid assumption given the location of the stack and building characteristics.
4. The model was set for rural setting considering the open land-use in Rose-Belle.

4.4 Multiple sources case- study

4.4.1 Site location and description of industrial Complex

The Vacoas-Phoenix industrial estate (VIE) is found in the central part of Mauritius. It was established in 1986 by the Development Bank of Mauritius (DBM).Valentina and Petit Camp is the two villages which lie close to the estate. The Valentina industrial estate has taken as a multiple source case- study since it comprises of numerous industrial stacks. The "Valentina problem" is a classic case of the juxtaposition of mutually antagonistic land uses viz. residential and industrial. At VIE, initially the location of small and medium enterprises was envisaged but spurred on by the success of the government policies in attracting new investments under the Export Processing Zone provisions, textile industries found the estate a convenient location to vertically integrate their activities. Food industries also joined the community of companies in the estate. The enterprise used the technology and equipment that was available at the lowest capital costs, sometimes the processes and equipment used was old or second hand. This led to excessive consumption of resources and generation of emission. Figure 4.2 gives the site location of the industries in the estates together with the two sites selected for modelling. The Village of valentine adjoins the following three factories: Transpack, REOP, and Sonia Wear. (Ramjeawon, 2002)

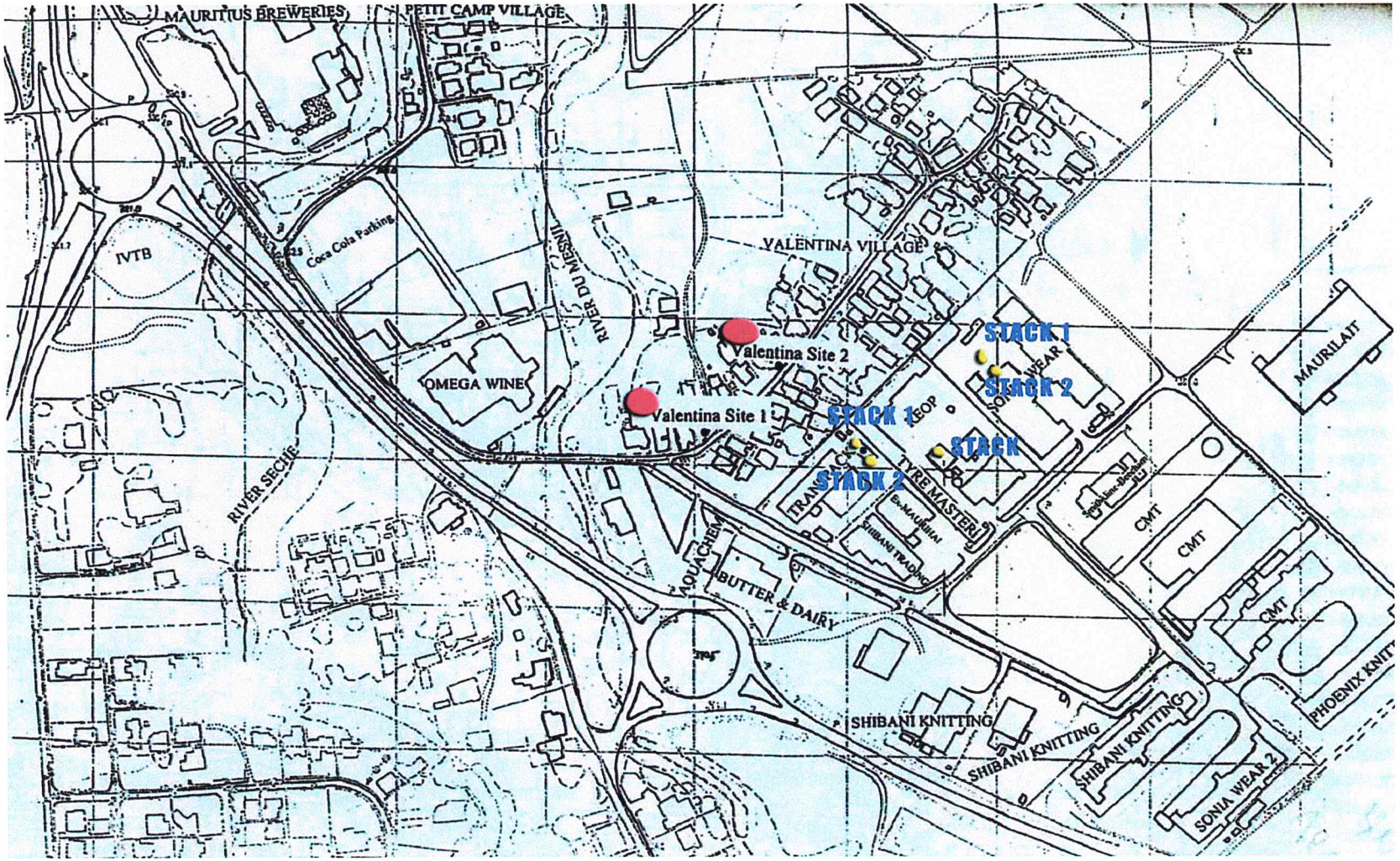


Figure 4.2: Location of the factories and stacks in the industrial estates in relation to the receptors in the residential area.

Table 4.2: Description of factories in and around VIE

Sr No	Name of Factory	Type of Activity	Heavy – fuel oil consumption
1	Transpack	Manufacturing of washing liquids& powders; bleaching liquid;dyeing auxillaries	69920 Kg/month
2	Ramdanee Edible Oil Products Ltd	Refining of edible vegetable oils. Packing and distribution	25392 Kg/month
3	Sonia Wear	Textile dying and knitting	21242 /kg/month

Sulphur dioxide emissions are generated during oil combustion from the oxidation of sulphur containing heavy – fuel oil (at about 3.5 % of S).

4.4.2 Stack Characteristics and Emission Factors

Transpack

The stack characteristics are as follows:

Baseline case

1. Stack diameter= 0.5m.
2. Stack height = 18m
3. Exit velocity = 6.19 m/s
4. Emission rate = 0.966 g/s
5. Efflux temperature = 401^0c

The emission rate was calculated as follows:

HFO fuel consumption of factory= 35,880 Kg/ day= 0.0138 Kg / s

Since the fuel contain 3.5 % 0f sulphur

Mass of sulphur burnt = 3.5 / 100 * 0.0138 = 0.483 g/s

From the stoichiometric equation of the conversion of S into $S0_2$

0.483 g of sulphur will give (64/32) *0.483 = 0.966 g/s of $S0_2$

Therefore the emission rate = 0.966 g/s

The flue gas rate has been calculated using the following theoretical equation (wikipedia, 2007)

$$Q = CA\sqrt{2gH\left(\frac{T_i - T_0}{T_i}\right)}$$

Q= 0.65 * 0.196*√ [(2* 9.81 *18)* (401-298) /298]

= 1.213 m^3/s

V = 6.19 m/s

For Sonia wear

The stack characteristics are as follows:

1 Stack diameter= 0.5m

2 Stack height = 15 m

3 Exit velocity = 4.72 m/s

4 Emission rate = 1.673 g/s

5 Efflux temperature = 363^0c

The emission rate was calculated as follows:

HFO fuel consumption of factory= 62040 Kg/month= 0.0239 kg/s

Since the fuel contain 3.5 % 0f sulphur

Mass of sulphur burnt = 3.5 / 100 * 0.0239 = 0.8365 g/s

From the stoichiometric equation of the conversion of S into $S0_2$

0.805 g of sulphur will give (64/32) *0.88365 = 1.673 g/s of $S0_2$

Therefore the emission rate = 1.673 g/s

The flue gas rate has been calculated using the following theoretical equation

$$Q = CA\sqrt{2gH\left(\frac{T_i - T_0}{T_i}\right)}$$

Q = 0.65 * 0.196*√ [(2* 9.81 *15)* (363-298) /298]

= 0.925 m^3/s

V = 4.72 m/s

For REOP

The stack characteristics are as follows:

1. Stack diameter= 0.7m.
2. Stack height = 11m
3. Exit velocity =3.32 m/s
4. Emission rate = 0.686 g/s
5. Efflux temperature =348^{0}c

The emission rate was calculated as follows:

HFO fuel consumption of factory= 25,392=0.00979 kg/s

Since the fuel contain 3.5 % 0f sulphur

Mass of sulphur burnt = 3.5 / 100 * 0.00979 = 0.343 g/s

From the stoichiometric equation of the conversion of S into $S0_2$

9.73g of sulphur will give (64/32) *0.343 = 0.686 g/s of $S0_2$

Therefore the emission rate = 0.686 g/s

The flue gas rate has been calculated using the following theoretical equation

$$Q = CA\sqrt{2gH\left(\frac{T_i - T_0}{T_i}\right)}$$

$Q = 0.65 * 0.385*\sqrt{}[(2* 9.81 *11)* (348-298) /298]$

$= 1.394\ m^3/s$

$V = 3.62\ m/s$

Where:

Q = flue gas flow rate, m^3/s

A = cross-sectional area of chimney, m2 (assuming it has a constant cross-section)

C = discharge coefficient (usually taken to be from 0.65 to 0.70)

g = gravitational acceleration at sea level, 9.807 m/s^2

H = height of chimney, m

T_i = absolute average temperature of the flue gas in the stack, K

T_o = absolute outside air temperature, K

The calculated exit velocity and the efflux temperature used in this study are in accordance with on –site measurements made by the factory occasionally through the monitoring service of the University of Mauritius.

4.4.3 Meteorological Data

One –year (2002) of hourly sequential meteorological data has been used from the Plaisance weather station, situated approximately 20 Km south of the site Plaisance is the closest weather station that records sufficient meteorological variables over a one-year period suitable for creating a data set as input to the dispersion model. The similarity is that the wind data from the various weather station (situated at about 5 Km of the site) and the Plaisance weather station shows that the Plaisance data is representative for this modelling. A wind rose of the meteorological data for Plaisance station is given in appendix C, showing a predominantly easterly direction.

4.4.4 Assumptions

While running the model, various assumptions had to be made, these include:

1. The topography of the area is such that including it will not result in significantly higher concentrations than modelling without terrain.
2. The meteorological data for the region is approximately the same as that of Plaisance region.
3. There is no building downwash around the factories.
4. The model was set for rural setting.

4.5 Modelling Scenarios

In order to meet the ambient air quality standards for sulphur dioxide, 4 main options and their combinations were considered in the modelling exercise. The table 4.3 below summarises the options considered and the assumptions made.

Table 4.3: Modelling Scenarios

Option	Description	Assumptions
Raising the stack Heights	The height of the boiler stack plays an important role in deciding the fate of pollutants emitted from the stacks. The higher the stack better is the dispersion of pollutants and lesser is the impact at ground	For both case study different stack height raise were considered.

	levels.	
Implement Cleaner Production options (CP)	These include possibilities such as improved fuel storage and preparation, optimized boiler operations, training of operators, practicing of heat conservation, rationalization of operating practices, modifying or adding in more efficient equipments.	An average 30% reduction in the emission (g/s) in each case was considered due to cp for the purpose of modelling. This is based on the results achieved in a factory on the island which has implemented CP options. CP options lead to reduction in steam consumption and ultimately in fuel consumption.
Installation of a wet scrubber equipments on the boiler stacks.	Wet scrubber is emission control options that captures the gaseous pollutant such as SO2 into liquid and intercept the particles, thus cleaning the emissions effectively that leave the stacks.	Typically wet scrubbers have efficiency ranging from 70% to 90%. For this modelling exercise a removal efficiency of 80% was assumed.
Construction of a Common Heat	A CHP will cater to the steam and power requirements of all	A CHP stack was considered to replace the

Power (CHP) system.(only for multiple stacks)	industries and could reduce the emissions substantially.	stacks of the four stacks to be modeled. A 20% reduction in the total fuel consumption is assumed A CHP is a more efficient steam generation system than individual boilers

For the single source case-study, the following scenarios were considered:

1. Base line case, where the stack height is 21 m
2. Increasing the stack height to 30m
3. Change from a high sulphur content to a low sulphur content fuel
4. Implementation of cleaner production opportunities
5. Installation of a wet scrubber
6. Implementation of Cleaner Production + installation of a wet scrubber

For the multiple sources case-study, the following scenarios were considered:

1. Baseline scenarios with existing stack heights.
2. Increase of stack heights to 20m and 30m respectively.
3. Implementation Cleaner Production opportunities only.
4. Installation of a wet scrubber on each boiler.
5. Implementation of Cleaner Production opportunities + installation of a wet scrubber
6. Implementing of a Central Heat Power plant

7. Installation of Central Heat Power + wet scrubber

8. Implementation of CP opportunities + installation of CHP

9. Installation CHP,CP and scrubber

4.6 Cost of Pollution Control Systems

To determine the most cost – effective option, data were collected from manufacturers and industries on the cost of various pollution control options.

❖ **Change of stack height**

An increase of stack height of 5 m cost about Rs 50,000, while a raise of 10m entails a cost of about Rs 100,000 (1 USD = Rs 32)

❖ **Change in fuel**

The change of fuel considered is from HFO (1500 Rs) to diesel. The price as at 2005 was as follows:

Cost of fuel	HFO (1500s)	Diesel
Price Rs/lit	13.50.	19.75

For example, if the case of Transpack industry is taken into consideration , where the factory consumes 3,600 litres of fuel per day, the fuel cost difference amounts to Rs 22,500 daily and Rs 675,000 monthly. Together with this, a maintenance cost comprising of cleaning of tubes, daily cleaning of burner and air duct fans blocks have to be considered.

❖ **Introduction of cleaner production**

The cost for CP implementation will depend on the individual industries. Based on data gathered in a few factories on the island which has implemented CP options, the minimum cost to implement CP is around Rs 100,000.

❖ **Scrubber installation**

Typically a wet scrubber for a small capacity boiler stack is about Rs 2.5 million, with an annual operating cost Rs 100,000.

❖ **Combined Heat and Power (CHP)**

Placing a CHP in the middle of industrial estate in replacement of the existing boilers will cost the industries about Rs 20 million

CHAPTER FIVE

RESULTS & DISCUSSION

CHAPTER FIVE

RESULTS & DISCUSSION

5.1 Predicted concentrations of pollutants for single source case-study

The predicted concentration for the 21m and 30m stack height under different pollution control options is presented in Tables 5.1, 5.2, and 5.3 and Figures from 5.1 to 5.6 and compared with the evaluation criteria. Contour diagrams are presented in Appendix D and reports for one hour average for the baseline case is given in Appendix E.

Table 5.1: Predicted sulphur dioxide modelling concentrations for single source (1 hour average). All concentrations are in µg/m^3. Evaluation criteria = 260 µg/m^3

OPTIONS	STACK HEIGHT 21M		STACK HEIGHT 30M	
	Receptor - 1 (Marie Jeannie)	Receptor - 2 (Govt School)	Receptor- 1 (Marie Jeannie)	Receptor- 2 (Govt School)
Baseline	729	667	508	463
Change in Fuel	552	536	391	379
Implementation of CP	501	461	353	319
Implementation of CP + Change of	382	371	**259**	**254**

Fuel				
Installation of Scrubber	**139**	**133**	**102**	**92.6**
Installation of Scrubber + Change of Fuel	**110**	**106**	**78.1**	**75.7**
Implementation of CP+ Scrubber	**97.3**	**93.2**	**71.0**	**64.7**
Implementation of CP+ Scrubber + Change in Fuel	**77.4**	**74.9**	**54.9**	**53.0**

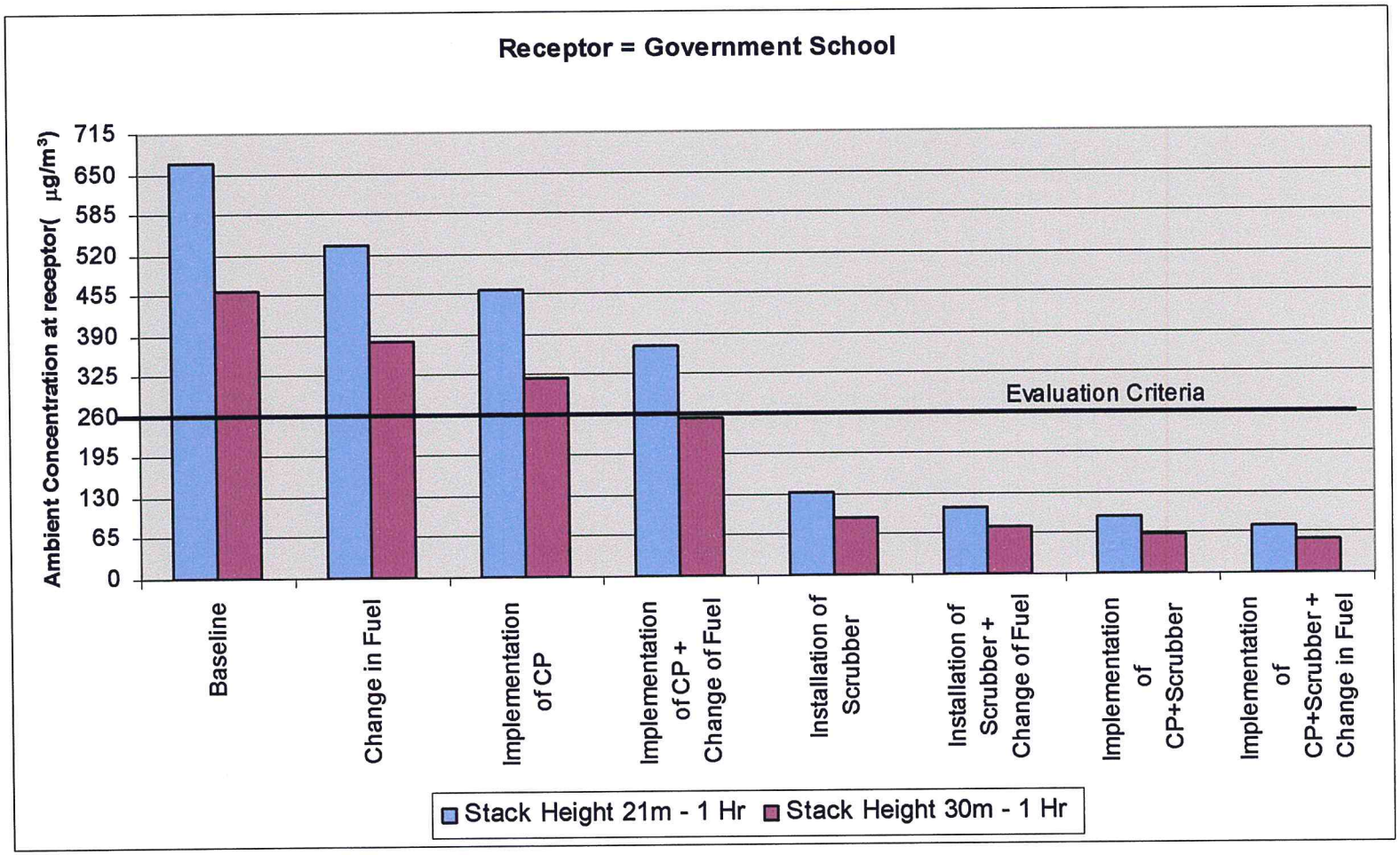


Figure 5.1 – Ambient SO2 concentration at Government school for a stack height 21m & 30m for a time period of 1-hour average

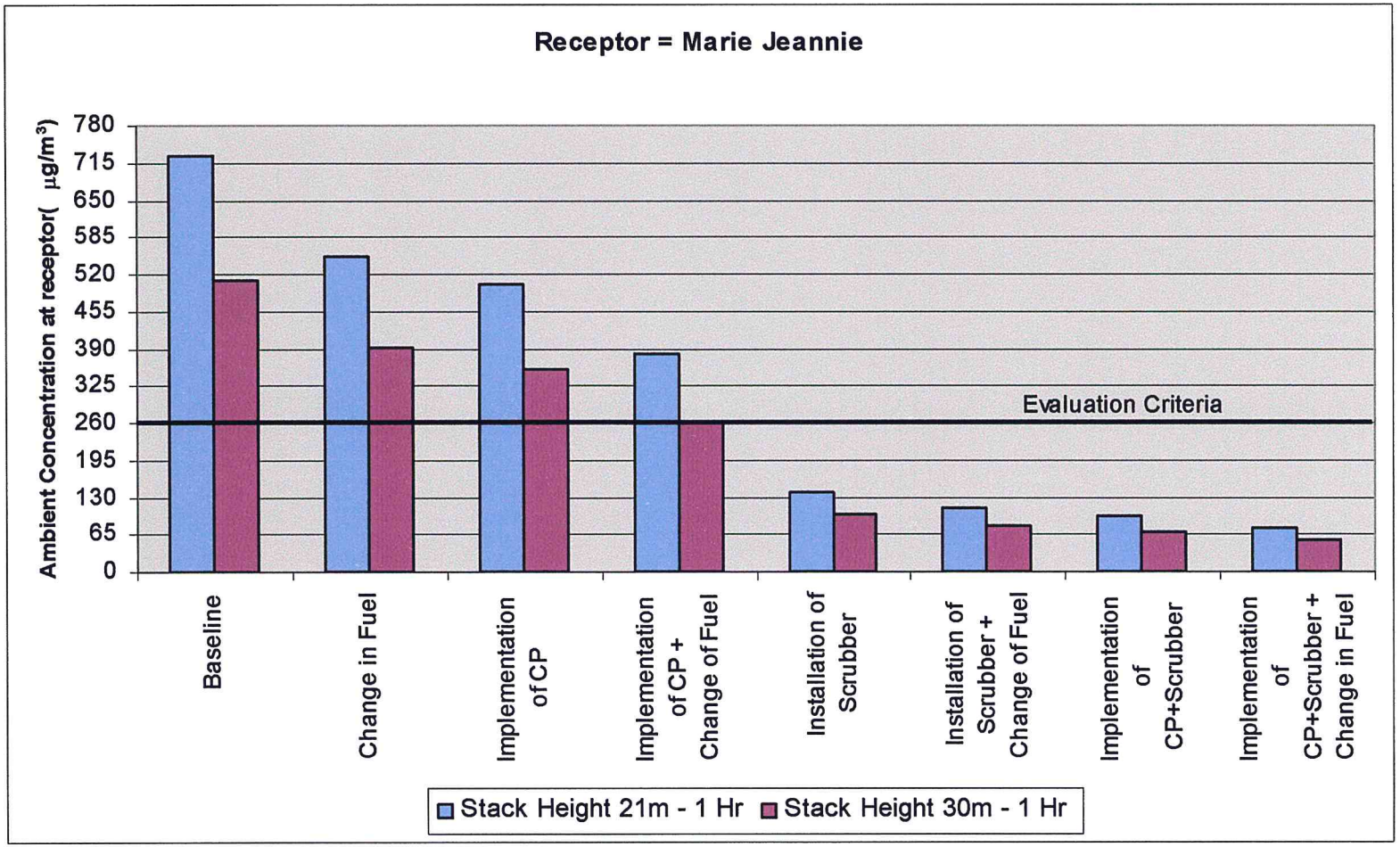


Figure 5.2 – Ambient SO2 concentration at Marie Jeannie for a stack height of 21m and 30m for a time period of 1 hour average

Table 5.2: Predicted sulphur dioxide Modelling concentration for single source (24 hour average). All concentrations in µg/m^3. Evaluation criteria = 110 µg/m^3

OPTIONS	STACK HEIGHT 21M		STACK HEIGHT 30M	
	Receptor - 1 (Marie Jeannie)	Receptor- 2 (Govt School)	Receptor- 1 (Marie Jeannie)	Receptor- 2 (Govt School)
Baseline	260	223	133	126
Change in Fuel	204	177	111	**108**
Implementation of CP	181	154	**91.7**	**86.8**
Implementation of CP + Change of Fuel	141	122	**76.4**	**74.4**
Installation of Scrubber	**51.9**	**44.5**	**26.6**	**25.1**
Installation of Scrubber + Change of Fuel	**40.6**	**35.3**	**22.2**	**21.6**
Implementation of CP+ Scrubber	**36.3**	**31.1**	**18.6**	**17.6**
Implementation of CP+ Scrubber + Change in Fuel	**28.5**	**24.7**	**15.5**	**15.1**

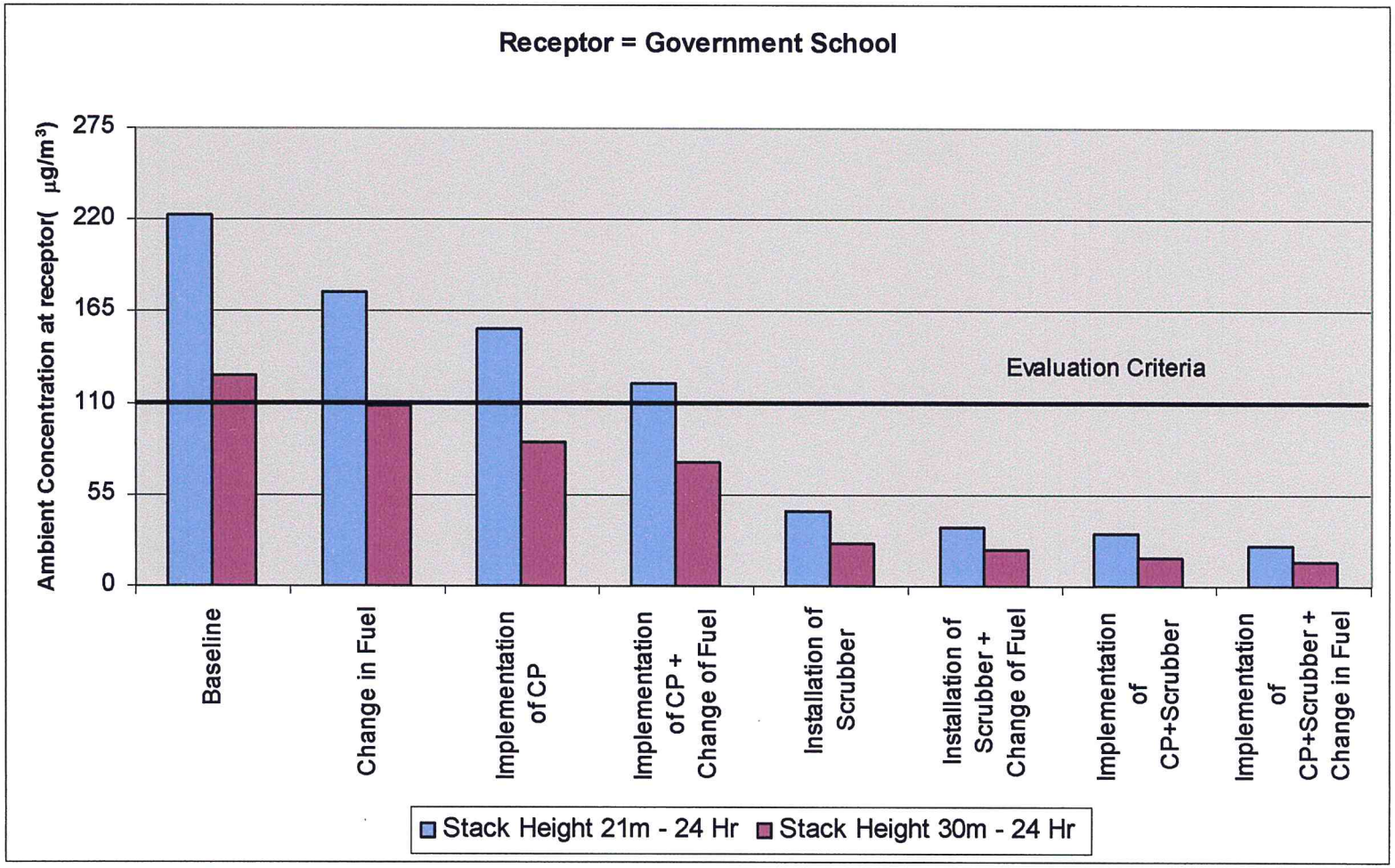


Figure 5.3– Ambient SO2 concentration for Govt. School for a stack height of 21m and 30m for a time period of 24 hour average

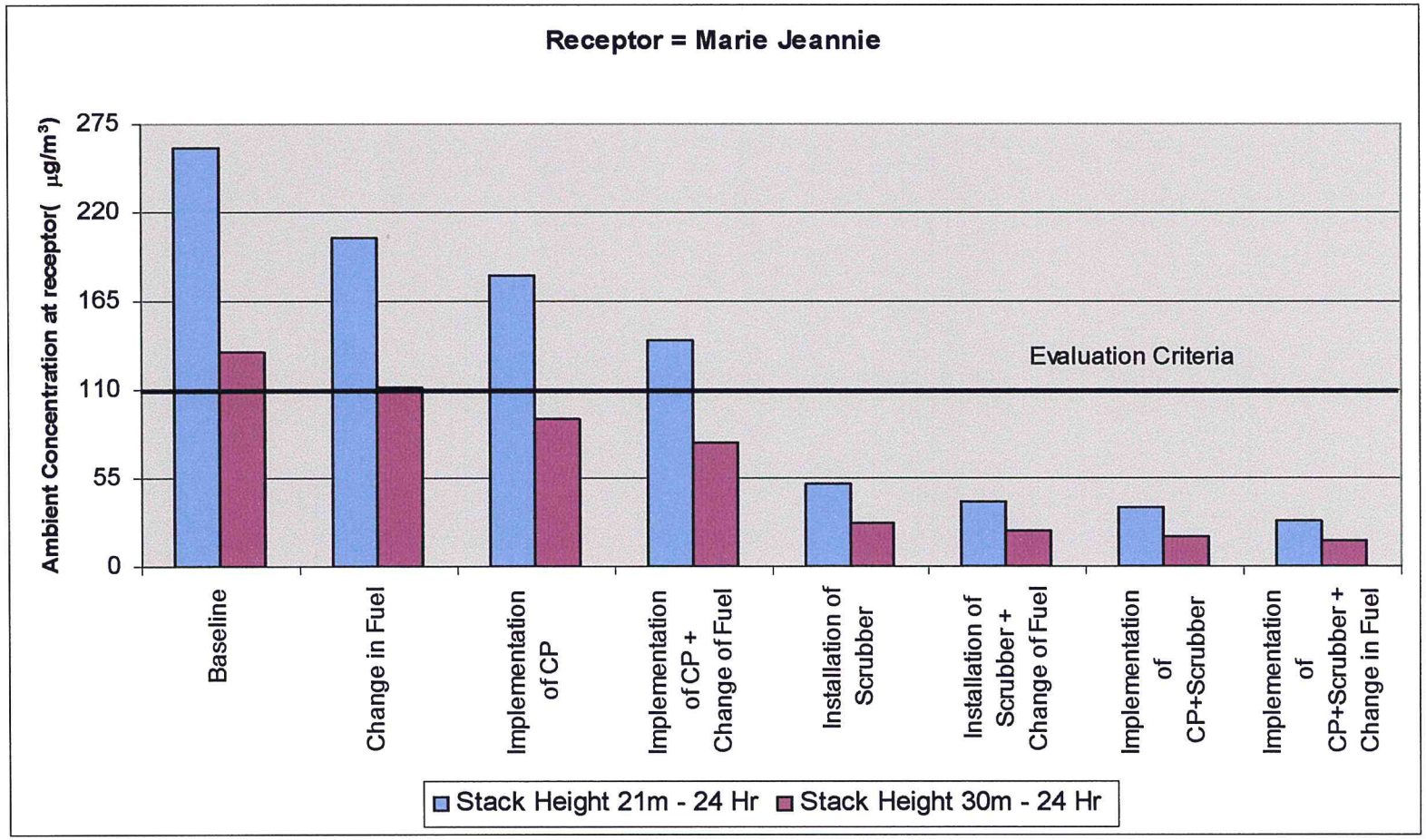


Figure 5.4– Ambient SO2 concentration at Marie Jeannie for a stack height of 21m and 30m for a time period of 24 hour average

Table 5.3: Predicted sulphur dioxide modelling concentration for single source (annual average). All concentrations in µg/m^3. Evaluation criteria = 50 µg/m^3

OPTIONS	STACK HEIGHT 21M		STACK HEIGHT 30M	
	Receptor- 1 (Marie Jeannie)	Receptor- 2 (Govt School)	Receptor- 1 (Marie Jeannie)	Receptor -2 (Govt School)
Baseline	59.1	**26.9**	**27.6**	**11.6**
Change in Fuel	**47.5**	**22.9**	**21.2**	**12.3**
Implementation of CP	**40.6**	**15.6**	**19.4**	**10.5**
Implementation of CP + Change of Fuel	**31.6**	**15.2**	**14.6**	**8.42**
Installation of Scrubber	**11.9**	**5.6**	**5.62**	**3.17**
Installation of Scrubber + Change of Fuel	**9.13**	**4.51**	**4.32**	**2.45**
Implementation of CP+ Scrubber	**8.30**	**3.93**	**3.93**	**2.13**
Implementation of CP+ Scrubber + Change in Fuel	**6.38**	**3.15**	**2.97**	**1.71**

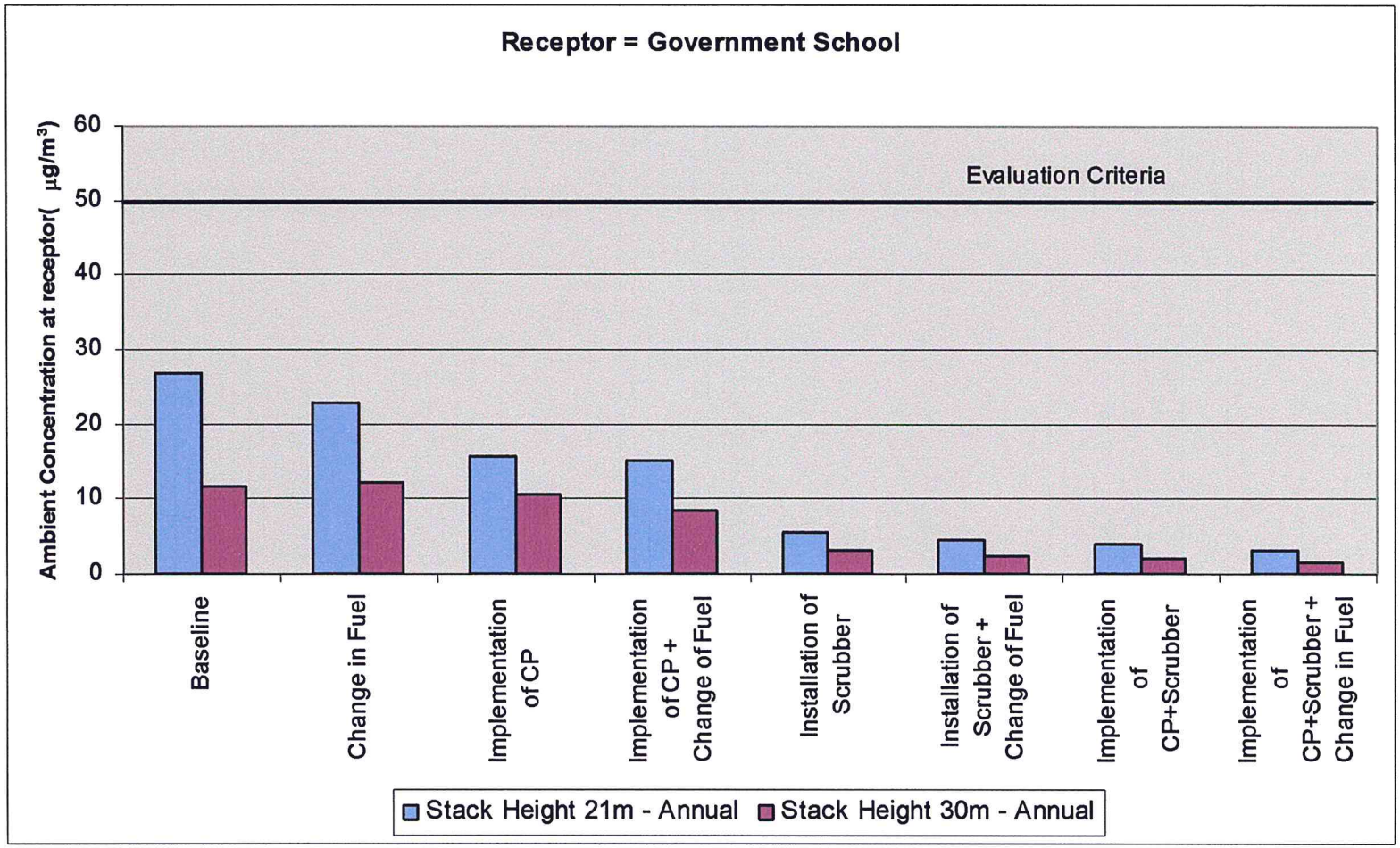


Figure 5.5 – Ambient SO2 concentration for Govt. School for a stack height of 21m and 30m for Annual average

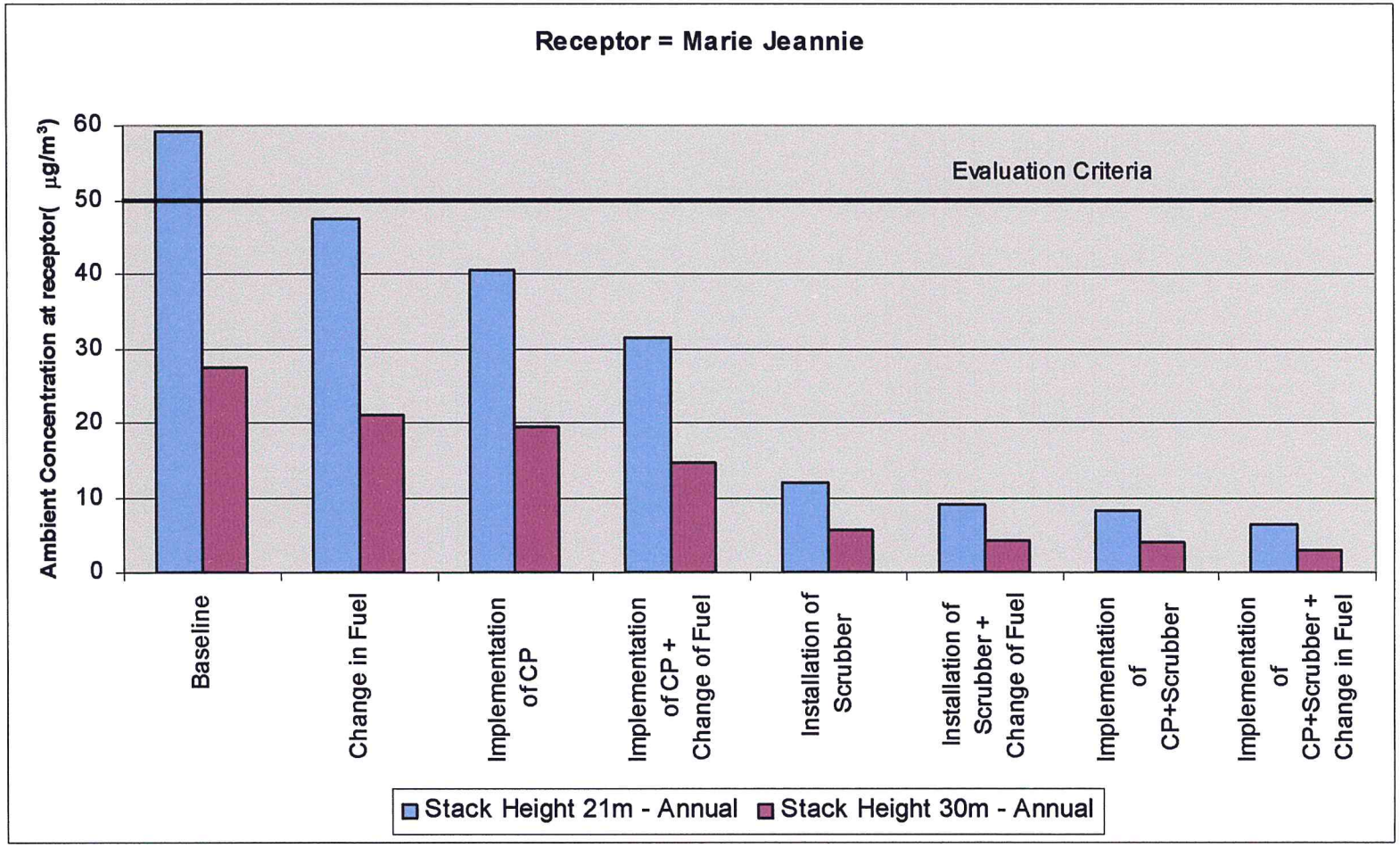


Figure 5.6– Ambient SO2 concentration at Marie Jeannie for a stack height of 21m and 30m for Annual average

5.2 Predicted concentrations of pollutants for multiple sources case study

The predicted concentrations under different pollution control options are presented in Tables 5.4 to 5.6 and the figures 5.7 to 5.9 and compared with the Evaluation criteria. The contour diagrams are given in Appendix D and reports for one hour average for the baseline case is given in Appendix E.

Table 5.4: summary of results of sulphur dioxide modelling for multiple-source (1 hour average). All concentrations in μg/m^3. Evaluation criteria = 260 μg/m^3

OPTIONS	BASELINE		All stacks at 20m		All stacks at 30m	
	Site 1	Site 2	Site1	Site2	Site1	Site2
Baseline value	637	556	323	318	**171**	**69.5**
Change of fuel	443	397	**231**	**199**	**106**	**49.5**
Implementation of CP	434	367	**226**	**195**	**104**	**48.6**
Implementation of CP + change of fuel	310	278	**161**	**139**	**74.1**	**56.0**
Installation of scrubber	**116**	**106**	**62.7**	**55.0**	**33.8**	**12.8**
Installation of scrubber+ change of fuel	**85.7**	**76.4**	**44.4**	**38.4**	**21.5**	**16.0**
CP + Scrubber	**24.5**	**21.9**	**12.5**	**11.0**	**5.93**	**2.74**
CP + Scrubber + change of Fuel	**16.2**	**14.4**	**8.88**	**7.69**	**3.34**	**1.91**

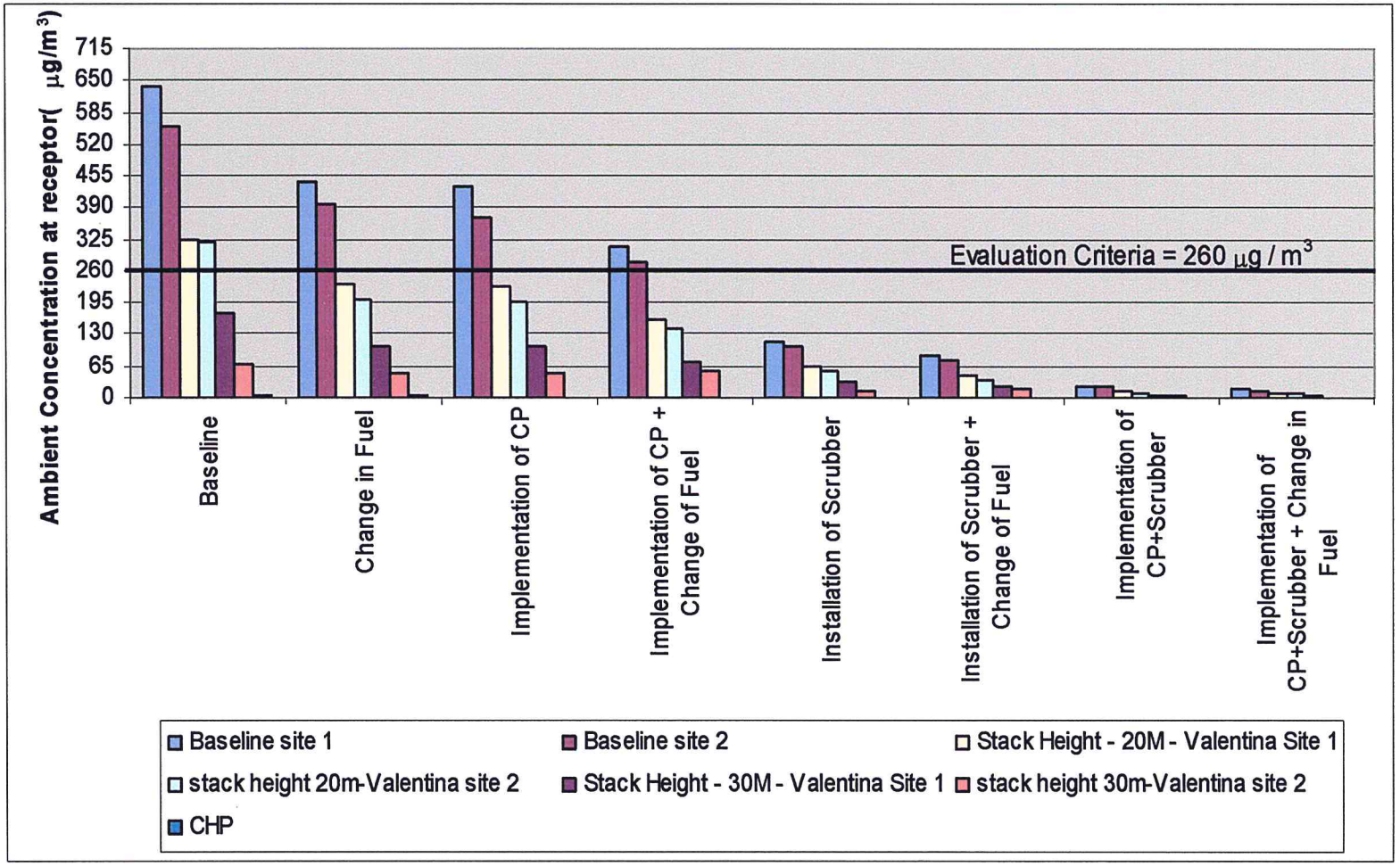


Figure 5.7- graphs of time period of 1 hour average for baseline stack height 20m, 30m and CHP

Table 5.5: summary of results of sulphur dioxide modelling for multiple-source (24 hour average). All concentrations in µg/m^3. Evaluation criteria = 110 µg/m^3

OPTIONS	BASELINE		All stacks at 20m		All stacks at 30m	
	Site 1	Site 2	Site1	Site2	Site1	Site2
Baseline value	154	117	**84.7**	**42.9**	**30.2**	**15.5**
Change of fuel	112	**103**	**65.7**	**30.6**	**26.2**	**11.1**
Implementation of CP	**100**	**78.9**	**56.6**	**30.0**	**21.2**	**6.15**
Implementation of CP + change of fuel	**78.7**	**62.4**	**39.0**	**21.4**	**16.5**	**4.39**
Installation of scrubber	**31.1**	**22.2**	**15.4**	**10.8**	**5.96**	**1.73**
Installation of scrubber+ change of fuel	**19.8**	**15.5**	**11.6**	**5.90**	**4.31**	**2.03**
CP + Scrubber	**6.22**	**4.55**	**3.08**	**1.69**	**1.19**	**0.906**
CP + Scrubber + change of Fuel	**3.95**	**3.10**	**2.15**	**1.18**	**0.611**	**0.242**

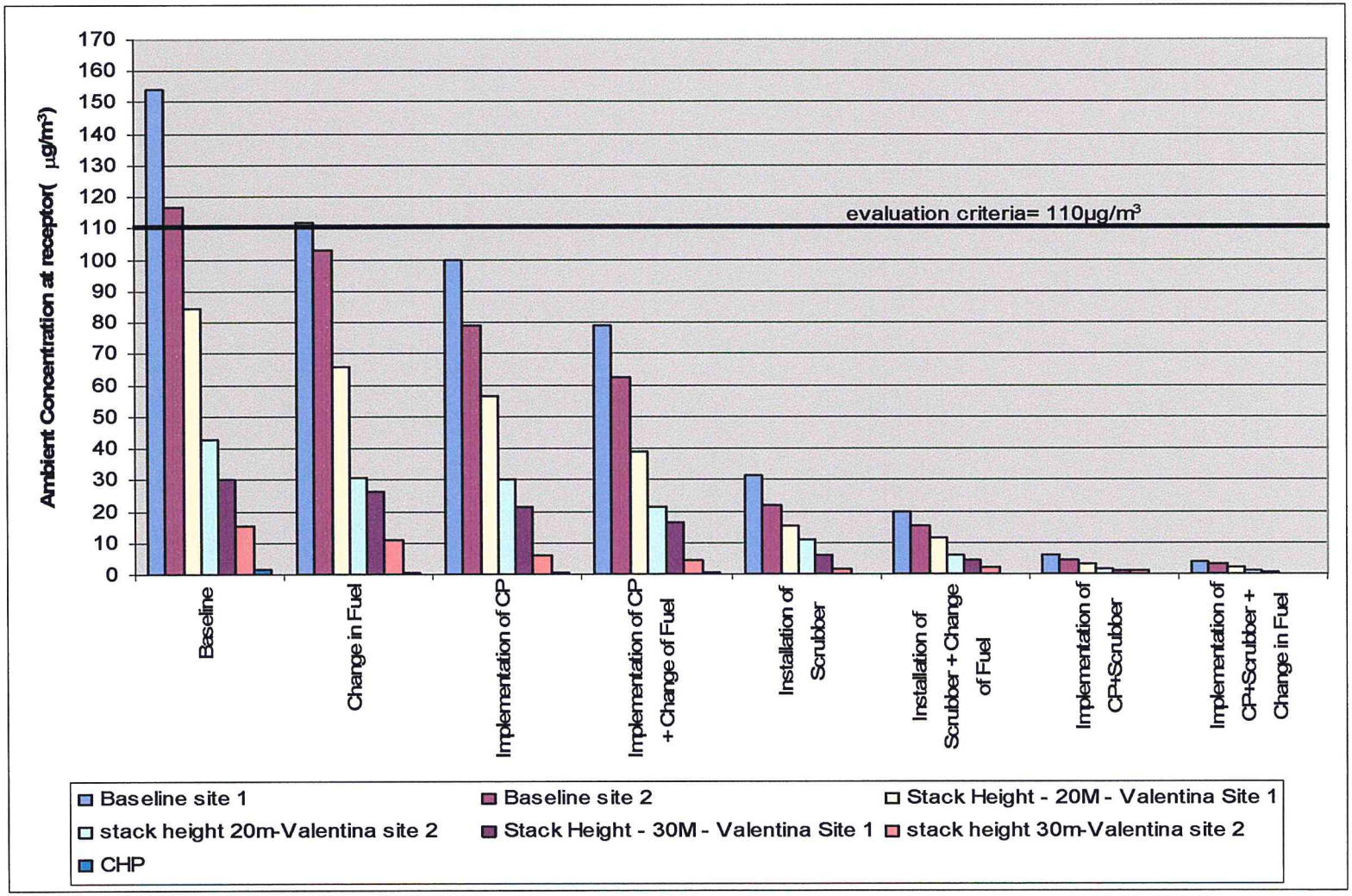


Figure 5.8 - graphs for a time period of 24 hour average for baseline, stack height 20m, 30m and CHP

Table 5.6: summary of results of sulphur dioxide modelling for multiple-source (annual average). All concentrations in µg/m^3. Evaluation criteria = 50 µg/m^3

OPTIONS	BASELINE		All stacks at 20m		All stacks at 30m	
	Site 1	Site 2	Site1	Site2	Site1	Site2
Baseline value	**40.2**	**16.3**	**11.2**	**4.94**	**2.18**	**1.71**
Change of fuel	**31.2**	**13.6**	**10.95**	**4.54**	**1.61**	**1.22**
Implementation of CP	**26.9**	**13.3**	**9.87**	**3.21**	**1.58**	**1.20**
Implementation of CP + change of fuel	**19.2**	**8.6**	**8.54**	**2.67**	**1.13**	**0.513**
Installation of scrubber	**7.59**	**3.76**	**2.20**	**1.56**	**0.615**	**0.385**
Installation of scrubber+ change of fuel	**6.58**	**2.63**	**1.54**	**0.633**	**0.322**	**0.244**
CP + Scrubber	**1.73**	**0.753**	**0.442**	**0.181**	**0.089**	**0.068**
CP + Scrubber + change of Fuel	**1.21**	**0.526**	**0.307**	**0.127**	**0.062**	**0.028**

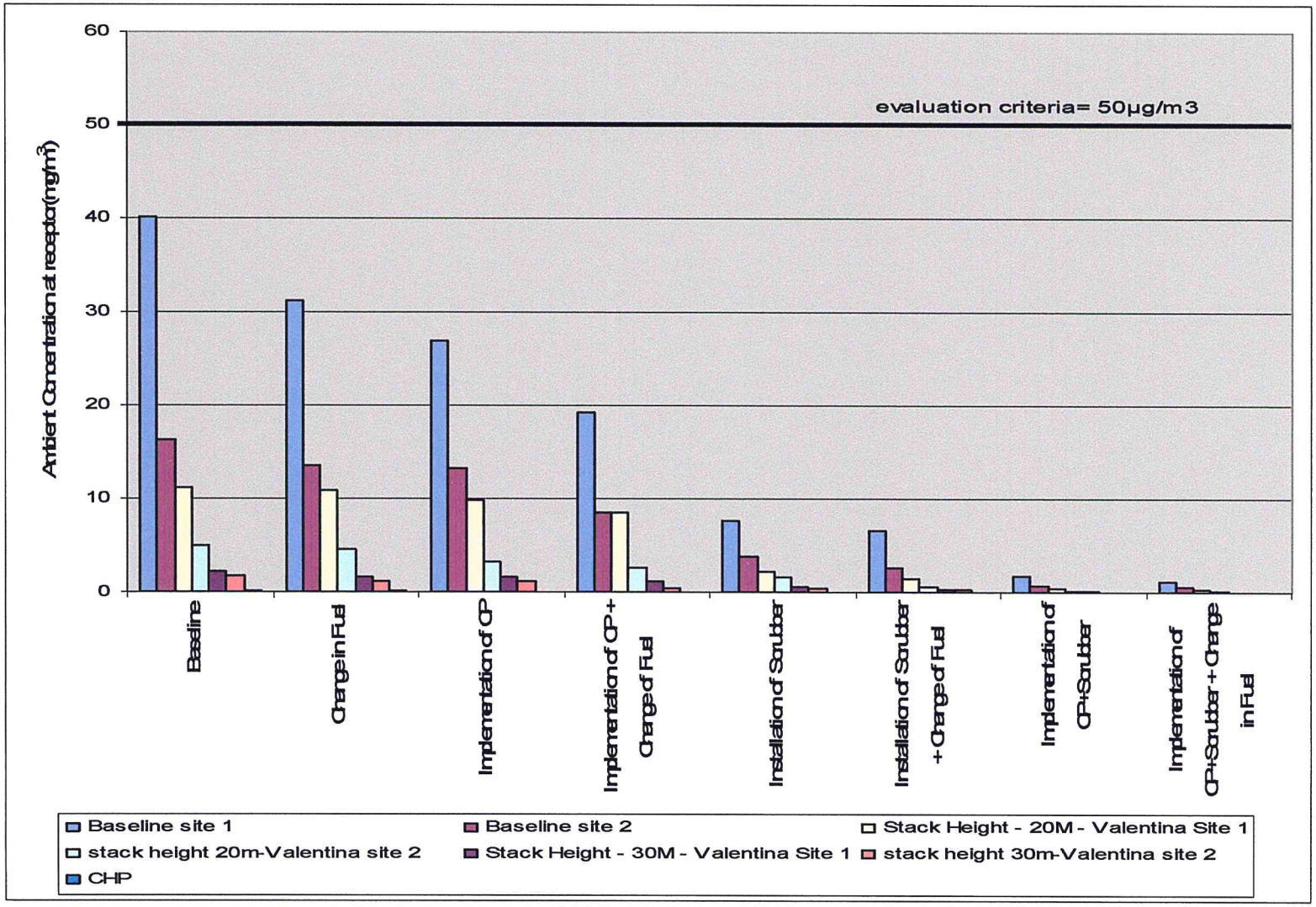


Figure 5.9 - graphs for annual average for baseline, stack height 20m, 30m and CHP

5.3 Discussion

5.3.1 Comparison of Modelling results with Monitoring Data

Ambient Air Monitoring has been carried out by the Ministry of Environment using its mobile station only near the two sites at Valentina in March and April 2002 (MOE, 2002). No monitoring data was available for the single-source study.

The monitoring data for the multiple-source case study shows that there is a very significant increase in the average SO_2 concentration in Valentina 2 (115 ug/m3) and Valentina 1 (43 ug/m3) when compared to the upwind background concentration (3 ug/m3). On 5 days out of the 22 days monitoring period (i.e. on 22 % occasions) the 24-hour air quality SO_2 standards was exceeded in Valentina site - 2. 24-hour maximum values range from 150 to 270 ug/m^3. Modeled maximum 24-hour concentrations in this study range from 117 to 154 ug/m3.

On 20 occasions out of the 500 hours of monitoring period, the hourly SO_2 concentration standard was exceeded in Valentina 2.

The monitoring and modeled data are therefore comparable in order of magnitudes and this justifies the use of the modeled data for decision-making purposes.

5.3.2 Single source case-study

It may be observed that for the base-case, 1-hour and 24-hour average concentrations of sulphur dioxide have a high probability of not meeting standards at the two receptors. The annual average concentrations are however below the standards with the exception of receptor 1.

Raising the stack height to 30m does not resolve the problem although there is a significant decrease in the concentrations of SO_2. CP options alone or change in fuel alone also are not enough to resolve the problem.

The installation of a wet scrubber is found to be very effective, although it is initially an expensive option for the factory. Similar results are obtained if a change of fuel and CP options are pursued. Pollution control method to be selected by the factory would depend on the cost- benefit analysis of these two options and the initial investment involved and availability of funding. Table 5.10 below gives an estimated capital and operating cost of pollution control measures for the single source case study.

Table 5.7: Estimated cost of pollution control options for single source

Options	Capital Cost (Rs)	Operating cost/year (Rs)
Increase of stack height from 21m to 30m	100,000	-
Change in Fuel		500,000
Implementation of CP	100,000	100,000
Implementation of CP + Change of Fuel	100,000	600,000
Installation of Scrubber	2.5 million	200,000
Installation of Scrubber + Change of Fuel	2.5 million	700,000
Implementation of CP+ Scrubber	2.6 million	300,000
Implementation of CP+ Scrubber + Change in Fuel	2.6 million	800,000

If the factory considers the option of keeping the stack height to 21m, followed by implementation of CP and change of fuel, the capital cost involved is reasonable and can be met by the factory itself. However, the yearly operating cost is high and would tend to increase with rising oil prices. On the other hand, for the installation of a wet scrubber the factory will most probably need to take a loan from a bank.

5.3.3 **Multiple source case-study**

It will be observed that for the base case, 1-hour and 24-hour average concentration of sulphur dioxide has a high probability of not meeting standards at the two receptors. The annual average concentrations are always below the standards. Raising the stack to 20m does not resolve the problem while raising it to 30m is effective. Options like change of fuel alone or implementation of CP on the base case are not enough to resolve the problem and though there is a significant decrease in sulphur dioxide concentration yet there is a high probability of not meeting the standards.

An increase of stack height to 20m, followed by change of fuel is found to be an effective option; however similar results are obtained if only the stack heights are raised to 30m. This is the most cost effective option but the concentration of sulphur dioxide can further be decreased if implementation of CP is considered.

Change of fuel and installation of scrubbers are expensive pollution control options in this context. Table 5.11 below gives the estimated capital and operating cost involved for the multiple source case study.

Table 5.8: Total Cost of pollution control options for multiple sources

Options	Capital Cost (Rs)	Operating cost/year (Rs)
Increase of stack height from baseline to 20m	250,000	-
Increase of stack height from baseline to 30m	375,000	-
Change in Fuel		1.5 million
Implementation of CP	300,000	300,000
Implementation of CP + Change of Fuel	300,000	1.8 million
Installation of Scrubber	7.5 million	600,000
Installation of Scrubber + Change of Fuel	7.5 million	2.1 million
Implementation of CP+ Scrubber	7.8 million	900,000
Implementation of CP+ Scrubber + Change in Fuel	7.8 million	2.4 million
CHP	20 million	200,000

The option of a CHP is indeed one of the best options that integrate win-win situations of saving in fuel consumption and alleviation of high sulphur dioxide concentration. However, the institutional framework and policies are not yet in place for the installation of CHPs on industrial estates in Mauritius.

The modelling also helps in assessing the source contribution of each factory to the pollution problem in the village. Figure 5.10 gives a diagrammatic representation of source sulphur dioxide contributions at Valentina village.

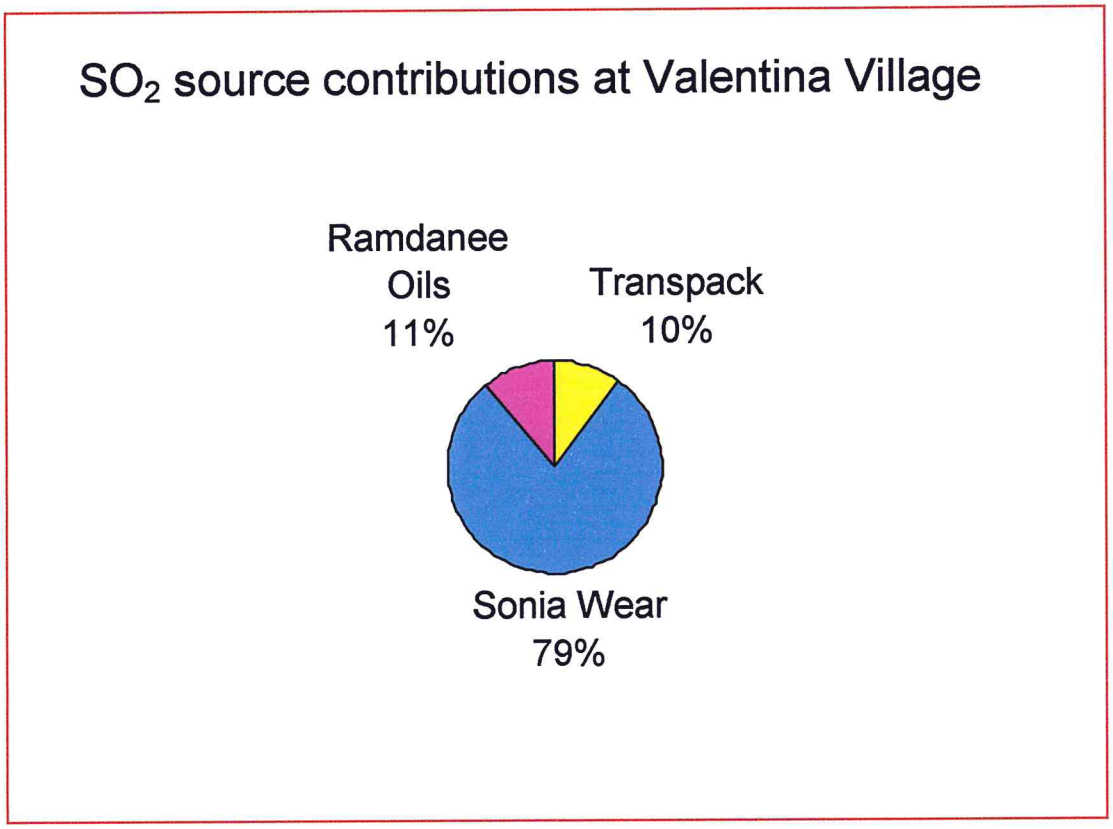


Figure 5.10: Source contribution at Valentina Village

This source apportionment shows that the focus of intervention of the regulatory authority should be on the Sonia wear factory.

5.3.4 General discussion

- The modelling results show that raising stack heights and changing fuels as well as implementing Cleaner Production are effective pollution control options to be considered by industries operating boilers in Mauritius.
- A regulation should be enacted by the Ministry of Environment which imposes a minimum stack height conforming to Good Engineering practice (GEP) as well as enabling the Ministry to impose a change in fuel for a particular factory.
- For implementation of CP, both the regulatory authority and the industrial sector should work together for capacity building in CP. Simple measures like improved fuel storage and preparation, trained boiler operators, heat conservation and modifications and addition of more efficient equipment must be replicated in the industry.
- The MOE should strengthen its enforcement capacity to ensure that the standards are enforced.

CHAPTER SIX

CONCLUSIONS &

RECOMMENDATIONS

CHAPTER SIX

CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

The aim of this project was to use an air dispersion model for the selection of air pollution control systems for industrial boilers on the island of Mauritius. The specific objectives of this study were as follows:

- ❖ To carry out a literature review on the types of regulatory air dispersion models available and subsequently choose one suitable for the Mauritian context.
- ❖ To predict the ambient sulphur dioxide concentration in the residential areas downwind of a single industrial boiler and downwind of an industrial estate consisting of multiple industrial boilers using the model under different modelling scenarios.
- ❖ To determine the optimum air pollution control system in each case based on a cost-benefit analysis.
- ❖ Make recommendations for proper use of Air Quality modelling in Mauritius

The main conclusions of this study are as follows:

1. During the last decade there have been an increasing number of complaints to the Ministry of Environment regarding pollution from industrial boilers in Mauritius. Industry is under increasing pressure from

the regulatory authority and from the general public to control the air pollution from industrial boilers using high sulphur content fuel oil. The measures taken are usually 'adhoc' in nature and there has been no proper scientific methodology to justify the nature of the pollution control interventions that need to be taken by the industry. This project aims at being a scientific approach in the form of an air dispersion model to help industries (and the regulatory authority) in the selection of the most cost-effective pollution control options. Air modelling as a planning tool provides this scientific methodology to industries and the regulatory authority to select among the possible options such as raising stack heights, change of fuels, implementing cleaner production opportunities or installation of wet-scrubbers.

2. Over the past 15-20 years, the Industrial Source Complex (ISC) model has been the preferred model for most regulatory modelling applications around the world. This model is being replaced by the more sophisticated AERMOD model as the USEPA's preferred model for regulatory applications in the U.S. The AERMOD model is however quite complex and requires a lot more inputs (especially advanced meteorological and terrain data) that would be difficult for Mauritius to apply. Given the limitations regarding the availability of met data, for most applications, a steady state Gaussian dispersion model such as ISCST is suitable. This model enables a number of different source configurations to be assessed

and can incorporate simple terrain and building wake effects. There is a movement towards more sophisticated and more accurate model s but this movement is not without its drawbacks, most notable the requirement for much more robust meteorological data to improve the accuracy of model predictions. Given such constraints, it is recommended to start using established and simple modelling methods as the complexity of the more refined models requires a relatively long learning curve to be able to use the model correctly. Simple models such as Industrial Source Complex 3 (ISC3) have a relatively good history for regulatory applications and their strengths and weaknesses are well understood.

3. The application of the ISCST-3 model to a single-source case study showed that for the base-case, 1-hour and 24-hour average concentrations of sulphur dioxide have a high probability of not meeting standards at the two receptors. Raising the stack height to 30m does not resolve the problem although there is a significant decrease in the concentrations of SO_2. CP options alone or change in fuel alone also are not enough to resolve the problem. The best option is raising the stack height to 30 m and either a change of fuel and implementing CP or an investment in a wet-scrubber system.

4. The application of the ISCST-3 model to a multiple sources case study showed that by increasing the stack heights of all factories to 30 m the

problem can be resolved cost-effectively. Implementing CP options will further decrease ambient concentrations. A source apportionment identified that one factory was responsible for 79% of the ambient levels and will need to be closely monitored by the regulatory authority.

5. The regulatory authority need to review the current standards to include a regulation on stack height as well as to enable it to mandate a change of fuel if need be. Also, there is a need for capacity building on cleaner production opportunity assessments for industrial boilers in Mauritius.

6. This study has shown the applicability of an air dispersion model in determining the most cost-effective pollution control option for industrial boilers in Mauritius. The regulatory authority and the industry need to use this scientific tool in devising pollution control strategies in all industrial estates around the island.

6.2 Recommendations for Effective Air Quality Modelling in Mauritius

- An Air Quality Modelling Guideline needs to be developed by the Ministry of Environment to ensure consistency in the use of dispersion models for regulatory applications in Mauritius. The objectives of the guidelines are to provide for uniform benchmarking and detail the required content of assessments that are submitted to the Ministry. These guidelines

would set out guidance on appropriate models and technical methods as well as the information required to demonstrate that a source meets the ambient air quality standards. These guidelines will be particularly useful for preparing and reviewing EIAs with illustrative on "do's" and "don'ts" and solved problems.

- The Ministry of Environment and the Meteorological Services (together with other appropriate stakeholders such as research institutions) should work closely together to design an appropriate format of meteorological data to be used as input to Air Quality Modelling software. About 5 regional stations representing typical climates in Mauritius need to be selected and at least one year data from these stations need to be put in the appropriate format to be used by modellers.

- Capacity need to build within the Ministry of Environment. At least 2 modellers would have to be trained so that they are able to run the data provided by project proponents on ISC and check that the results submitted by proponents conform to source data. (The Ministry could request that the ".IMP" file be sent along with the modelling report).

- There is a need to establish and rationalize air quality and meteorological monitoring network. The Environment Impact Assessment Division and the National Environmental Laboratory should work closely so as to

regularly calibrate the model with actual monitoring data. Pilot model applications would need to be run, together with planned monitoring of isolated stacks to assess the calibration.

- As the Ministry of Environment gathers experience in the application of ISC air quality modelling, other more specialized models applicable to specific circumstances such as AERMOD, CALPUFF, and ADMS (Advanced Dispersion Modelling System) could be probed into in the medium term

6.3 Recommendations for Further research

- A scientific method needs to be developed based on modelling studies to help in deciding the most appropriate stack height for a factory for a given level of emissions. This method can be part of the regulation for a minimum stack height.
- ISC should not be used in cases of shoreline fumigation. Given that Mauritius is an island, there are cases of shoreline fumigation from industrial and power-plant emissions. More research on shoreline fumigation cases and exposure assessment need to be carried out.
- Source apportionments need to be carried out in all industrial estates and traffic hot spots to enable the Ministry of Environment to focus its interventions

- ❖ There is a need to undertake similar modelling studies for major traffic junctions and Develop/adapt emission factors for vehicles.

Recommendations for Department of Environment, GoM

On

Air Quality Management

Action Points: Immediate basis

- Develop air quality modelling guidelines for preparing and reviewing EIAs with illustratives on “do’s” and “don’ts” and solved problems
- Build capacity within DoE, select academica/research bodies and private sector on application of air quality models on this basis
- Establish/rationalize air quality and meteorological monitoring network

Action Points: Medium term basis

- Sponsor pilot modelling studies (including monitoring) for major traffic junctions and industrial estates
- Develop/adapt emission factors for vehicles and major industrial sources
- Undertake pilot regional studies for applying models to take decisions

Action Points: Long term basis

- Establish based on regional studies, air quality planning guidelines
- Focus on select research topics such as shoreline fumigation, exposure assessment
- Set up twinning arrangements on modelling

REFERENCES

Abdul-Wahab, S.A (2003).SO_2 Dispersion and Monthly evaluation of Industrial Source Complex short-term (ISCS 32) model at Mina Al – Falal Refinery , Oman. Environmental Management. Vol 32, Issue 2, 2003.pp 276-291.

Andretta, M; Brazzi , L; Pinni,C and Righi,S (2004). A benchmark of two different simulation Models for air quality evaluation in a Complex Industrial area. Management Information System. Vol 9, 2004.pp 629-638.

Atkinson. Dennis .G. Desmond. T.Bailey; John .S. Irwin and Jawad . S. Touma (1996). Improvements of the EPA Industrial Source Complex Dispersion Model by Atmospheric Sciences Modeling Division, Air Resources Laboratory, National Oceanic and Atmospheric Administration, Research Triangle park, North California. Journal of applied methodology. Vol 36, No 8. pp1088-1095.

Bedassy, N (2004). Application of Air Quality Model to assess the impacts of point and line sources on Air Quality. BSc(Hons), thesis. University of Mauritius.

Brower , R; Coriol, L and shernelle, J (1996). Evaluation of AMS/EPA regulatory Model (AERMOD) using Maryland Power Plant field data. Proceeding of the Air and Waste Management Association's Annual Meeting & Exhibition, 1996.

Central Statistics Office (2004). Digest of Environmental Statistics – Vol I. Ministry of Finance and Economic Development. Republic of Mauritius.

"Citizen's Guide of Air Dispersion Modelling, Air Quality". (06 August 2002) Available: www.pca.state.mn.us / Publications / aq 1 – 06 [Accessed 8th January 2007].

Curtis.P. Wagner (1996),"GAIA model base: Industrial Source Complex Model, "GAIA [online] Available: cesimo.ing.ula.ve/GAIA/models/ISC.html. [Accessed 17th February 2007]

David Copper, C; and Alley, F.C (1990). Air Pollution Control, A design Approach. Wavel and Press. Inc (1990).

DOE(1998). Global Environment Outlook II, National Report, Ministry of Environment, July 1998.

EPA (2002). The Environmental Protection Act 2002. Ministry of Environment.

Environmental Resource Management [ERM](1996).National Environmental strategies for the Republic of Mauritius, National Environment Action plan for the Next decade.

"Final energy consumption by sector, 1996-2005" (April 2007), Digest of Energy and Water Statistic (2005)], Available: www.gov.mu/portal/goc/cso/report/natacc/energy05/toc.htm. [Accessed 16th May 2007]

"Flue gas stack", Wikipedia.org/wiki/flue_gas_stack.(Accessed 4th May 2007)

Fushmi, A; Kawashima,H and Kaajihara, H (2005). Source appointment based on an atmospheric dispersion model and multiple linear regression analysis, Atmospheric Environment. Vol 39, Issue 7, 2005.pp 1323- 1334

Garg, S.K (1996). Sewage Disposal and Air Pollution Engineering. Vol III, 12th (9th revised) edition, Khanna Publishers, Delhi, India.

Holper.Paul and Noonan.J (2006, April. 11),"urban and regional Air pollution information sheet," CSIRO [online] Available: www.dar.CSIRO.au/information/urban pollution.html [Accessed on 11th December 2006]

Homar Paul (1993). Urban and Regional Air Pollution, CSIRO Atmospheric Research Information sheet. 1993, Australia.

Kumar, A; Bellam, N.K and Sud, A (1999). Performance of an Industrial Source Complex Model: Predicting long- term concentrations in an urban area. Environmental Progress. Vol 18, Issue 2, 1996. pp 93-100

Long, D (2004). Comparison of the performance of AERMOD and ISC on elevated point sources. Proceeding of the Air and waste management Associations, Annual Exhibition, 2004. pp 597-613.

Mackenzie. L, D and Cornwell D.A. (1991). An introduction to environmental Engineering, New- York; McGraw-Hill. 1991.

Modak, P (2002). Environmental Management of Industrial Estates Vacoas-Phoenix Industrial Estate. Ministry of Environment, 2002.

MOE (1999). National Environmental strategies for the Republic of Mauritius. Ministry of Environment, July 1999.

National Institute of Water and Atmospheric Research (2002). Good engineering practice guide for atmospheric dispersion modeling. Aurora Pacific Limited and Earth TEC Incorporated for the Ministry of Environment. Air quality Technical Report No 27. New-Zealand, 2002.

Padya(1994). The climate of Mauritius. Mahatma Gandhi Institute Press. Mauritius.

Patil (2005). An integrated Air Quality Modeling Package for Economic Evolution of Health Impacts for an Industrialised region in Mumbai. NOA\EPA Golden Jublee Symposium on Air Quality and its Application. 2005. Durham,NC.

Rajkoomar , D (2004). A review of Economic instruments for Pollution Control and their application in the Mauritian Context, MSc thesis, University of Mauritius.

Ramakrishna, T; reddy, M and Sing, R (2005). Impact of Industrilal Complex on the ambient air quality, case-study using a dispersion Model. Atmospheric Environment. Vol 39, Issue 29, September 2005. pp 5395-5409.

Ramjeawon, T and Ramchurn, S (2002). Assessment of Impact of Road traffic and industrial sources on Air Quality through monitoring and atmospheric dispersion modeling interim report, MRC Funded Project (MRC\Run- 00130)

Ramjeawon, T (2002). Environmental management of Industrial Estates Vacoas-Phoenix Industrial Estate. Ministry of Environment, 2002.

Rao.M.V and Rao H.N.V(1989). Air Pollution. TATA: McGraw- Hill.1989.

Schnelle Karl, B (1992). Atmospheric Dispersion Modeling Compliance Guide, New- York: McGraw-Hill. 1999.

Schroeder, A.J (2004). Comparison of two dispersion models: A bulk petroleum storage terminal study. Proceeding of Air and waste management Associations Annual meeting and Exhibition, 2004. pp 615- 631.

Sivacoumar, R; Bhanakar, A.D;Goyal,S.K; Aggrawal,A.L (2001). Air Pollution Modeling for an industrial Complex and model performance evaluation, Environmental Pollution. Vol III, Issue 3, 2001. pp 471-477.

The American Meteorological Society(1997). Scientific Journals, improvements to the EPA Industrial Source Complex Model, AMS,1997.

Tilhoo, R (2002). Mathematical Modeling and Stimulation studies process for waste water treatment. BSc thesis, University of Mauritius.

USEPA(1998). Compilation of Air Pollution Emission Factors, Vol 1, Fifth Edition, AP – 42.

WHO (2003). Report on overview on Air Pollution. Scientific Consensus. March 2003.

World Bank (1995).Initial draft of Industrial Pollution prevention and Abatement Handbook. Available : www.worldbank.org/html/ftd/em/power/standards/airqstd.stm. [Accessed on 10th June 2007].

World Bank (2000).Urbanisation and Urban Air Pollution, Washington.

APPENDIX A

Main Energy indicators, Republic of Mauritius, 1996 – 2005

Details	Unit	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Total primary Energy Requirement	Ktoe	910.3	943.7	1007.7	999.5	1113.1	1182.0	1157.3	1222.8	1255.8	1293.2
Imported	Ktoe	634.7	647.3	707.2	778.9	849.0	901.2	896.8	956.3	980.1	1030.5

Imports of energy sources (Energy unit), Republic of Mauritius, 1996-2005

Thousand tonnes of oil equivalent (Ktoe)

Energy sources	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Fuel oil	186.6	239.2	263.2	236.4	210.0	264.1	200.2	276.5	277.3	316.7

Fuel input for electricity production, (Energy unit), Republic of Mauritius, 1996-2005

Thousand tonnes of oil equivalent (Ktoe)

Fuel	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
(Island of Mauritius) Fuel oil	139.6	154.4	169.0	183.1	164.5	173.8	167.9	192.1	206.7	201.7
Diesel oil	2.2	2.3	2.6	3.1	2.9	2.6	2.8	2.4	2.4	1.9
Coal	4.1	11.4	27.6	69.5	141.7	169.5	177.9	178.0	164.4	211.2

Final energy consumption by sector and type (physical unit), Republic of Mauritius, 1996-2005

Sector	Unit	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Manufacturing Fuel oil	tonne	36,590	39,518	42,774	45,150	49,000	60,630	61,439	55,615	49,857	46,763
Diesel oil	tonne	23,367	26,622	30,233	32,650	41,600	37,533	37,406	41,273	43,372	41,127
Coal	tonne	33,727	27,242	25,713	24,490	24,464	25,781	25,888.	29,000	24,220	23,162

Final energy consumption by sector (Energy unit), Republic of Mauritius, 1996-2005

Thousand tonne of equivalent (Ktoe)

Sector	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Manufacturing	292.2	311.8	299.3	240.2	249.9	262.4	249.2	262.3	259.3	248.6
Transport	285.5	291.4	309.2	326.0	355.9	372.3	364.1	390.2	408.7	418.6
Household	84.2	86.9	89.8	92.0	99.2	101.8	102.8	107.0	111.0	115.5
Commercial And Distributive Trade	26.0	29.1	32.3	34.1	36.9	40.8	41.7	47.7	51.5	55.7
Agriculture	3.9	3.9	4.4	4.3	4.8	4.8	4.8	4.8	4.4	4.7
Other (n.e.s) and losses	1.4	1.5	1.6	1.8	2.3	2.3	2.4	2.9	3.2	3.1
TOTAL	693.1	724.5	736.6	698.3	749.0	784.4	765.1	814.9	838.1	846.1

Percentage share of final energy Consumption by sector, Republic of Mauritius, 1996-2005

Sector	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Manufacturing	42.2	43.0	40.6	33.4	33.4	33.5	32.6	32.2	30.9	29.4
Transport	41.2	40.2	42.0	46.7	47.5	47.5	47.6	47.9	48.8	49.5
Household	12.1	12.0	12.2	13.2	13.2	13.0	13.4	13.2	13.2	13.6
Commercial And Distributive Trade	3.8	4.0	4.4	4.9	4.9	5.2	5.5	5.9	6.1	6.6
Agriculture	0.6	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.6
Other (n.e.s) and losses	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

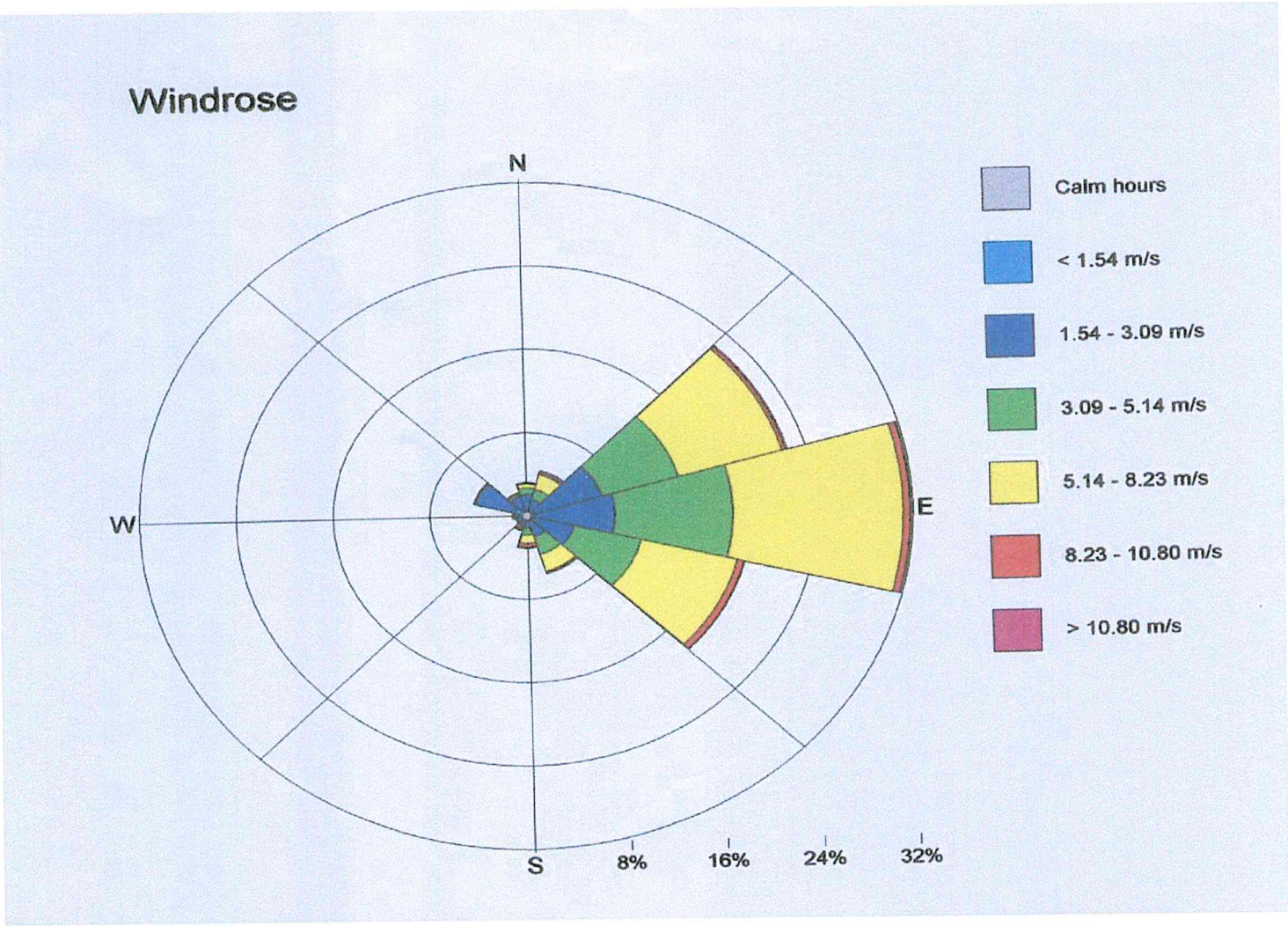
APPENDIX B

Plaisance Monthly Mean, Maximum and Minimum temperatures

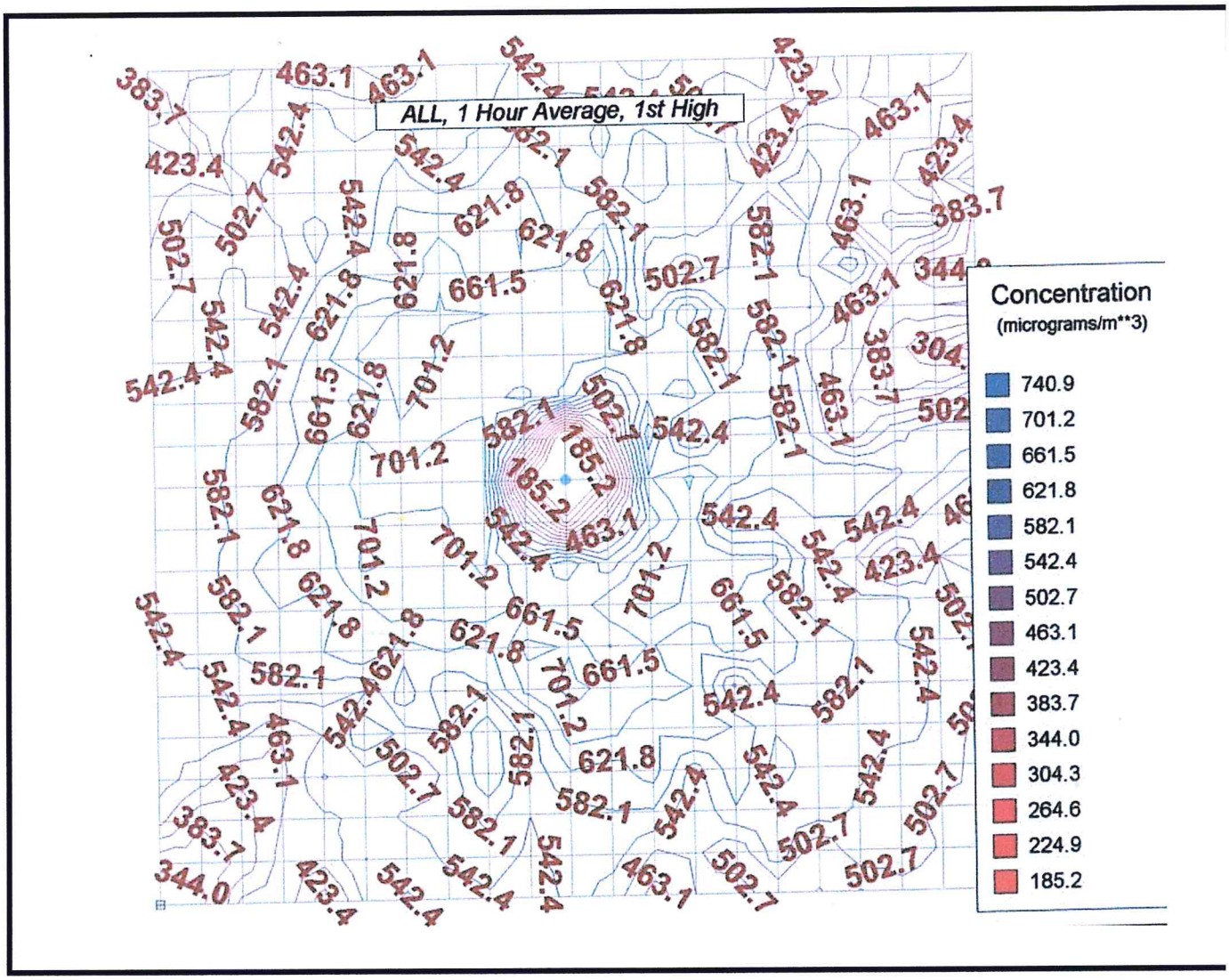
Month	Maximum Temp (^{0}C)	Minimum Temp (^{0}C)	Mean Temp (^{0}C)
January	29.3	22.5	25.9
February	29.3	22.7	26.0
March	28.9	22.5	25.7
April	28.1	21.3	24.7
May	26.3	19.7	23.6
June	25.0	18.3	21.7
July	24.1	17.8	21.0
August	23.7	17.4	20.6
September	24.6	17.7	21.2
October	25.9	18.6	25.6
November	27.6	20.1	23.6
December	28.6	21.5	25.2

APPENDIX C

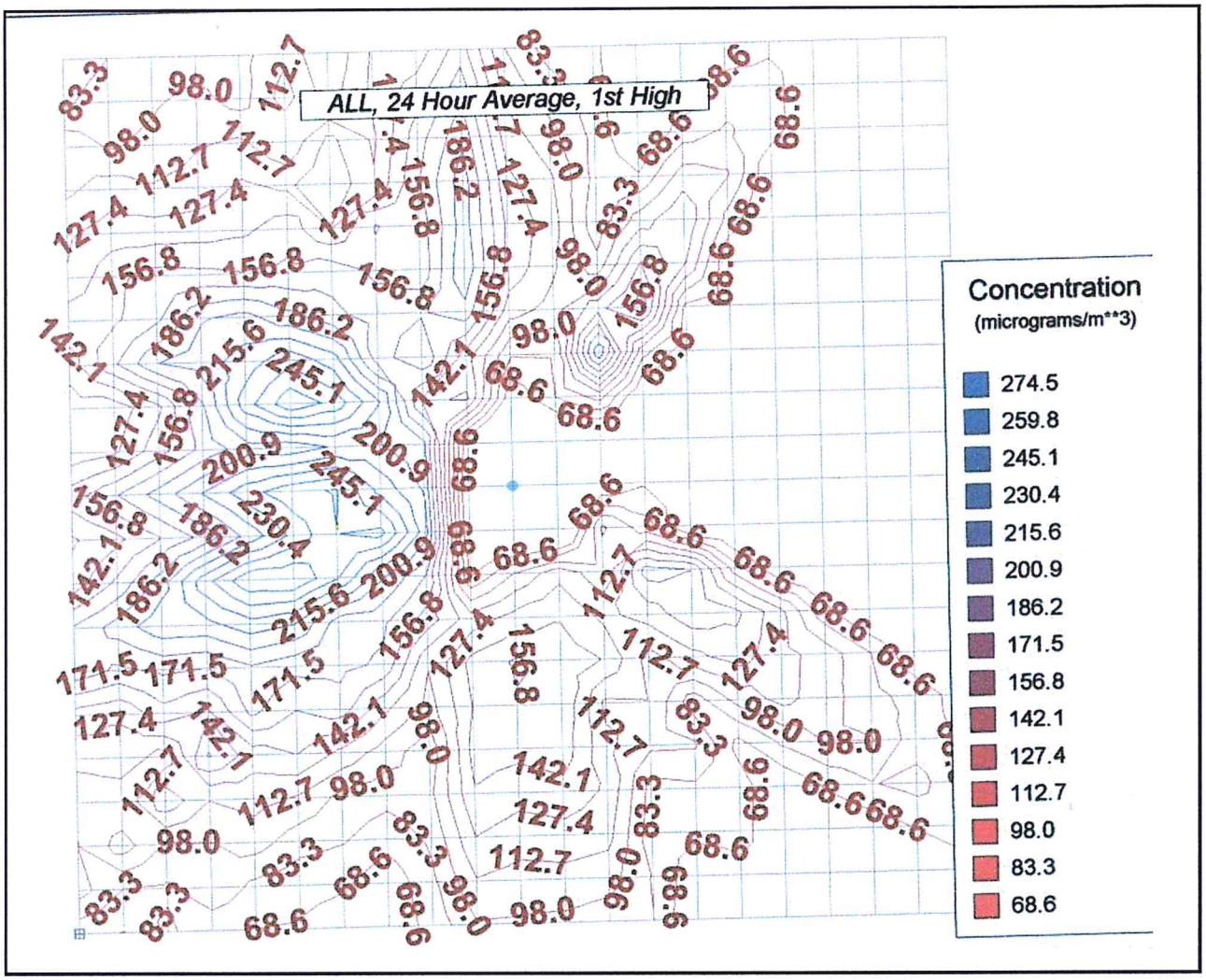
Figure Showing Windrose for Plaisance Station



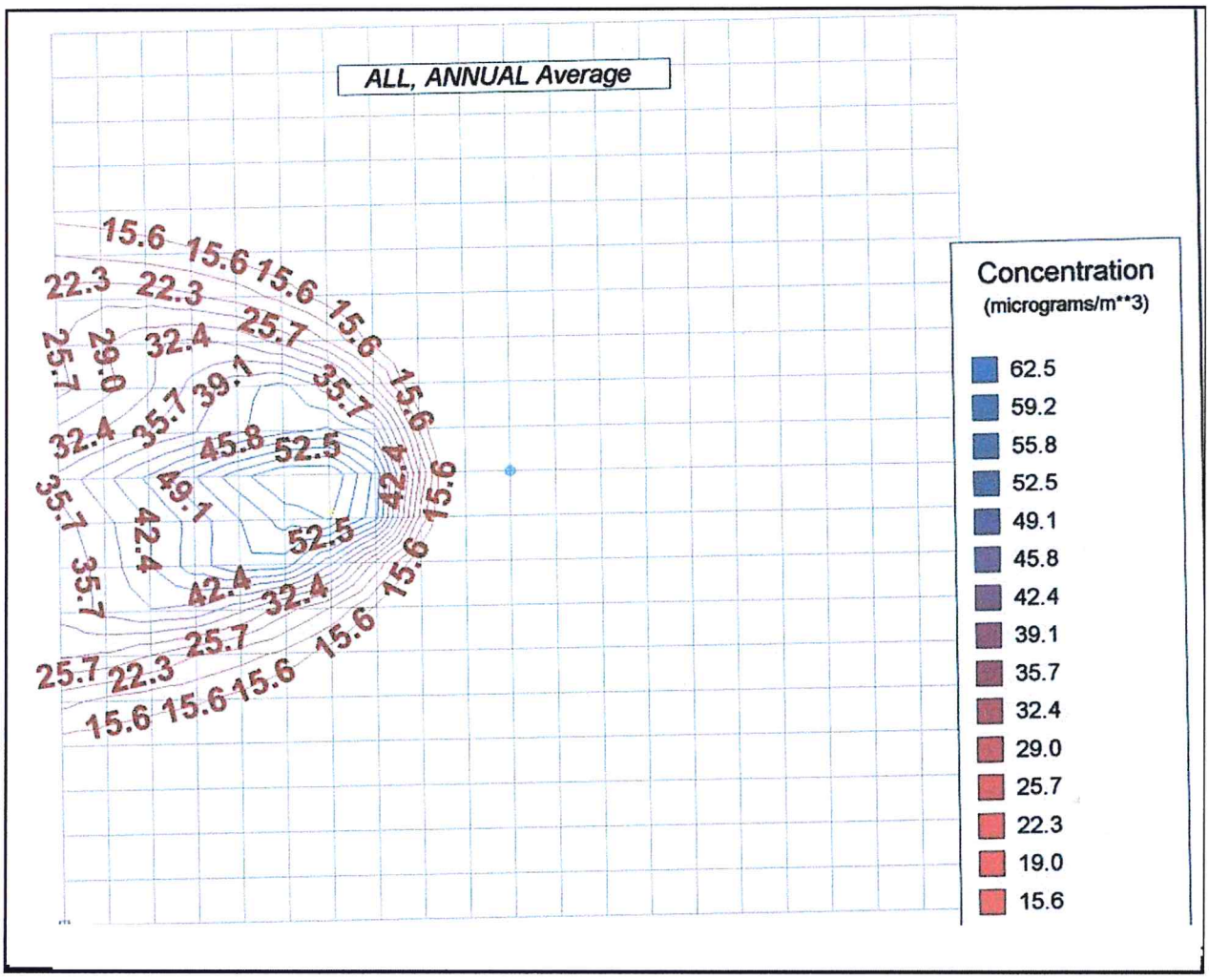
APPENDIX D



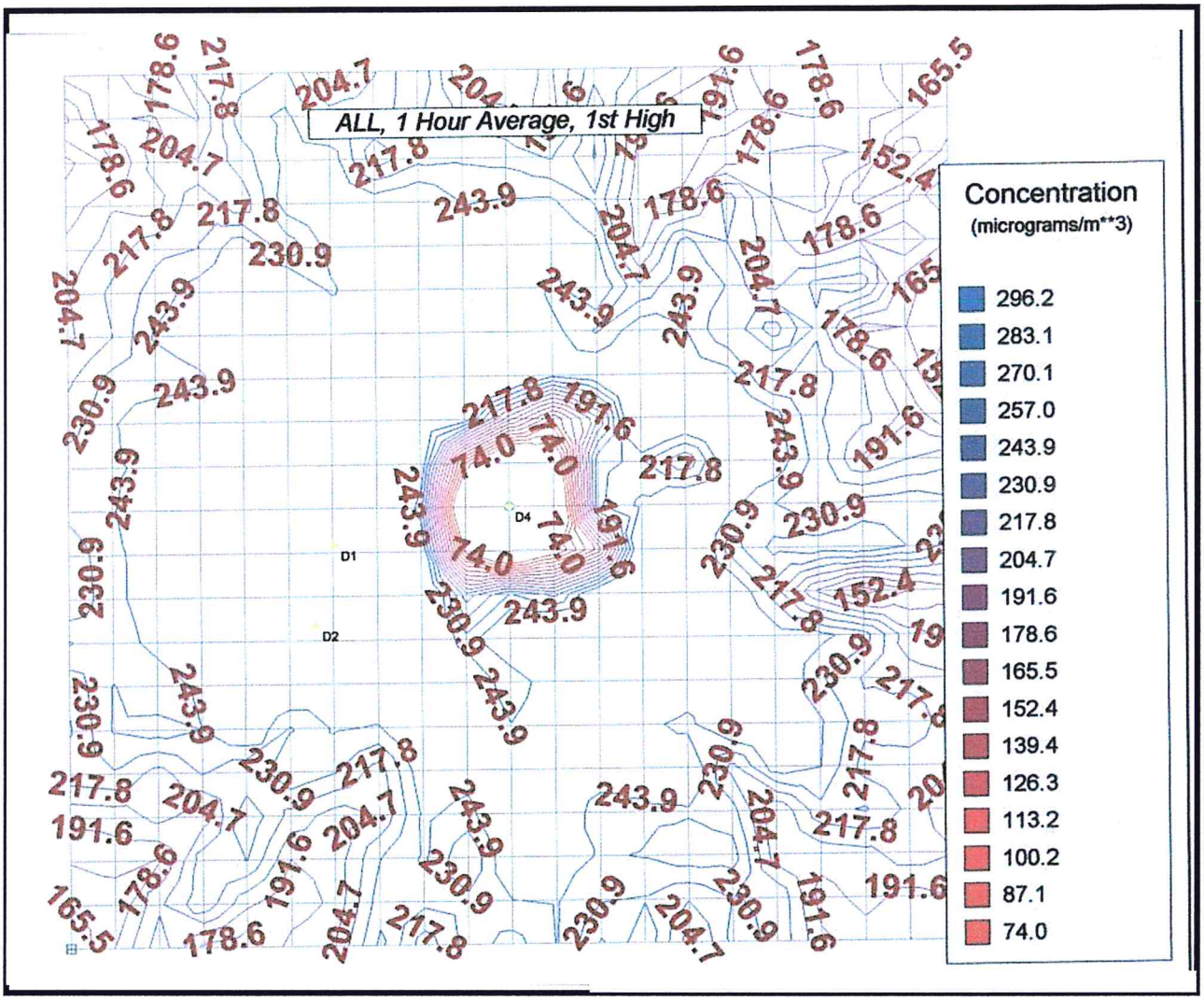
Contour diagram for 1 hour average with a stack height of 21m	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Marie -Jeannie	729
Government school	667



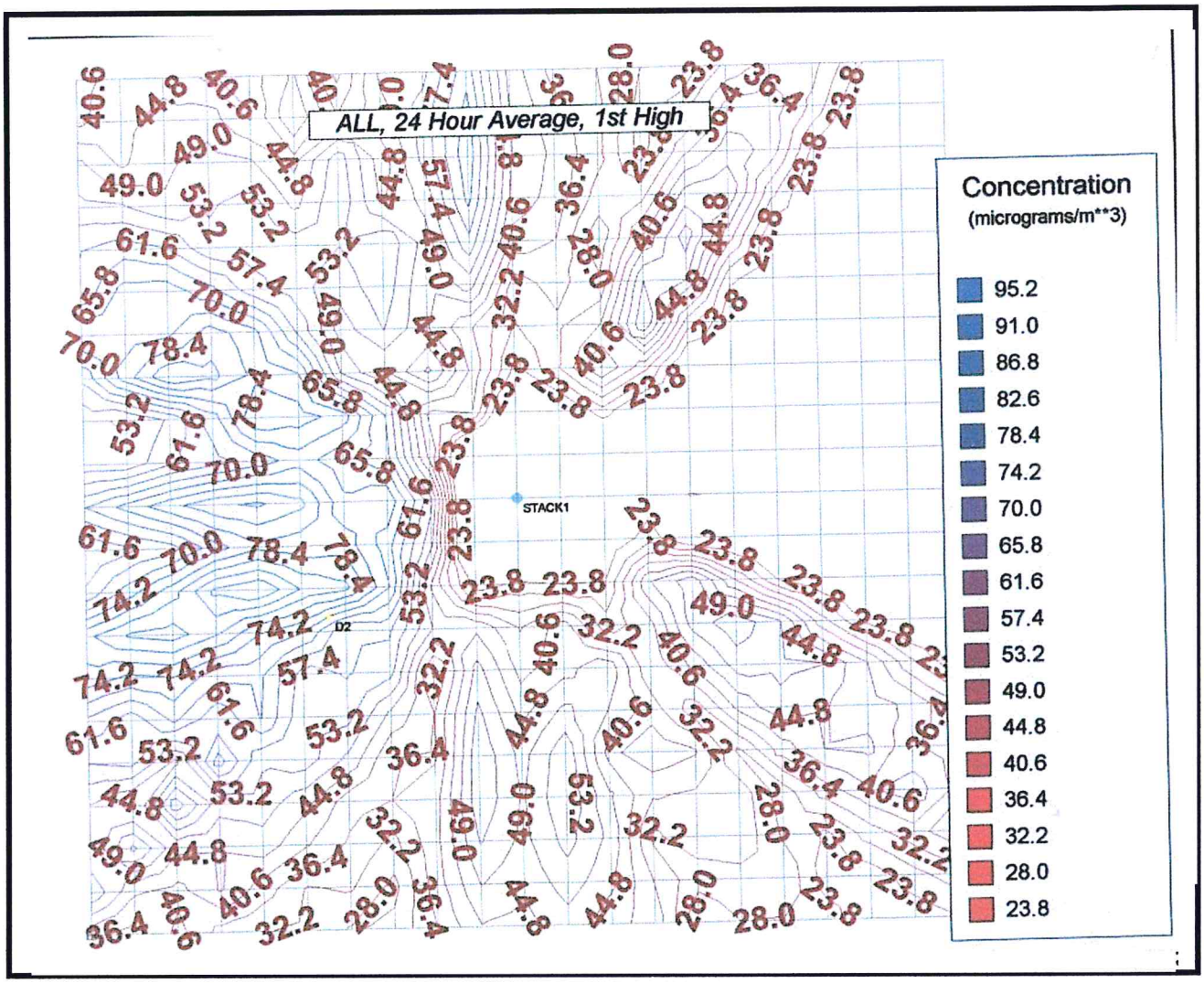
Contour diagram for 24 hour average with a stack height of 21m	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Marie -Jeannie	260
Government school	223



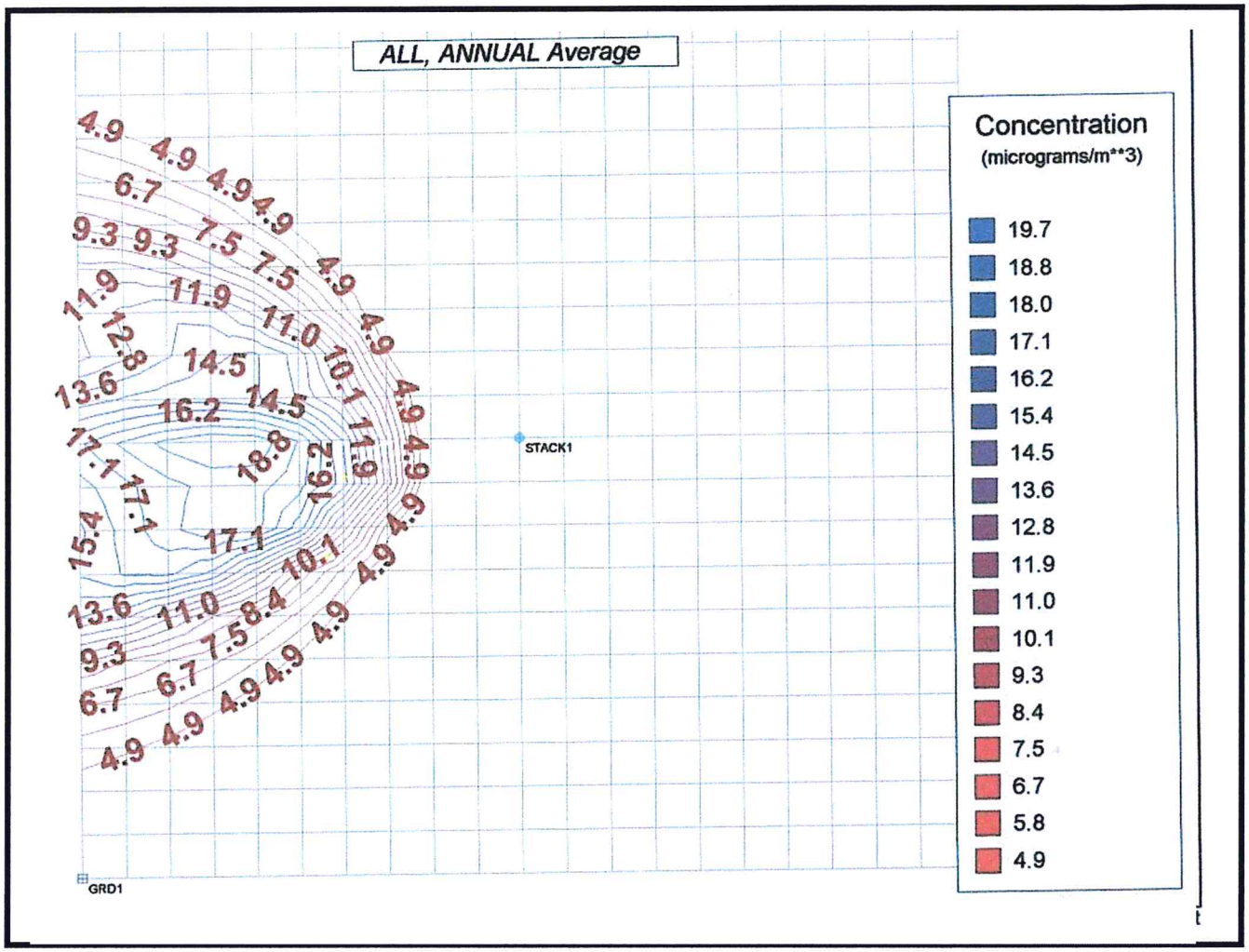
Contour diagram for annual average with a stack height of 21m	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Marie -Jeannie	59.1
Government school	26.1



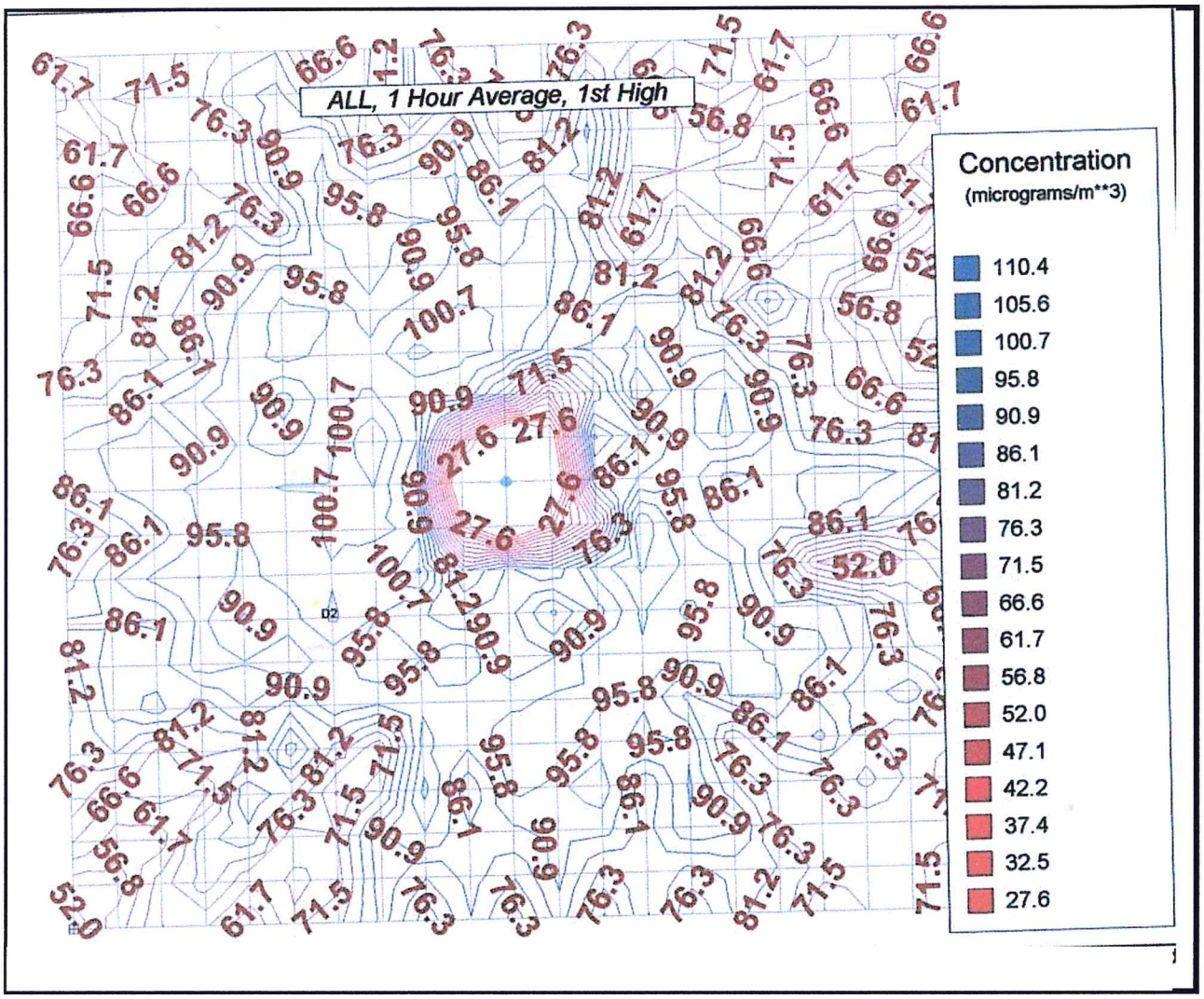
Contour diagram for 1 hour average with a stack height of 30m with implementation of CP and change of fuel	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Marie -Jeannie	259
Government school	254



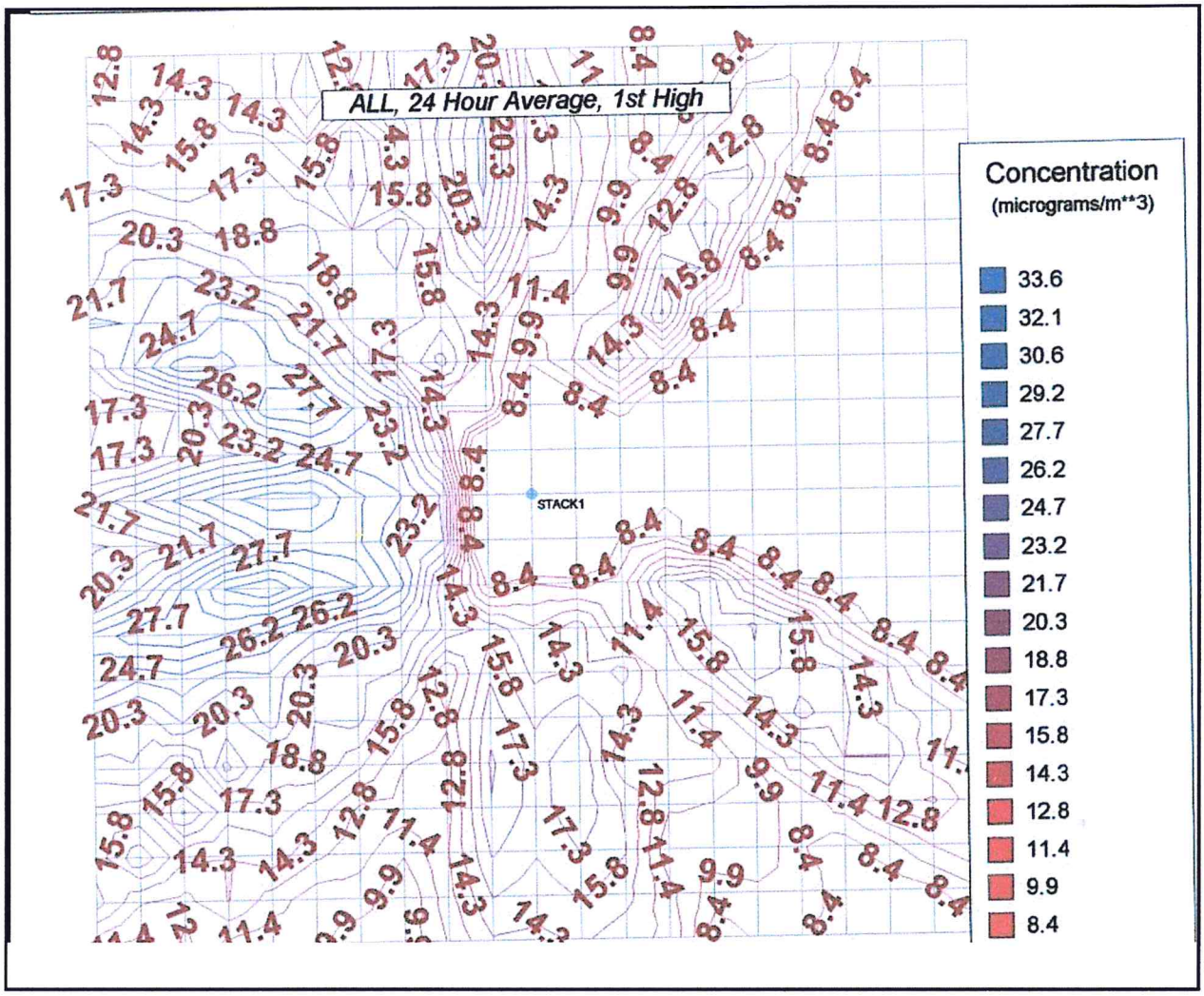
Contour diagram for 24 hour average with a stack height of 30m with implementation of CP and change of fuel	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Marie -Jeannie	76.4
Government school	74.4



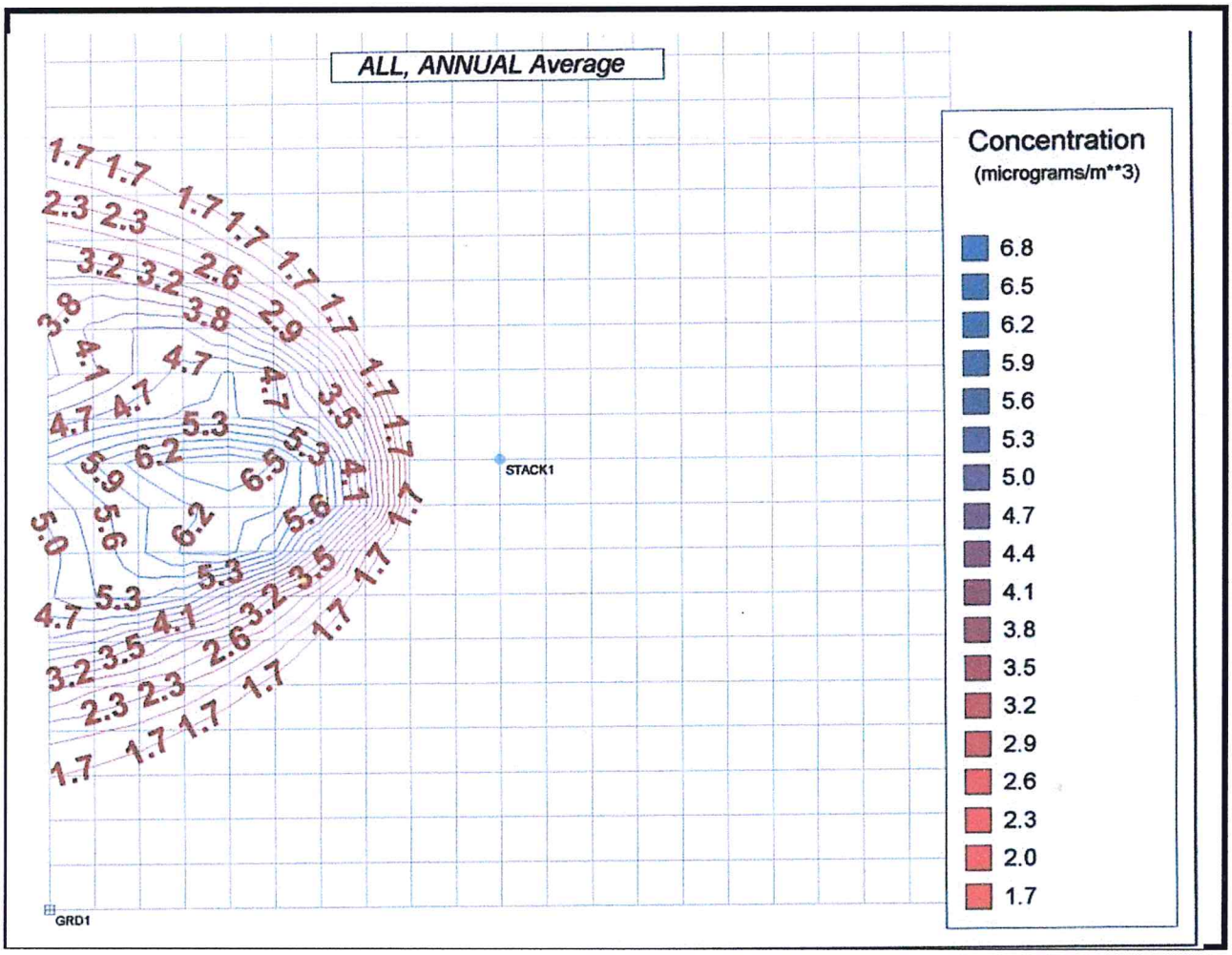
Contour diagram for annual average with a stack height of 30m with implementation of CP and change of fuel	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Marie -Jeannie	14.6
Government school	8.42



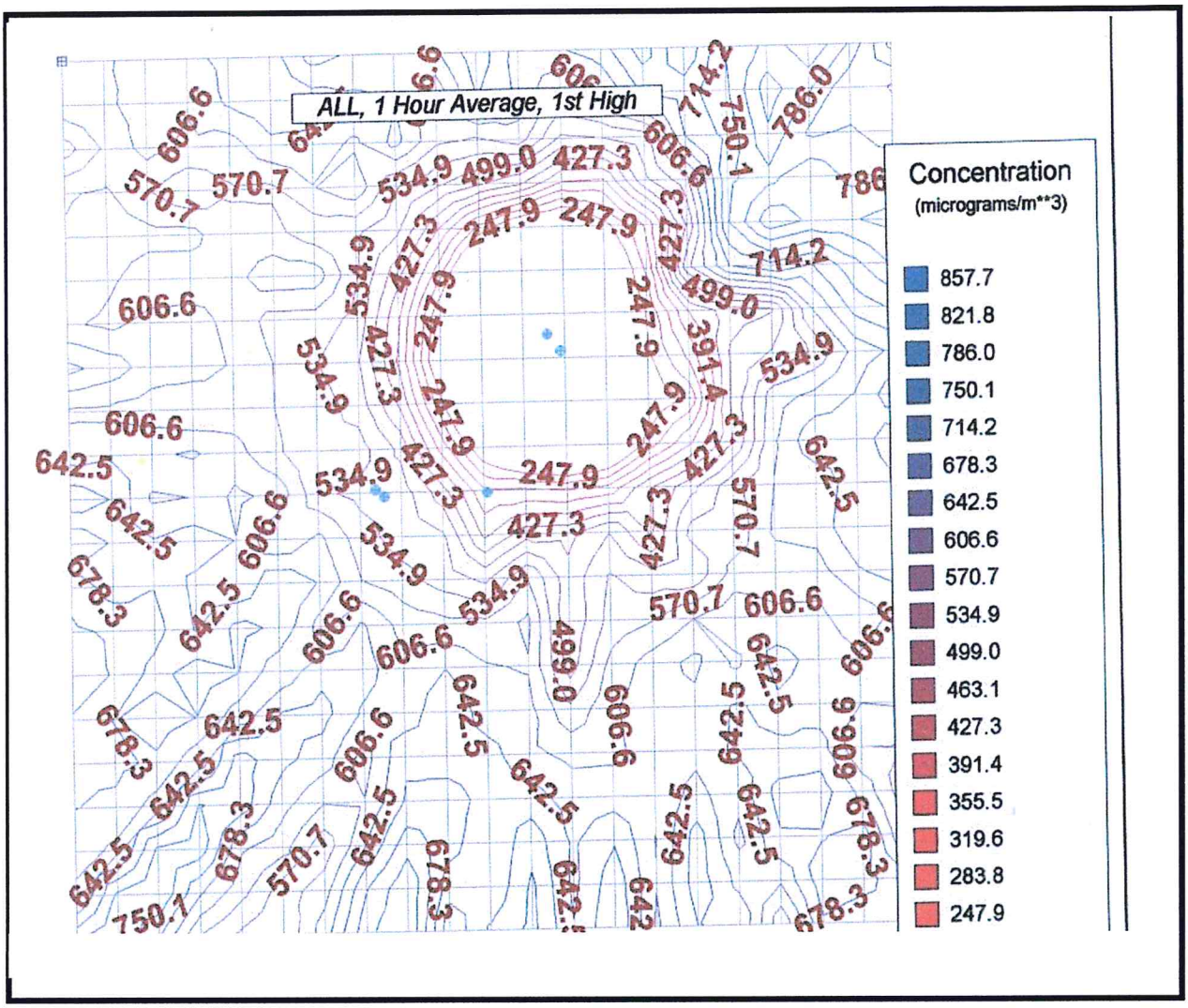
Contour diagram for 1 hr average with a stack height of 30m with installation of Scrubber	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Marie -Jeannie	102
Government school	92.6



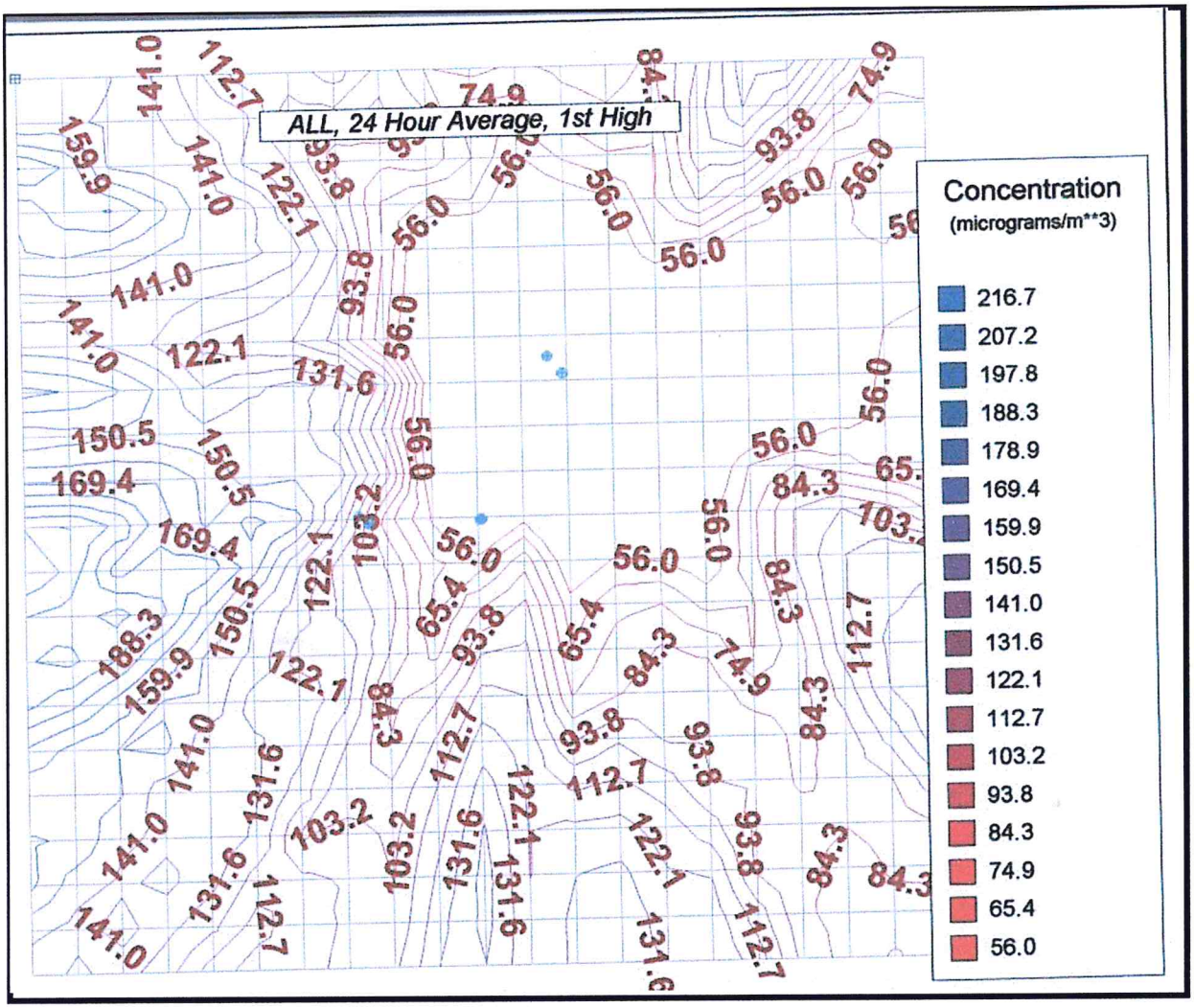
Contour diagram for 24 hr average with a stack height of 30m with installation of Scrubber	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Marie -Jeannie	26.6
Government school	25.1



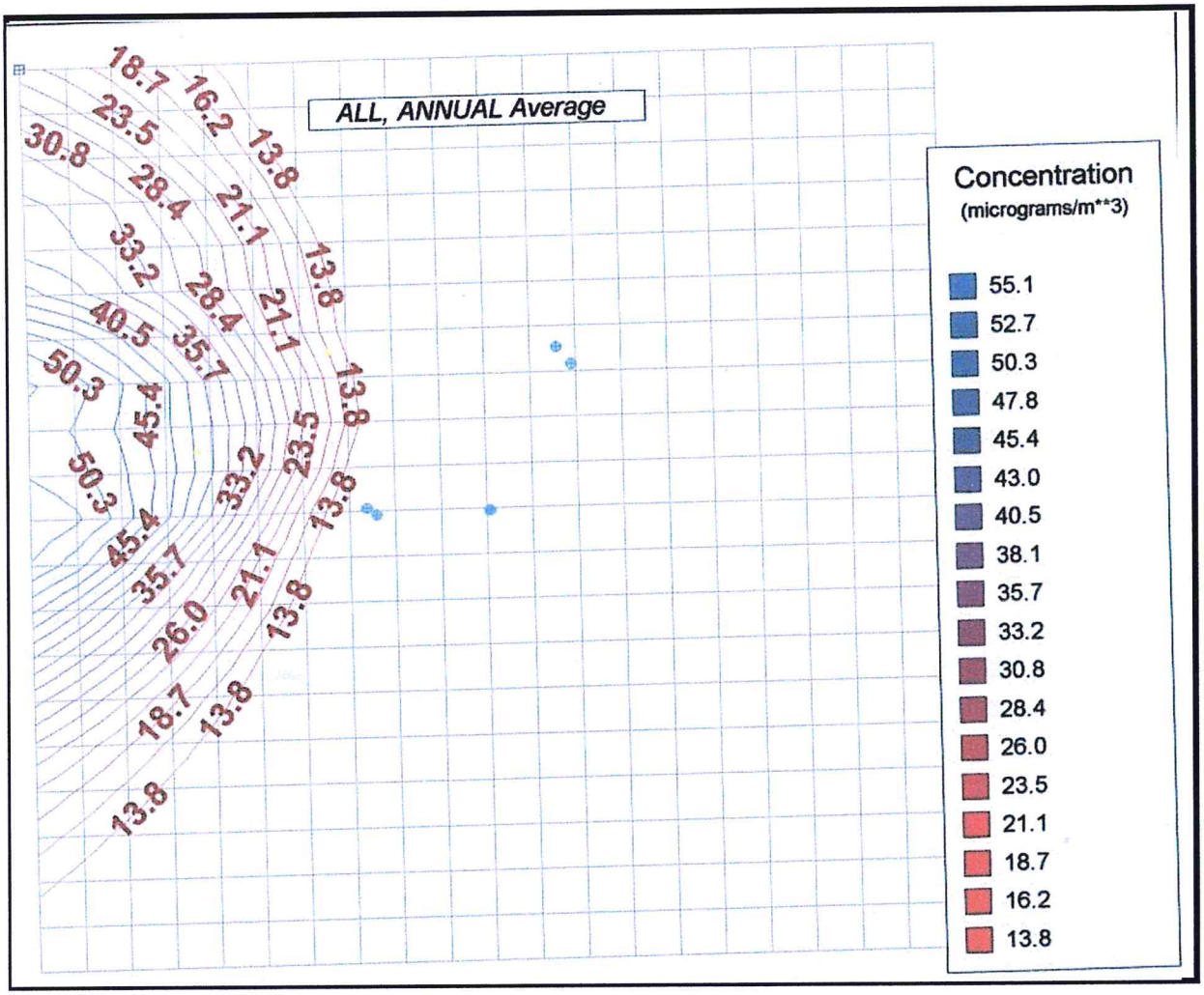
Contour diagram for Annual average with a stack height of 30m with installation of Scrubber	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Marie -Jeannie	5.62
Government school	3.17



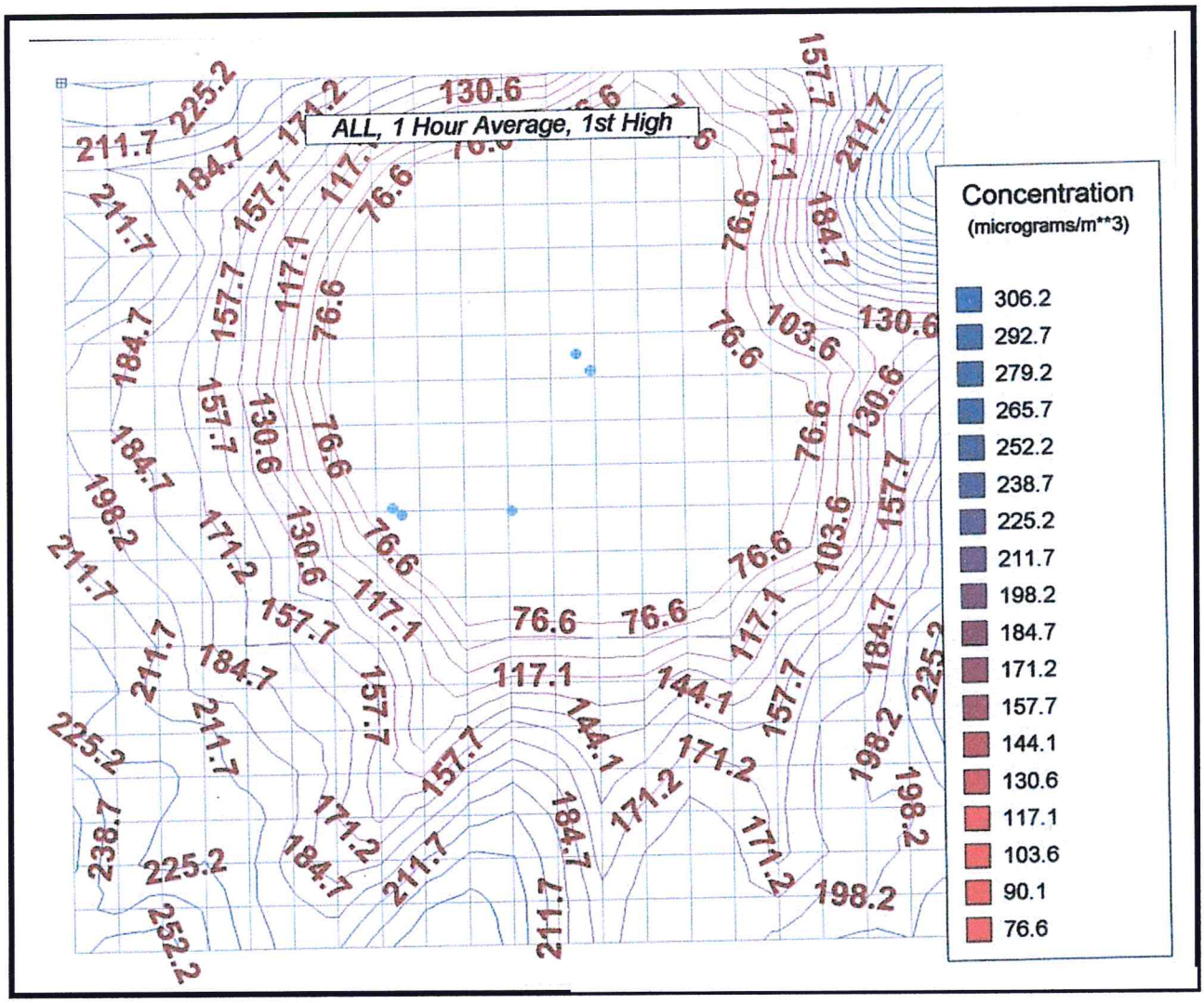
Contour diagram for 1 hour average (on baseline) for multiple source case	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Valentina site 1	637
Valentina site 2	556



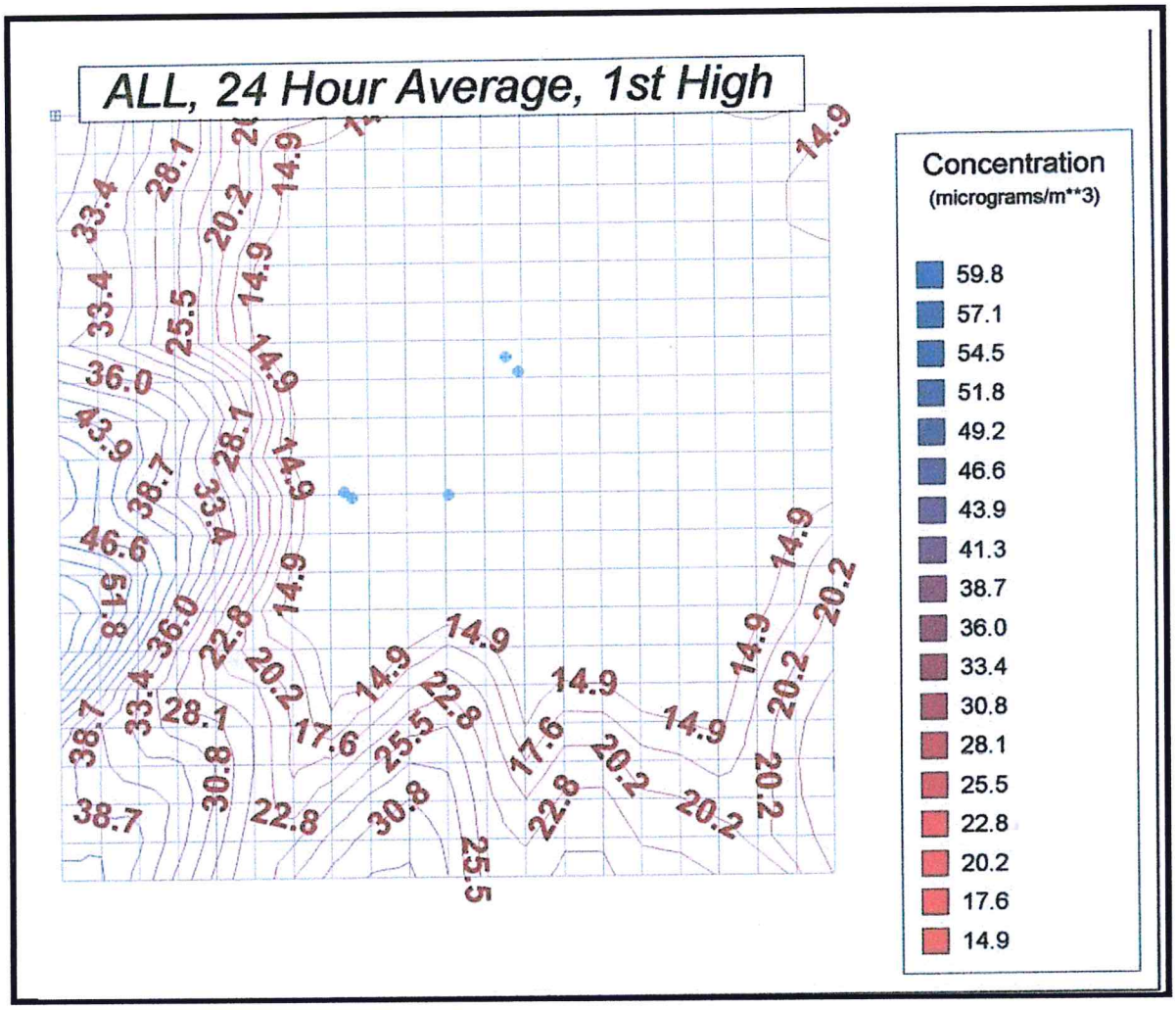
Contour diagram for 24 hour average (on baseline) for multiple source case	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Valentina site 1	154
Valentina site 2	117



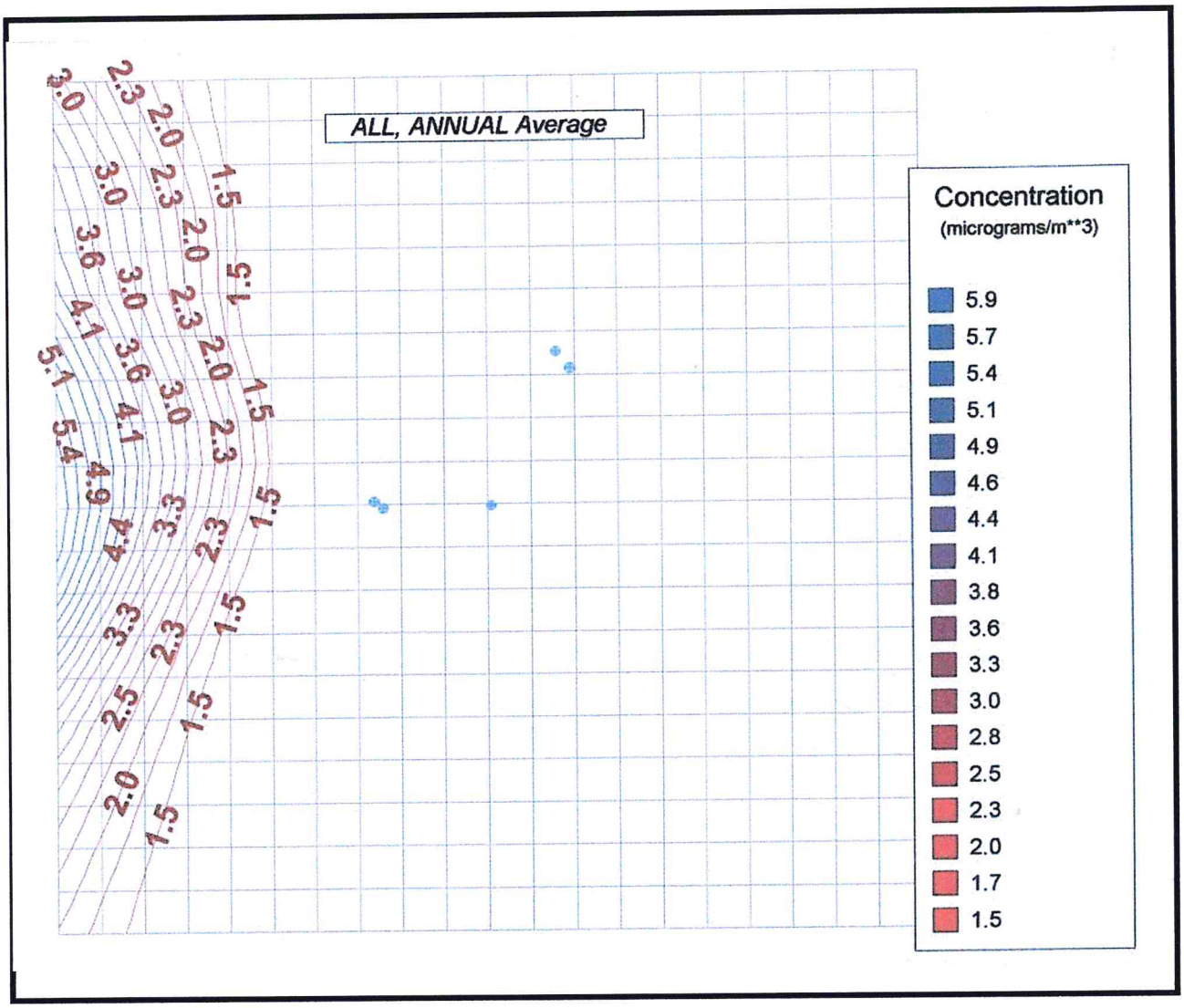
Contour diagram for annual average (on baseline) for multiple source case	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	Concentrations
Valentina site 1	40.2
Valentina site 2	16.3



Contour diagram for 1 hour average for a stack height of 30m	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	concentrations
Valentina site 1	171
Valentina site 2	69.5



Contour diagram for 24 hour average for a stack height of 30m	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	concentrations
Valentina site 1	30.2
Valentina site 2	15.5



Contour diagram for annual average for a stack height of 30m	
Key	Estimated Ambient SO_2 concentrations in $\mu g/m^3$
Receptors	concentrations
Valentina site 1	2.18
Valentina site 2	1.71

APPENDIX E

```
             ISCST3X  PC (32 BIT) VERSION  4.0.1
            (C) COPYRIGHT 1991-2002, Trinity Consultants

 Run Began on  7/24/2007 at 11:30:36

 ** BREEZE ISC GIS Pro v4.1.4 - C:\Documents and Settings\metramen\My Documents\Aruna\testa1.dat
 ** Trinity Consultants


 CO STARTING
 CO TITLEONE  single source Alcodis LTD
 CO MODELOPT  DFAULT  CONC  RURAL
 CO AVERTIME  1
 CO POLLUTID  OTHER
 CO TERRHGTS  FLAT
 CO RUNORNOT  RUN
 CO FINISHED

 SO STARTING
 SO ELEVUNIT  METERS
 SO LOCATION  STACK1  POINT  0.0  0.0  0
 SO SRCPARAM  STACK1  1.946000E+01  21  373.15  6  0.955
 SO SRCGROUP  ALL
 SO FINISHED

 RE STARTING
 RE GRIDCART GRD1 STA 0
 RE GRIDCART GRD1 XYINC  -1000.0  21  100.0  -1000.0  21  100.0
 RE GRIDCART GRD1 END
 RE DISCCART  -395.0  -84.0
 ** RCPDESCR  marie-jeannie
 RE DISCCART  -438.0  -266.4
 ** RCPDESCR  school
 RE FINISHED

 ME STARTING
 ME INPUTFIL  "C:\DOCUMENTS AND SETTINGS\METRAMEN\DESKTOP\PLAISANCE MET DATA.ASC.TXT"
 ME ANEMHGHT  10  METERS
 ME SURFDATA  61990  2002
 ME UAIRDATA  61990  2002
 ME STARTEND  2002  01  01  1  2002  12  31  24
 ME FINISHED

 OU STARTING
 OU RECTABLE  1  FIRST
 OU MAXTABLE  1  25
 OU FINISHED

 ** PROJECTN  0 104 7 -177 0 0.9996 500000 0
 ** IMAGE2  "C:\DOCUMENTS AND SETTINGS\METRAMEN\DESKTOP\MAP REDUCE.TAB"
 ** OUTFILE  "C:\Documents and Settings\metramen\My Documents\Aruna\testa1.LST"
 ** RAWFILE  "C:\Documents and Settings\metramen\My Documents\Aruna\testa1.RAW"
 ** RAWFMT  2
 ** HILLBOUN  0 0 0 0

 ************************************
 *** SETUP Finishes Successfully ***
 ************************************

1 *** ISCST3 - VERSION 02035 ***    ***  single source Alcodis LTD                                    ***
07/24/07                                ***                                                          ***

11:30:36
 **MODELOPTs:
PAGE   1
 CONC                    RURAL FLAT          DFAULT

                                        ***     MODEL SETUP OPTIONS SUMMARY       ***
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
 - - - - -

 **Intermediate Terrain Processing is Selected

 **Model Is Setup For Calculation of Average CONCentration Values.

   --  SCAVENGING/DEPOSITION LOGIC --
 **Model Uses NO DRY DEPLETION.  DDPLETE =  F
 **Model Uses NO WET DEPLETION.  WDPLETE =  F
 **NO WET SCAVENGING Data Provided.
 **NO GAS DRY DEPOSITION Data Provided.
 **Model Does NOT Use GRIDDED TERRAIN Data for Depletion Calculations
```

2. Stack tip Downwash.
3. Buoyancy-induced Dispersion.
4. Use Calms Processing Routine.
5. Not Use Missing Data Processing Routine.
6. Default Wind Profile Exponents.
7. Default Vertical Potential Temperature Gradients.
8. "Upper Bound" Values for Supersquat Buildings.
9. No Exponential Decay for RURAL Mode

**Model Assumes Receptors on FLAT Terrain.

**Model Assumes No FLAGPOLE Receptor Heights.

**Model Calculates 1 Short Term Average(s) of: 1-HR

**This Run Includes: 1 Source(s); 1 Source Group(s); and 443 Receptor(s)

**The Model Assumes A Pollutant Type of: OTHER

**Model Set To Continue RUNning After the Setup Testing.

**Output Options Selected:
Model Outputs Tables of Highest Short Term Values by Receptor (RECTABLE Keyword)
Model Outputs Tables of Overall Maximum Short Term Values (MAXTABLE Keyword)

**NOTE: The Following Flags May Appear Following CONC Values: c for Calm Hours
m for Missing Hours
b for Both Calm and Missing Hours

**Misc. Inputs: Anem. Hgt. (m) = 10.00 ; Decay Coef. = 0.0000 ; Rot. Angle = 0.0
Emission Units = GRAMS/SEC ; Emission Rate Unit Factor =
0.10000E+07
Output Units = MICROGRAMS/M**3

**Approximate Storage Requirements of Model = 1.2 MB of RAM.

**Input Runstream File: C:\DOCUMENTS AND SETTINGS\METRAMEN\MY DOCUMENTS\ARUNA\TESTA1.DAT
**Output Print File: C:\DOCUMENTS AND SETTINGS\METRAMEN\MY DOCUMENTS\ARUNA\TESTA1.LST
1 *** ISCST3 - VERSION 02035 *** *** single source Alcodis LTD ***
07/24/07 *** ***
11:30:36
**MODELOPTs:
PAGE 2
CONC RURAL FLAT DFAULT

*** POINT SOURCE DATA ***

SOURCE ID	NUMBER PART. CATS.	EMISSION RATE (GRAMS/SEC)	X (METERS)	Y (METERS)	BASE ELEV. (METERS)	STACK HEIGHT (METERS)	STACK TEMP. (DEG.K)	STACK EXIT VEL. (M/SEC)	STACK DIAMETER (METERS)	BUILDING EXISTS	EMISSION RATE SCALAR VARY BY
STACK1	0	0.19460E+02	0.0	0.0	0.0	21.00	373.15	6.00	0.96	NO	

1 *** ISCST3 - VERSION 02035 *** *** single source Alcodis LTD ***
07/24/07 *** ***
11:30:36
**MODELOPTs:
PAGE 3
CONC RURAL FLAT DFAULT

*** SOURCE IDs DEFINING SOURCE GROUPS ***

GROUP ID	SOURCE IDs
ALL	STACK1 ,

1 *** ISCST3 - VERSION 02035 *** *** single source Alcodis LTD ***
07/24/07 *** ***
11:30:36
**MODELOPTs:
PAGE 4
CONC RURAL FLAT DFAULT

NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART ***

*** X-COORDINATES OF GRID ***
(METERS)

```
     -1000.0,   -900.0,   -800.0,   -700.0,   -600.0,   -500.0,   -400.0,   -300.0,   -200.0,   -100.0,
         0.0,    100.0,    200.0,    300.0,    400.0,    500.0,    600.0,    700.0,    800.0,    900.0,
      1000.0,
```

*** Y-COORDINATES OF GRID ***
(METERS)

```
     -1000.0,   -900.0,   -800.0,   -700.0,   -600.0,   -500.0,   -400.0,   -300.0,   -200.0,   -100.0,
         0.0,    100.0,    200.0,    300.0,    400.0,    500.0,    600.0,    700.0,    800.0,    900.0,
      1000.0,
```


*** DISCRETE CARTESIAN RECEPTORS ***
(X-COORD, Y-COORD, ZELEV, ZFLAG)
(METERS)

```
    (  -395.0,    -84.0,      0.0,      0.0);        (  -438.0,   -266.4,      0.0,      0.0);
```


* SOURCE-RECEPTOR COMBINATIONS FOR WHICH CALCULATIONS MAY NOT BE PERFORMED *
LESS THAN 1.0 METER OR 3*ZLB IN DISTANCE, OR WITHIN OPEN PIT SOURCE

SOURCE ID	- - RECEPTOR LOCATION - - XR (METERS)	YR (METERS)	DISTANCE (METERS)
STACK1	0.0	0.0	0.00

*** METEOROLOGICAL DAYS SELECTED FOR PROCESSING ***
(1=YES; 0=NO)

```
 1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1
1 1
 1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1
1 1
 1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1
1 1
 1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1
1 1
 1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1
1 1
 1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1
1 1
 1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1
1 1
 1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1
```

METEOROLOGICAL DATA PROCESSED BETWEEN START DATE: 2002 1 1 1
AND END DATE: 2002 12 31 24

NOTE: METEOROLOGICAL DATA ACTUALLY PROCESSED WILL ALSO DEPEND ON WHAT IS INCLUDED IN THE DATA FILE.

*** UPPER BOUND OF FIRST THROUGH FIFTH WIND SPEED CATEGORIES ***
(METERS/SEC)

WIND PROFILE EXPONENTS

STABILITY CATEGORY	WIND SPEED CATEGORY 1	2	3	4	5	6
A	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01
B	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01
C	.10000E+00	.10000E+00	.10000E+00	.10000E+00	.10000E+00	.10000E+00
D	.15000E+00	.15000E+00	.15000E+00	.15000E+00	.15000E+00	.15000E+00
E	.35000E+00	.35000E+00	.35000E+00	.35000E+00	.35000E+00	.35000E+00
F	.55000E+00	.55000E+00	.55000E+00	.55000E+00	.55000E+00	.55000E+00

*** VERTICAL POTENTIAL TEMPERATURE GRADIENTS ***
(DEGREES KELVIN PER METER)

STABILITY CATEGORY	WIND SPEED CATEGORY 1	2	3	4	5	6
A	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
B	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
C	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
D	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
E	.20000E-01	.20000E-01	.20000E-01	.20000E-01	.20000E-01	.20000E-01
F	.35000E-01	.35000E-01	.35000E-01	.35000E-01	.35000E-01	.35000E-01

*** THE FIRST 24 HOURS OF METEOROLOGICAL DATA ***

FILE: C:\DOCUMENTS AND SETTINGS\METRAMEN\DESKTOP\PLAISANCE MET DATA.ASC.TXT
FORMAT: (4I2,2F9.4,F6.1,I2,2F7.1,f9.4,f10.1,f8.4,i4,f7.2)
SURFACE STATION NO.: 61990 UPPER AIR STATION NO.: 61990
NAME: UNKNOWN NAME: UNKNOWN
YEAR: 2002 YEAR: 2002

YR	MN	DY	HR	FLOW VECTOR	SPEED (M/S)	TEMP (K)	STAB CLASS	MIXING HEIGHT (M) RURAL	MIXING HEIGHT (M) URBAN	USTAR (M/S)	M-O LENGTH (M)	Z-0 (M)	IPCODE	PRATE (mm/HR)
02	01	01	01	91.0	1.03	295.9	4	180.6	729.2	0.0000	0.0	0.0000	0	0.00
02	01	01	02	238.0	4.12	295.9	4	1371.6	1814.4	0.0000	0.0	0.0000	0	0.00
02	01	01	03	134.0	2.06	295.4	4	575.7	1026.8	0.0000	0.0	0.0000	0	0.00
02	01	01	04	133.0	1.54	295.4	4	270.9	1026.8	0.0000	0.0	0.0000	0	0.00
02	01	01	05	133.0	1.54	295.4	5	69.7	483.7	0.0000	0.0	0.0000	0	0.00
02	01	01	06	132.0	1.54	295.4	6	69.7	483.7	0.0000	0.0	0.0000	0	0.00
02	01	01	07	145.0	1.54	295.9	5	69.7	467.1	0.0000	0.0	0.0000	0	0.00
02	01	01	08	133.0	1.54	296.5	6	69.7	466.8	0.0000	0.0	0.0000	0	0.00
02	01	01	09	177.0	1.54	298.1	5	69.7	466.1	0.0000	0.0	0.0000	0	0.00
02	01	01	10	211.0	3.09	299.8	5	407.5	624.2	0.0000	0.0	0.0000	0	0.00
02	01	01	11	234.0	3.61	300.4	4	1180.4	1568.5	0.0000	0.0	0.0000	0	0.00
02	01	01	12	206.0	4.12	301.5	4	1373.0	1815.8	0.0000	0.0	0.0000	0	0.00
02	01	01	13	233.0	4.64	302.0	4	1562.4	2060.1	0.0000	0.0	0.0000	0	0.00
02	01	01	14	239.0	4.12	302.6	4	1373.3	1816.0	0.0000	0.0	0.0000	0	0.00
02	01	01	15	242.0	4.12	302.6	4	1458.5	1898.0	0.0000	0.0	0.0000	0	0.00
02	01	01	16	244.0	2.06	300.4	4	887.9	1072.8	0.0000	0.0	0.0000	0	0.00
02	01	01	17	251.0	3.61	300.9	4	1441.9	1734.4	0.0000	0.0	0.0000	0	0.00
02	01	01	18	257.0	4.64	301.5	4	1730.8	2197.4	0.0000	0.0	0.0000	0	0.00
02	01	01	19	264.0	0.00	297.0	4	813.6	828.7	0.0000	0.0	0.0000	0	0.00
02	01	01	20	207.0	4.64	296.5	4	1698.8	2171.7	0.0000	0.0	0.0000	0	0.00
02	01	01	21	180.0	2.06	295.9	3	1253.3	1357.0	0.0000	0.0	0.0000	0	0.00
02	01	01	22	222.0	3.09	295.9	3	1582.1	1773.4	0.0000	0.0	0.0000	0	0.00
02	01	01	23	180.0	1.03	296.5	4	1116.3	1065.7	0.0000	0.0	0.0000	0	0.00
02	01	01	24	180.0	1.03	296.5	4	1141.1	1081.0	0.0000	0.0	0.0000	0	0.00

*** NOTES: STABILITY CLASS 1=A, 2=B, 3=C, 4=D, 5=E AND 6=F.
FLOW VECTOR IS DIRECTION TOWARD WHICH WIND IS BLOWING.

NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS)				
	-1000.00	-900.00	-800.00	-700.00	-600.00
1000.0	436.78943 (02112818)	456.94257 (02022116)	459.12833 (02060418)	512.85095 (02031620)	442.60666 (02042901)
900.0	342.81097 (02092520)	479.27185 (02112818)	499.06091 (02022116)	520.66699 (02060418)	558.77039 (02031620)
800.0	466.14569 (02121618)	397.86920 (02092520)	525.51074 (02112818)	536.85846 (02022116)	557.49231 (02060418)
700.0	437.55252 (02070607)	490.32623 (02121618)	460.96646 (02092520)	572.93695 (02112818)	554.42529 (02022116)
600.0	459.41757 (02102016)	523.92395 (02031920)	504.98679 (02070220)	528.55438 (02121618)	603.13202 (02112818)
500.0	472.45093 (02081819)	513.00293 (02081819)	554.31531 (02031920)	512.56641 (02031521)	573.23743 (02121618)
400.0	503.20377 (02121703)	538.99573 (02071924)	546.29474 (02121515)	544.47162 (02122201)	608.05194 (02042220)
300.0	521.78174 (02073123)	534.37335 (02121714)	545.12823 (02062022)	575.39636 (02121703)	642.99249 (02050316)
200.0	559.52380 (02012702)	566.17511 (02012702)	557.07391 (02040201)	599.95465 (02021701)	665.54535 (02012824)
100.0	551.66943 (02010220)	557.28705 (02110801)	587.36951 (02110801)	586.12506 (02110801)	654.53967 (02121623)
0.0	553.12555 (02121109)	572.29645 (02121701)	589.14349 (02120823)	618.06970 (02120823)	679.99713 (02010620)
-100.0	561.32941 (02020202)	568.85754 (02122424)	585.56824 (02122424)	609.63159 (02052823)	650.49286 (02052823)
-200.0	552.99310 (02042002)	559.65582 (02030524)	602.84229 (02120801)	653.95477 (02041518)	633.15643 (02102124)
-300.0	543.50647 (02102201)	568.89966 (02122401)	580.03741 (02110617)	619.87177 (02120701)	606.27362 (02012701)
-400.0	532.34869 (02022702)	555.16388 (02022702)	584.36090 (02010116)	614.62170 (02012701)	619.66174 (02022701)
-500.0	540.71588 (02121203)	515.02533 (02012701)	554.75476 (02022701)	554.60919 (02032302)	560.79596 (02032301)
-600.0	502.78622 (02060301)	530.53503 (02020501)	507.32782 (02032302)	462.64182 (02120309)	503.69406 (02122216)
-700.0	525.06091 (02032302)	479.17935 (02010219)	430.42651 (02120309)	453.37369 (02122216)	545.34552 (02032223)
-800.0	473.71869 (02010219)	389.85849 (02120309)	402.82187 (02122216)	465.02719 (02032223)	495.04156 (02032223)
-900.0	349.82202 (02120309)	358.68863 (02122216)	393.15866 (02032223)	483.06082 (02010309)	474.00766 (02042019)
-1000.0	320.77539 (02122216)	332.75259 (02032223)	477.13013 (02010309)	485.14200 (02121624)	400.58249 (02041601)

*** THE 1ST HIGHEST 1-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL ***

INCLUDING SOURCE(S): STACK1 ,

*** NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS)				
	-500.00	-400.00	-300.00	-200.00	-100.00
1000.0	465.65259 (02022119)	424.71457 (02042601)	540.44897 (02121619)	513.80310 (02042520)	549.02948 (02060505)
900.0	514.39032 (02022119)	524.72186 (02032417)	531.85394 (02121619)	525.87891 (02031420)	574.72131 (02012919)
800.0	549.19482 (02042321)	574.45026 (02022119)	511.63095 (02042601)	554.62140 (02042617)	592.71039 (02012919)
700.0	545.97186 (02042321)	609.44171 (02042901)	576.20099 (02032417)	589.36761 (02070118)	633.16815 (02031420)
600.0	537.71393 (02101518)	643.00464 (02042321)	656.20728 (02022119)	641.58398 (02070118)	664.04883 (02031420)

CONC RURAL FLAT DFAULT

*** THE 1ST HIGHEST 1-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL ***

INCLUDING SOURCE(S): STACK1 ,

*** NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 0.00	100.00	200.00	300.00	400.00
1000.0	516.13934 (02031516)	527.90283 (02042405)	464.63507 (02013101)	516.57227 (02031517)	519.66241 (02070202)
900.0	550.16150 (02031516)	546.84686 (02042405)	543.82068 (02013101)	521.54388 (02032502)	465.84247 (02012816)
800.0	576.38495 (02031516)	531.78937 (02042405)	602.84235 (02013101)	565.66138 (02102018)	542.12134 (02102024)
700.0	585.13623 (02031516)	562.88599 (02012817)	603.16016 (02013101)	567.25128 (02012816)	550.90527 (02060520)
600.0	598.42676 (02032423)	673.20612 (02012817)	554.09192 (02032502)	557.12677 (02060512)	536.88849 (02122810)
500.0	669.43542 (02032423)	730.36993 (02012817)	534.01263 (02012816)	473.73575 (02122720)	540.80719 (02012723)
400.0	685.21320 (02032423)	669.76562 (02032501)	560.08649 (02041617)	691.28406 (02012723)	575.87659 (02041616)
300.0	683.78748 (02012722)	667.56061 (02031923)	656.77417 (02070120)	630.89661 (02031421)	555.69519 (02091421)
200.0	652.97699 (02020121)	525.43549 (02041617)	652.06635 (02031421)	677.18549 (02042721)	591.80292 (02122724)
100.0	81.79213 (02020121)	377.70435 (02022020)	723.76495 (02020122)	525.95819 (02012822)	539.02423 (02041623)
0.0	0.00000 (00000000)	215.40891 (02031321)	657.05774 (02031321)	708.94757 (02012522)	641.04346 (02062123)
-100.0	212.86110 (02012423)	425.83069 (02010419)	598.86755 (02051520)	683.61395 (02011423)	539.58630 (02011423)
-200.0	687.19946 (02020921)	599.14069 (02031222)	695.45270 (02022423)	700.89093 (02022422)	678.19525 (02060424)
-300.0	624.94818 (02010523)	688.87622 (02120123)	721.15906 (02010519)	693.39227 (02051424)	561.93561 (02060422)
-400.0	697.28784 (02010121)	619.18610 (02041801)	665.80780 (02121121)	624.26599 (02112722)	593.60541 (02112724)
-500.0	713.69067 (02041819)	689.49048 (02012501)	675.46173 (02032322)	661.33887 (02071401)	496.44107 (02033102)
-600.0	683.45734 (02041819)	672.26703 (02012501)	627.51416 (02052724)	653.28540 (02022324)	519.66199 (02112723)

-900.0 | 562.50293 (02022601) 558.77216 (02121123) 498.55771 (02072604) 508.58826 (02120124)
475.07809 (02092324)
-1000.0 | 560.41223 (02121502) 521.45044 (02121123) 443.35187 (02102601) 503.07043 (02120124)
527.38995 (02092324)

CONC RURAL FLAT DFAULT

*** THE 1ST HIGHEST 1-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL
***

INCLUDING SOURCE(S): STACK1 ,

*** NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 500.00	600.00	700.00	800.00	900.00
1000.0	529.37726 (02102024)	394.26929 (02060520)	493.03500 (02102101)	441.68903 (02022101)	425.64221 (02031523)
900.0	495.92288 (02060520)	450.08380 (02102101)	468.10962 (02102101)	450.72977 (02022101)	475.87039 (02031523)
800.0	398.37680 (02122810)	534.86957 (02102101)	513.90601 (02022101)	475.68604 (02031523)	482.92023 (02013102)
700.0	531.91589 (02102101)	570.08008 (02022101)	482.19067 (02041616)	467.20792 (02013102)	402.15305 (02121418)
600.0	587.95892 (02022101)	539.42542 (02041616)	452.37177 (02091417)	517.04492 (02121418)	520.11639 (02121418)
500.0	583.03802 (02041616)	525.95831 (02091417)	608.35840 (02121418)	446.53021 (02091421)	326.80090 (02091421)
400.0	550.34222 (02091417)	584.53473 (02091421)	463.10287 (02091421)	402.17993 (02122802)	423.44138 (02102704)
300.0	626.33002 (02091421)	483.41769 (02122802)	442.63361 (02122802)	363.81934 (02012921)	298.31458 (02012921)
200.0	608.93152 (02012921)	514.29907 (02012921)	415.93393 (02041623)	374.90305 (02041623)	398.96393 (02010306)
100.0	631.63513 (02041623)	536.62018 (02041623)	436.67715 (02020902)	528.16003 (02020902)	567.83673 (02020902)
0.0	596.86993 (02062123)	615.94592 (02012601)	618.06903 (02012601)	589.14294 (02012601)	546.71619 (02012601)
-100.0	546.43146 (02041621)	583.39026 (02031522)	582.47083 (02031522)	540.65436 (02031522)	484.63712 (02031522)
-200.0	675.46173 (02031501)	556.26428 (02022302)	503.56561 (02022302)	390.90350 (02042802)	502.49664 (02042802)
-300.0	607.62506 (02032001)	561.69873 (02101001)	553.64343 (02042801)	548.61914 (02012802)	523.73834 (02022302)
-400.0	647.96344 (02060421)	602.01050 (02032001)	580.25513 (02101001)	540.23230 (02062201)	538.54565 (02031502)
-500.0	614.11456 (02112724)	614.99438 (02060420)	573.32635 (02120201)	564.47162 (02013002)	533.93182 (02032002)
-600.0	546.68518 (02041802)	556.10486 (02022502)	554.98627 (02060420)	557.49219 (02042224)	533.92786 (02112602)
-700.0	526.71759 (02022401)	560.56958 (02041802)	548.29626 (02052721)	526.80420 (02030204)	539.35376 (02122224)
-800.0	556.61249 (02031302)	571.03735 (02022401)	536.51044 (02042222)	527.71161 (02052721)	487.08963 (02010104)
-900.0	568.86157 (02121417)	469.47815 (02112723)	531.56366 (02022401)	518.54041 (02042222)	499.20810 (02052721)
-1000.0	472.32248 (02022324)	506.92490 (02031302)	460.42490 (02022401)	494.70709 (02111102)	489.55243 (02042222)

CONC RURAL FLAT DFAULT

*** THE 1ST HIGHEST 1-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL
***

INCLUDING SOURCE(S): STACK1 ,

*** NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

```
    1000.0 |    467.18677 (02031523)
     900.0 |    481.34671 (02013102)
     800.0 |    366.06705 (02091417)
     700.0 |    502.32812 (02121418)
     600.0 |    325.86722 (02091421)
     500.0 |    322.61264 (02122802)
     400.0 |    431.98703 (02102704)
     300.0 |    237.13660 (02012921)
     200.0 |    461.18497 (02010306)
     100.0 |    569.04700 (02020902)
       0.0 |    500.44159 (02012601)
    -100.0 |    434.19733 (02012601)
    -200.0 |    540.48431 (02042802)
    -300.0 |    466.92877 (02022302)
    -400.0 |    496.11844 (02012802)
    -500.0 |    515.27924 (02100202)
    -600.0 |    484.53104 (02022202)
    -700.0 |    469.47205 (02112801)
    -800.0 |    501.27841 (02122224)
    -900.0 |    470.81226 (02010104)
   -1000.0 |    468.37180 (02052721)
1 *** ISCST3 - VERSION 02035 ***    ***  single source Alcodis LTD                                    ***
07/24/07                            ***                                                           ***
11:30:36
 **MODELOPTs:
PAGE  14
 CONC                    RURAL FLAT          DFAULT

                              *** THE   1ST HIGHEST  1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL
***
                                 INCLUDING SOURCE(S):      STACK1  ,

                                      *** DISCRETE CARTESIAN RECEPTOR POINTS ***

                                    ** CONC OF OTHER    IN MICROGRAMS/M**3                        **

     X-COORD (M)  Y-COORD (M)        CONC      (YYMMDDHH)              X-COORD (M)  Y-COORD (M)        CONC
(YYMMDDHH)
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - -
         -395.00       -84.00      729.35400  (02122921)                -438.00      -266.40      667.06915
(02042317)        □□
1 *** ISCST3 - VERSION 02035 ***    ***  single source Alcodis LTD                                    ***
07/24/07                            ***                                                           ***
11:30:36
 **MODELOPTs:
PAGE  15
 CONC                    RURAL FLAT          DFAULT

                              *** THE MAXIMUM   25   1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL
***
                                 INCLUDING SOURCE(S):    STACK1  ,

                                    ** CONC OF OTHER    IN MICROGRAMS/M**3                        **

 RANK        CONC     (YYMMDDHH) AT      RECEPTOR (XR,YR) OF TYPE    RANK        CONC     (YYMMDDHH) AT      RECEPTOR
(XR,YR) OF TYPE
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - -
    1.      740.88068 (02022620) AT (   -200.00,     -100.00)  GC       14.      714.43011 (02120221) AT (   -400.00,
0.00)  GC
    2.      730.36993 (02012817) AT (    100.00,      500.00)  GC       15.      714.34167 (02121620) AT (   -400.00,
200.00)  GC
    3.      729.35400 (02122921) AT (   -395.00,      -84.00)  DC       16.      714.06439 (02121423) AT (   -100.00,
-400.00)  GC
    4.      729.17651 (02022117) AT (   -400.00,      300.00)  GC       17.      713.69067 (02041819) AT (      0.00,
-500.00)  GC
    5.      724.23816 (02031617) AT (   -400.00,      300.00)  GC       18.      713.40479 (02122123) AT (   -200.00,
100.00)  GC
    6.      723.76495 (02020122) AT (    200.00,      100.00)  GC       19.      712.02734 (02011822) AT (   -100.00,
200.00)  GC
    7.      721.15906 (02010519) AT (    200.00,     -300.00)  GC       20.      710.16431 (02012517) AT (   -400.00,
400.00)  GC
    8.      720.51556 (02122923) AT (   -200.00,     -100.00)  GC       21.      708.94824 (02022719) AT (   -300.00,
0.00)  GC
    9.      717.98822 (02011421) AT (   -200.00,      100.00)  GC       22.      708.94757 (02012522) AT (    300.00,
0.00)  GC
   10.      716.54083 (02041417) AT (   -395.00,      -84.00)  DC       23.      708.85565 (02041820) AT (      0.00,
-500.00)  GC
   11.      715.65680 (02022321) AT (   -200.00,        0.00)  GC       24.      708.85516 (02010620) AT (   -500.00,
0.00)  GC
```

*** THE SUMMARY OF HIGHEST 1-HR RESULTS ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

NETWORK GROUP ID	AVERAGE CONC	DATE (YYMMDDHH)	RECEPTOR (XR, YR, ZELEV, ZFLAG)	OF TYPE GRID-ID
ALL	HIGH 1ST HIGH VALUE IS	740.88068	ON 02022620: AT (-200.00, -100.00, 0.00, 0.00)	GC GRD1

*** Message Summary : ISCST3 Model Execution ***

--------- Summary of Total Messages --------

A Total of 0 Fatal Error Message(s)
A Total of 0 Warning Message(s)
A Total of 427 Informational Message(s)

A Total of 427 Calm Hours Identified

******** FATAL ERROR MESSAGES ********
*** NONE ***

******** WARNING MESSAGES ********
*** NONE ***

****
*** ISCST3 Finishes Successfully ***
****

Control

```
   Title one = single source Alcodis LTD
   Pollutant = OTHER
   Flat terrain
   Averaging:
      1 hour
   Dispersion options:
      Regulatory default option
      Concentration
      Rural
   List file = C:\Documents and Settings\metramen\My Documents\Aruna\testa1.lst
```

Meteorology

```
   Input file = C:\DOCUMENTS AND SETTINGS\METRAMEN\DESKTOP\PLAISANCE MET DATA.ASC.TXT
   File format = ASCII
   Anemometer height = 10
   Surface station number = 61990
   Surface station year = 2002
   Upper air station number = 61990
   Upper air station year = 2002
   Start date = 01/01/2002
   Start hour = 1
   End date = 12/31/2002
   End hour = 24
```

Source

```
   Sources = 1
       Min Elev:  0.0 m
       Max Elev:  0.0 m
   Groups = 1
```

Receptor

```
   Grids = 1
   Discrete receptors = 2
       Min Elev:  0.0 m
       Max Elev:  0.0 m
   Boundary receptors = 0
       Min Elev:  0.0 m
       Max Elev:  0.0 m
```

Output

```
   Receptor tables:
      1 hour = first high
   Maximum tables:
      1 hour = 25
```

```
** Trinity Consultants

CO STARTING
CO TITLEONE  single source Alcodis LTD
CO MODELOPT  DFAULT  CONC  RURAL
CO AVERTIME  1
CO POLLUTID  OTHER
CO TERRHGTS  FLAT
CO RUNORNOT  RUN
CO FINISHED

SO STARTING
SO ELEVUNIT  METERS
SO LOCATION  STACK1  POINT  0.0  0.0  0
SO SRCPARAM  STACK1  1.946000E+01  21  373.15  6  0.955
SO SRCGROUP  ALL
SO FINISHED

RE STARTING
RE GRIDCART GRD1 STA 0
RE GRIDCART GRD1 XYINC  -1000.0  21  100.0  -1000.0  21  100.0
RE GRIDCART GRD1 END
RE DISCCART  -395.0  -84.0
** RCPDESCR  marie-jeannie
RE DISCCART  -438.0  -266.4
** RCPDESCR  school
RE FINISHED

ME STARTING
ME INPUTFIL  "C:\DOCUMENTS AND SETTINGS\METRAMEN\DESKTOP\PLAISANCE MET DATA.ASC.TXT"
ME ANEMHGHT  10  METERS
ME SURFDATA  61990  2002
ME UAIRDATA  61990  2002
ME STARTEND  2002  01  01  1  2002  12  31  24
ME FINISHED

OU STARTING
OU RECTABLE  1  FIRST
OU MAXTABLE  1  25
OU FINISHED

** PROJECTN  0 104 7 -177 0 0.9996 500000 0
** IMAGE2  "C:\DOCUMENTS AND SETTINGS\METRAMEN\DESKTOP\MAP REDUCE.TAB"
** OUTFILE  "C:\Documents and Settings\metramen\My Documents\Aruna\testa1.LST"
** RAWFILE  "C:\Documents and Settings\metramen\My Documents\Aruna\testa1.RAW"
** RAWFMT  2
** HILLBOUN  0 0 0 0
```

```
            ISCST3X  PC (32 BIT) VERSION  4.0.1
           (C) COPYRIGHT 1991-2002, Trinity Consultants

 Run Began on  7/23/2007 at 16:20:18

 ** BREEZE ISC GIS Pro v4.1.4 - C:\Documents and Settings\metramen\My Documents\Aruna\testv2.dat
 ** Trinity Consultants


 CO STARTING
 CO TITLEONE  multiple source option
 CO MODELOPT  DFAULT  CONC  RURAL
 CO AVERTIME  1
 CO POLLUTID  OTHER
 CO TERRHGTS  FLAT
 CO RUNORNOT  RUN
 CO FINISHED

 SO STARTING
 SO ELEVUNIT  METERS
 SO LOCATION  trans1  POINT  -52.3  1.4  0
 SO LOCATION  trans2  POINT  -48.1  -1.8  0
 SO LOCATION  SRC4  POINT  1.3  -1.1  0
 SO LOCATION  reop  POINT  1.6  -0.8  0
 SO LOCATION  soniw1  POINT  31.8  70.8  0
 SO LOCATION  sonia2  POINT  38.2  63.1  0
 SO SRCPARAM  trans1  9.660000E-01  18  401  6.19  0.5
 SO SRCPARAM  trans2  9.660000E-01  18  401  6.19  0.5
 SO SRCPARAM  SRC4  0.000000E+00  0  0  0  0
 SO SRCPARAM  reop  6.860000E-01  11  348  4.72  0.7
 SO SRCPARAM  soniw1  1.673000E+00  15  363  3.62  0.5
 SO SRCPARAM  sonia2  1.673000E+00  15  363  3.62  0.5
 SO SRCGROUP  ALL
 SO FINISHED

 RE STARTING
 RE GRIDCART GRD1 STA 0
 RE GRIDCART GRD1 XYINC  -200.0  21  20.0  200.0  21  -20.0
 RE GRIDCART GRD1 END
 RE FINISHED

 ME STARTING
 ME INPUTFIL  "C:\Documents and Settings\metramen\Desktop\Plaisance Met Data.ASC.txt"
 ME ANEMHGHT  10  METERS
 ME SURFDATA  61990  2002
 ME UAIRDATA  61990  2002
 ME STARTEND  2002  01  01  1  2002  12  31  24
 ME FINISHED

 OU STARTING
 OU RECTABLE  1  FIRST
 OU MAXTABLE  1  25
 OU FINISHED

 ** PROJECTN  0 104 7 -177 0 0.9996 500000 0
 ** IMAGE2  "A:\val 1.tab"
 ** OUTFILE  "C:\Documents and Settings\metramen\My Documents\Aruna\testv2.lst"
 ** RAWFILE  "C:\Documents and Settings\metramen\My Documents\Aruna\testv2.RAW"
 ** RAWFMT  2
 ** HILLBOUN  0 0 0 0


  *** Message Summary For ISC3 Model Setup ***

  --------- Summary of Total Messages --------

 A Total of           0 Fatal Error Message(s)
 A Total of           1 Warning Message(s)
 A Total of           0 Informational Message(s)


    ******** FATAL ERROR MESSAGES ********
               ***  NONE  ***


    ********    WARNING MESSAGES    ********
 SO W320    31 PPARM :Input Parameter May Be Out-of-Range for Parameter       QS

 ************************************
 *** SETUP Finishes Successfully ***
 ************************************
```

*** MODEL SETUP OPTIONS SUMMARY ***

**Intermediate Terrain Processing is Selected

**Model Is Setup For Calculation of Average CONCentration Values.

-- SCAVENGING/DEPOSITION LOGIC --
**Model Uses NO DRY DEPLETION. DDPLETE = F
**Model Uses NO WET DEPLETION. WDPLETE = F
**NO WET SCAVENGING Data Provided.
**NO GAS DRY DEPOSITION Data Provided.
**Model Does NOT Use GRIDDED TERRAIN Data for Depletion Calculations

**Model Uses RURAL Dispersion.

**Model Uses Regulatory DEFAULT Options:
1. Final Plume Rise.
2. Stack-tip Downwash.
3. Buoyancy-induced Dispersion.
4. Use Calms Processing Routine.
5. Not Use Missing Data Processing Routine.
6. Default Wind Profile Exponents.
7. Default Vertical Potential Temperature Gradients.
8. "Upper Bound" Values for Supersquat Buildings.
9. No Exponential Decay for RURAL Mode

**Model Assumes Receptors on FLAT Terrain.

**Model Assumes No FLAGPOLE Receptor Heights.

**Model Calculates 1 Short Term Average(s) of: 1-HR

**This Run Includes: 6 Source(s); 1 Source Group(s); and 441 Receptor(s)

**The Model Assumes A Pollutant Type of: OTHER

**Model Set To Continue RUNning After the Setup Testing.

**Output Options Selected:
Model Outputs Tables of Highest Short Term Values by Receptor (RECTABLE Keyword)
Model Outputs Tables of Overall Maximum Short Term Values (MAXTABLE Keyword)

**NOTE: The Following Flags May Appear Following CONC Values: c for Calm Hours
m for Missing Hours
b for Both Calm and Missing Hours

**Misc. Inputs: Anem. Hgt. (m) = 10.00 ; Decay Coef. = 0.0000 ; Rot. Angle = 0.0
Emission Units = GRAMS/SEC ; Emission Rate Unit Factor = 0.10000E+07
Output Units = MICROGRAMS/M**3

**Approximate Storage Requirements of Model = 1.2 MB of RAM.

**Input Runstream File: C:\DOCUMENTS AND SETTINGS\METRAMEN\MY DOCUMENTS\ARUNA\TESTV2.DAT
**Output Print File: C:\DOCUMENTS AND SETTINGS\METRAMEN\MY DOCUMENTS\ARUNA\TESTV2.LST

*** POINT SOURCE DATA ***

SOURCE ID	NUMBER PART. CATS.	EMISSION RATE (GRAMS/SEC)	X (METERS)	Y (METERS)	BASE ELEV. (METERS)	STACK HEIGHT (METERS)	STACK TEMP. (DEG.K)	STACK EXIT VEL. (M/SEC)	STACK DIAMETER (METERS)	BUILDING EXISTS	EMISSION RATE SCALAR VARY BY
TRANS1	0	0.96600E+00	-52.3	1.4	0.0	18.00	401.00	6.19	0.50	NO	
TRANS2	0	0.96600E+00	-48.1	-1.8	0.0	18.00	401.00	6.19	0.50	NO	

```
1 *** ISCST3 - VERSION 02035 ***      *** multiple source option                                                         ***
07/23/07
                                      ***                                                                                ***
16:20:18
 **MODELOPTs:
PAGE   3
 CONC                     RURAL FLAT         DFAULT


                                                   *** SOURCE IDs DEFINING SOURCE GROUPS ***

 GROUP ID                                                        SOURCE IDs


  ALL       TRANS1   , TRANS2   , SRC4     , REOP     , SONIW1   , SONIA2   ,
1 *** ISCST3 - VERSION 02035 ***      *** multiple source option                                                         ***
07/23/07
                                      ***                                                                                ***
16:20:18
 **MODELOPTs:
PAGE   4
 CONC                     RURAL FLAT         DFAULT


                                              *** GRIDDED RECEPTOR NETWORK SUMMARY ***

                                        *** NETWORK ID: GRD1     ;  NETWORK TYPE: GRIDCART ***

                                                   *** X-COORDINATES OF GRID ***
                                                             (METERS)

        -200.0,    -180.0,    -160.0,    -140.0,    -120.0,    -100.0,     -80.0,     -60.0,     -40.0,     -20.0,
           0.0,      20.0,      40.0,      60.0,      80.0,     100.0,     120.0,     140.0,     160.0,     180.0,
         200.0,

                                                   *** Y-COORDINATES OF GRID ***
                                                             (METERS)

         200.0,     180.0,     160.0,     140.0,     120.0,     100.0,      80.0,      60.0,      40.0,      20.0,
           0.0,     -20.0,     -40.0,     -60.0,     -80.0,    -100.0,    -120.0,    -140.0,    -160.0,    -180.0,
        -200.0,
1 *** ISCST3 - VERSION 02035 ***      *** multiple source option                                                         ***
07/23/07
                                      ***                                                                                ***
16:20:18
 **MODELOPTs:
PAGE   5
 CONC                     RURAL FLAT         DFAULT


                                                   *** METEOROLOGICAL DAYS SELECTED FOR PROCESSING ***
                                                                    (1=YES; 0=NO)

           1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
1 1
           1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
1 1
           1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
1 1
           1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
1 1
           1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
1 1
           1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
1 1
           1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
1 1
           1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1

                 METEOROLOGICAL DATA PROCESSED BETWEEN START DATE: 2002   1  1  1
                                                   AND END DATE: 2002  12 31 24

             NOTE:  METEOROLOGICAL DATA ACTUALLY PROCESSED WILL ALSO DEPEND ON WHAT IS INCLUDED IN THE DATA FIL


                                        *** UPPER BOUND OF FIRST THROUGH FIFTH WIND SPEED CATEGORIES ***
                                                                 (METERS/SEC)

                                                 1.54,    3.09,    5.14,    8.23,   10.80,
```

STABILITY CATEGORY	1	2	3	4	5	6
A	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01
B	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01	.70000E-01
C	.10000E+00	.10000E+00	.10000E+00	.10000E+00	.10000E+00	.10000E+00
D	.15000E+00	.15000E+00	.15000E+00	.15000E+00	.15000E+00	.15000E+00
E	.35000E+00	.35000E+00	.35000E+00	.35000E+00	.35000E+00	.35000E+00
F	.55000E+00	.55000E+00	.55000E+00	.55000E+00	.55000E+00	.55000E+00

*** VERTICAL POTENTIAL TEMPERATURE GRADIENTS ***
(DEGREES KELVIN PER METER)

STABILITY	WIND SPEED CATEGORY					
CATEGORY	1	2	3	4	5	6
A	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
B	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
C	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
D	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
E	.20000E-01	.20000E-01	.20000E-01	.20000E-01	.20000E-01	.20000E-01
F	.35000E-01	.35000E-01	.35000E-01	.35000E-01	.35000E-01	.35000E-01

CONC RURAL FLAT DFAULT

*** THE FIRST 24 HOURS OF METEOROLOGICAL DATA ***

FILE: C:\Documents and Settings\metramen\Desktop\Plaisance Met Data.ASC.txt
FORMAT: (4I2,2F9.4,F6.1,I2,2F7.1,f9.4,f10.1,f8.4,i4,f7.2)
SURFACE STATION NO.: 61990 UPPER AIR STATION NO.: 61990
NAME: UNKNOWN NAME: UNKNOWN
YEAR: 2002 YEAR: 2002

YR	MN	DY	HR	FLOW VECTOR	SPEED (M/S)	TEMP (K)	STAB CLASS	MIXING HEIGHT (M) RURAL	MIXING HEIGHT (M) URBAN	USTAR (M/S)	M-O LENGTH (M)	Z-0 (M)	IPCODE	PRATE (mm/HR)
02	01	01	01	91.0	1.03	295.9	4	180.6	729.2	0.0000	0.0	0.0000	0	0.00
02	01	01	02	238.0	4.12	295.9	4	1371.6	1814.4	0.0000	0.0	0.0000	0	0.00
02	01	01	03	134.0	2.06	295.4	4	575.7	1026.8	0.0000	0.0	0.0000	0	0.00
02	01	01	04	133.0	1.54	295.4	4	270.9	1026.8	0.0000	0.0	0.0000	0	0.00
02	01	01	05	133.0	1.54	295.4	5	69.7	483.7	0.0000	0.0	0.0000	0	0.00
02	01	01	06	132.0	1.54	295.4	6	69.7	483.7	0.0000	0.0	0.0000	0	0.00
02	01	01	07	145.0	1.54	295.9	5	69.7	467.1	0.0000	0.0	0.0000	0	0.00
02	01	01	08	133.0	1.54	296.5	6	69.7	466.8	0.0000	0.0	0.0000	0	0.00
02	01	01	09	177.0	1.54	298.1	5	69.7	466.1	0.0000	0.0	0.0000	0	0.00
02	01	01	10	211.0	3.09	299.8	5	407.5	624.2	0.0000	0.0	0.0000	0	0.00
02	01	01	11	234.0	3.61	300.4	4	1180.4	1568.5	0.0000	0.0	0.0000	0	0.00
02	01	01	12	206.0	4.12	301.5	4	1373.0	1815.8	0.0000	0.0	0.0000	0	0.00
02	01	01	13	233.0	4.64	302.0	4	1562.4	2060.1	0.0000	0.0	0.0000	0	0.00
02	01	01	14	239.0	4.12	302.6	4	1373.3	1816.0	0.0000	0.0	0.0000	0	0.00
02	01	01	15	242.0	4.12	302.6	4	1458.5	1898.0	0.0000	0.0	0.0000	0	0.00
02	01	01	16	244.0	2.06	300.4	4	887.9	1072.8	0.0000	0.0	0.0000	0	0.00
02	01	01	17	251.0	3.61	300.9	4	1441.9	1734.4	0.0000	0.0	0.0000	0	0.00
02	01	01	18	257.0	4.64	301.5	4	1730.8	2197.4	0.0000	0.0	0.0000	0	0.00
02	01	01	19	264.0	0.00	297.0	4	813.6	828.7	0.0000	0.0	0.0000	0	0.00
02	01	01	20	207.0	4.64	296.5	4	1698.8	2171.7	0.0000	0.0	0.0000	0	0.00
02	01	01	21	180.0	2.06	295.9	3	1253.3	1357.0	0.0000	0.0	0.0000	0	0.00
02	01	01	22	222.0	3.09	295.9	3	1582.1	1773.4	0.0000	0.0	0.0000	0	0.00
02	01	01	23	180.0	1.03	296.5	4	1116.3	1065.7	0.0000	0.0	0.0000	0	0.00
02	01	01	24	180.0	1.03	296.5	4	1141.1	1081.0	0.0000	0.0	0.0000	0	0.00

*** NOTES: STABILITY CLASS 1=A, 2=B, 3=C, 4=D, 5=E AND 6=F.
FLOW VECTOR IS DIRECTION TOWARD WHICH WIND IS BLOWING. ***

CONC RURAL FLAT DFAULT

*** THE 1ST HIGHEST 1-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL

*** INCLUDING SOURCE(S): TRANS1 , TRANS2 , SRC4 , REOP , SONIW1 , SONI

Y-COORD (METERS)	X-COORD (METERS) -200.00	-180.00	-160.00	-140.00	-120.00
-200.0	745.35931 (02032223)	785.22546 (02032223)	713.35132 (02032223)	604.13312 (02093024)	561.50635 (02093024)
-180.0	630.21710 (02032223)	756.74829 (02032223)	783.94397 (02032223)	682.10364 (02032223)	617.29114 (02093024)
-160.0	662.32867 (02092523)	632.13953 (02032223)	759.29578 (02032223)	769.70544 (02032223)	647.91998 (02033122)
-140.0	679.28339 (02092523)	669.91431 (02092523)	626.13416 (02032223)	752.66071 (02032223)	734.87762 (02032223)
-120.0	684.77502 (02032301)	687.79504 (02112720)	670.96265 (02111024)	617.92358 (02111024)	731.94867 (02032223)
-100.0	709.50281 (02022701)	676.80798 (02022622)	699.02844 (02112720)	677.64233 (02111024)	622.33521 (02111024)
-80.0	741.92096 (02022701)	710.81573 (02022701)	664.94397 (02022622)	697.28540 (02022622)	678.85425 (02112720)
-60.0	719.72229 (02012701)	709.41028 (02012701)	691.78711 (02022701)	639.75769 (02022622)	688.21729 (02022622)
-40.0	703.77332 (02120701)	660.85809 (02022623)	676.79492 (02012701)	633.07660 (02022701)	609.86224 (02022622)
-20.0	609.60327 (02041518)	645.66602 (02120701)	645.89014 (02120701)	662.96527 (02022623)	641.53882 (02022624)
0.0	704.58411 (02041518)	676.79529 (02041518)	600.91577 (02120624)	607.41284 (02022623)	651.08643 (02022623)
20.0	627.36420 (02120801)	637.63062 (02120801)	636.67871 (02120624)	647.29785 (02120624)	620.18115 (02120624)
40.0	599.43628 (02100220)	597.86389 (02052823)	588.51685 (02052823)	571.08179 (02120624)	587.95142 (02120624)
60.0	688.52576 (02120823)	662.69360 (02120823)	625.34674 (02033121)	626.19275 (02033121)	602.74243 (02033121)
80.0	612.27136 (02110801)	598.81885 (02063022)	616.46136 (02033121)	620.32275 (02033121)	596.97412 (02033121)
100.0	636.92358 (02110801)	613.54443 (02072601)	587.01208 (02121623)	587.17505 (02072524)	593.55737 (02120721)
120.0	610.22852 (02042218)	625.87720 (02112819)	618.45575 (02072524)	618.61261 (02072524)	580.49725 (02072524)
140.0	602.82642 (02012824)	611.80664 (02012824)	573.26495 (02012824)	537.94019 (02121621)	566.91528 (02122122)
160.0	517.36792 (02012824)	577.00201 (02050316)	619.87988 (02050316)	600.31702 (02122201)	590.29163 (02120718)
180.0	595.65161 (02050316)	599.92657 (02122201)	621.78650 (02120718)	610.18616 (02042220)	648.77734 (02051723)
200.0	580.38330 (02122201)	603.51965 (02120718)	614.98407 (02042220)	633.70648 (02022117)	650.95630 (02122121)

CONC RURAL FLAT DFAULT

*** THE 1ST HIGHEST 1-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL ***

INCLUDING SOURCE(S): TRANS1 , TRANS2 , SRC4 , REOP , SONIW1 , SONI ,

*** NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) -100.00	-80.00	-60.00	-40.00	-20.00
-200.0	540.92773 (02051321)	628.60291 (02092124)	741.44226 (02092124)	781.28101 (02113019)	616.32019 (02052522)
-180.0	551.76978 (02093024)	592.52722 (02051321)	712.13489 (02092124)	781.64832 (02113019)	656.99133 (02113019)
-160.0	619.67859 (02093024)	546.34833 (02051321)	642.46210 (02051321)	735.97839 (02113019)	694.06348 (02113019)
-140.0	656.54425 (02093024)	608.52637 (02093024)	608.12592 (02051321)	682.58325 (02051321)	697.65839 (02113019)
-120.0	688.68689 (02033122)	661.29846 (02093024)	591.26270 (02041721)	673.02295 (02051321)	658.67084 (02051321)
-100.0	681.70117 (02032223)	691.18872 (02033122)	636.97205 (02093024)	618.69415 (02112721)	675.23499 (02051321)

CONC RURAL FLAT DFAULT

*** THE 1ST HIGHEST 1-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL ***

INCLUDING SOURCE(S): TRANS1 , TRANS2 , SRC4 , REOP , SONIW1 , SONIA ,

*** NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 0.00	20.00	40.00	60.00	80.00
-40.0	672.36945 (02022622)	640.19519 (02112720)	572.03027 (02041723)	549.11658 (02033122)	517.74695 (02041721)
-20.0	572.90845 (02120724)	614.60388 (02022622)	550.89380 (02022323)	516.70447 (02111120)	503.22589 (02102521)
0.0	632.12122 (02022623)	544.24933 (02092219)	524.45081 (02011820)	519.11975 (02111120)	442.06091 (02102521)
20.0	576.28381 (02031224)	541.52173 (02012624)	550.62946 (02022620)	489.15436 (02011820)	339.44531 (02111120)
40.0	570.15588 (02122323)	552.57788 (02012521)	519.86639 (02012521)	421.63370 (02120621)	256.84143 (02020622)
60.0	569.41278 (02012621)	535.88123 (02022322)	503.77258 (02020522)	383.93091 (02020522)	193.43893 (02011521)
80.0	556.09619 (02111221)	555.59412 (02022721)	524.43518 (02022721)	396.73969 (02012620)	211.48767 (02020821)
100.0	630.16809 (02120721)	627.49054 (02120721)	537.90875 (02120721)	441.33459 (02011421)	298.06619 (02012520)
120.0	582.34363 (02120721)	547.78076 (02122122)	542.23120 (02122123)	507.72260 (02111719)	391.71606 (02011723)
140.0	564.91467 (02122122)	604.70679 (02120722)	634.35706 (02120722)	539.17114 (02120722)	503.42529 (02011823)
160.0	634.60950 (02051723)	633.05493 (02120722)	598.72955 (02120722)	653.81360 (02011823)	577.70044 (02011822)
180.0	668.06213 (02122121)	660.54065 (02122124)	650.17029 (02011823)	639.35748 (02011823)	580.96387 (02012721)
200.0	663.29498 (02122124)	591.99890 (02011823)	612.18811 (02011823)	616.07263 (02012519)	634.68646 (02011422)
-200.0	685.07562 (02041524)	724.03186 (02041524)	644.50964 (02121123)	712.69318 (02121123)	598.99445 (02012501)
-180.0	646.74323 (02041524)	720.61371 (02041524)	634.74670 (02041819)	701.75769 (02121123)	608.54999 (02012501)
-160.0	647.57202 (02071324)	700.68518 (02041524)	636.56561 (02041819)	674.84375 (02121123)	604.98230 (02012501)
-140.0	662.09448 (02071324)	658.91321 (02041524)	625.86597 (02041819)	625.81000 (02121123)	619.48914 (02092221)
-120.0	656.70312 (02071324)	615.12000 (02071324)	596.91602 (02041819)	598.82184 (02092221)	622.14209 (02092221)
-100.0	622.12646 (02071324)	617.58569 (02071324)	541.06238 (02041819)	601.68109 (02092221)	628.12799 (02011624)
-80.0	609.25360 (02011623)	603.60468 (02011623)	481.06604 (02121122)	582.36169 (02092221)	623.65540 (02011624)
-60.0	578.12909 (02011623)	615.34375 (02011623)	466.62689 (02011623)	548.57587 (02121122)	568.12036 (02120122)
-40.0	490.54785 (02011623)	571.67474 (02011623)	475.50238 (02020921)	538.32129 (02121522)	511.62747 (02120122)
-20.0	383.06400 (02012421)	447.58273 (02010321)	450.34009 (02020921)	497.93866 (02121522)	420.32904 (02020922)
0.0	325.13431 (02011622)	324.95175 (02012421)	316.04150 (02020921)	332.57718 (02121522)	423.41406 (02020922)
20.0	207.52785 (02011622)	124.49744 (02012421)	88.09491 (02020921)	141.65067 (02020922)	265.09360 (02020123)
40.0	63.87473 (02110521)	49.93755 (02020122)	104.55851 (02020122)	176.98087 (02020122)	213.99318 (02020122)
60.0	44.65122 (02020121)	59.26801 (02022020)	115.27684 (02020122)	188.75641 (02020122)	241.74667 (02020122)
80.0	84.81647 (02020121)	80.06596 (02022022)	110.07129 (02022022)	154.85286 (02020122)	251.10063 (02020122)
100.0	108.68108 (02020121)	112.71677 (02032422)	141.32298 (02032422)	160.58966 (02032422)	290.69971 (02020122)
120.0	268.58356 (02100320)	188.69208 (02020121)	162.74831 (02032422)	233.34047 (02032422)	327.08722 (02022022)
140.0	467.29834 (02012721)	433.95050 (02020121)	354.18024 (02020121)	349.05746 (02032424)	

683.37988 (02031923)
200.0 | 704.42004 (02011422) 624.61243 (02042820) 638.93237 (02012722) 662.80035 (02070124)
733.10724 (02031923)

CONC RURAL FLAT DFAULT

*** THE 1ST HIGHEST 1-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL
***

INCLUDING SOURCE(S): TRANS1 , TRANS2 , SRC4 , REOP , SONIW1 , SONIA2
,

*** NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

Y-COORD (METERS)	X-COORD (METERS) 100.00	120.00	140.00	160.00	180.00
-200.0	679.34155 (02120124)	672.77362 (02120124)	542.74854 (02052724)	673.82233 (02022324)	657.66577 (02022324)
-180.0	698.26111 (02120124)	631.14062 (02120124)	612.19324 (02022324)	700.51447 (02022324)	690.85376 (02041822)
-160.0	694.97864 (02120124)	596.83276 (02052724)	674.26056 (02022324)	675.25781 (02022324)	695.07397 (02112723)
-140.0	653.48938 (02120124)	618.78894 (02041523)	693.69330 (02022324)	696.83093 (02041822)	629.85791 (02112723)
-120.0	633.39886 (02011624)	645.30139 (02041523)	645.72290 (02041822)	657.96045 (02112723)	571.00323 (02091322)
-100.0	631.24951 (02041523)	644.49493 (02041523)	635.41064 (02112722)	622.26978 (02112722)	606.99268 (02091322)
-80.0	652.06354 (02041523)	598.37335 (02112722)	657.50134 (02112722)	627.99121 (02091322)	610.71069 (02112724)
-60.0	606.03088 (02041523)	636.74750 (02112722)	614.52197 (02091322)	614.17761 (02091322)	584.40649 (02060420)
-40.0	505.42139 (02112722)	584.74115 (02022421)	587.22687 (02031322)	591.72992 (02102522)	639.57446 (02033124)
-20.0	547.26746 (02020123)	544.56287 (02031322)	613.63153 (02102522)	620.55688 (02033124)	674.87585 (02031422)
0.0	487.40015 (02020123)	558.22156 (02102522)	607.77594 (02102522)	616.45404 (02031422)	665.36414 (02041622)
20.0	350.92725 (02102522)	460.02173 (02102522)	601.81146 (02011423)	672.18298 (02011423)	663.04266 (02011423)
40.0	258.15186 (02012523)	467.25287 (02011423)	591.34070 (02011423)	616.73071 (02011423)	645.98407 (02041621)
60.0	329.12277 (02031321)	468.27295 (02012523)	502.81128 (02012523)	539.06628 (02041621)	620.69751 (02041621)
80.0	391.13889 (02020122)	447.57083 (02020122)	460.14288 (02041623)	609.25732 (02041623)	691.70276 (02041623)
100.0	559.70972 (02020122)	676.93127 (02012822)	705.36865 (02012822)	678.32977 (02012921)	740.18054 (02041623)
120.0	503.65411 (02012822)	748.06958 (02012822)	846.07568 (02012822)	815.36987 (02012822)	818.92163 (02012921)
140.0	558.28326 (02031421)	740.43115 (02031421)	775.06250 (02012822)	815.89807 (02012822)	774.35284 (02012822)
160.0	679.80121 (02070120)	724.11804 (02070123)	816.27515 (02031421)	743.89856 (02031421)	755.07397 (02042721)
180.0	698.15747 (02070120)	743.53955 (02070120)	840.23730 (02070123)	790.32849 (02031421)	720.72327 (02031421)
200.0	640.66602 (02031923)	751.95251 (02070120)	794.12115 (02070123)	857.68994 (02070123)	781.55084 (02070123)

CONC RURAL FLAT DFAULT

*** THE 1ST HIGHEST 1-HR AVERAGE CONCENTRATION VALUES FOR SOURCE GROUP: ALL
***

INCLUDING SOURCE(S): TRANS1 , TRANS2 , SRC4 , REOP , SONIW1 , SONIA
,

*** NETWORK ID: GRD1 ; NETWORK TYPE: GRIDCART ***

** CONC OF OTHER IN MICROGRAMS/M**3 **

|

```
-------

    -200.0 |    669.51880 (02112723)
    -180.0 |    653.86462 (02112723)
    -160.0 |    571.42920 (02112723)
    -140.0 |    547.90674 (02091322)
    -120.0 |    569.99231 (02091322)
    -100.0 |    611.02429 (02112724)
     -80.0 |    644.09167 (02060420)
     -60.0 |    619.24719 (02033124)
     -40.0 |    658.87061 (02031422)
     -20.0 |    668.96649 (02041622)
       0.0 |    644.60364 (02041622)
      20.0 |    614.20404 (02011423)
      40.0 |    707.61292 (02041621)
      60.0 |    651.59766 (02041621)
      80.0 |    721.79224 (02041623)
     100.0 |    794.59369 (02041623)
     120.0 |    837.48962 (02012921)
     140.0 |    782.07581 (02012921)
     160.0 |    726.89355 (02091421)
     180.0 |    754.13306 (02091421)
     200.0 |    665.71136 (02031421)
1 *** ISCST3 - VERSION 02035 ***     ***  multiple source option                                                    ***
07/23/07                                 ***                                                                       ***

16:20:18
 **MODELOPTs:
PAGE  12
 CONC                    RURAL FLAT          DFAULT

                                *** THE MAXIMUM   25   1-HR AVERAGE CONCENTRATION   VALUES FOR SOURCE GROUP:  ALL
***
                                INCLUDING SOURCE(S):    TRANS1  , TRANS2  , SRC4    , REOP    , SONIW1  , SONIA
,

                                ** CONC OF OTHER    IN MICROGRAMS/M**3                                    **

 RANK        CONC     (YYMMDDHH) AT      RECEPTOR (XR,YR) OF TYPE    RANK        CONC     (YYMMDDHH) AT      RECEPTOR
(XR,YR) OF TYPE
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - -
    1.     857.68994 (02070123) AT (    160.00,     200.00)  GC       14.     783.94397 (02032223) AT (   -160.00,
-180.00)  GC
    2.     846.07568 (02012822) AT (    140.00,     120.00)  GC       15.     782.07581 (02012921) AT (    200.00,
140.00)  GC
    3.     840.23730 (02070123) AT (    140.00,     180.00)  GC       16.     781.64832 (02113019) AT (    -40.00,
-180.00)  GC
    4.     837.48962 (02012921) AT (    200.00,     120.00)  GC       17.     781.55084 (02070123) AT (    180.00,
200.00)  GC
    5.     818.92163 (02012921) AT (    180.00,     120.00)  GC       18.     781.28101 (02113019) AT (    -40.00,
-200.00)  GC
    6.     816.27515 (02031421) AT (    140.00,     160.00)  GC       19.     776.62170 (02122724) AT (    160.00,
140.00)  GC
    7.     815.89807 (02012822) AT (    160.00,     140.00)  GC       20.     775.06250 (02012822) AT (    140.00,
140.00)  GC
    8.     815.36987 (02012822) AT (    160.00,     120.00)  GC       21.     774.35284 (02012822) AT (    180.00,
140.00)  GC
    9.     794.59369 (02041623) AT (    200.00,     100.00)  GC       22.     769.70544 (02032223) AT (   -140.00,
-160.00)  GC
   10.     794.12115 (02070123) AT (    140.00,     200.00)  GC       23.     764.19739 (02122724) AT (    180.00,
140.00)  GC
   11.     790.32849 (02031421) AT (    160.00,     180.00)  GC       24.     760.00476 (02042721) AT (    160.00,
140.00)  GC
   12.     785.75458 (02070123) AT (    160.00,     180.00)  GC       25.     759.29578 (02032223) AT (   -160.00,
-160.00)  GC
   13.     785.22546 (02032223) AT (   -180.00,    -200.00)  GC

  *** RECEPTOR TYPES:  GC = GRIDCART
                       GP = GRIDPOLR
                       DC = DISCCART
                       DP = DISCPOLR
                       BD = BOUNDARY
1 *** ISCST3 - VERSION 02035 ***     ***  multiple source option                                                    ***
07/23/07                                 ***                                                                       ***

16:20:18
 **MODELOPTs:
PAGE  13
 CONC                    RURAL FLAT          DFAULT

                                *** THE SUMMARY OF HIGHEST  1-HR RESULTS ***
```

```
 GROUP ID                          AVERAGE CONC      (YYMMDDHH)            RECEPTOR (XR, YR, ZELEV, ZFLAG)     OF
TYPE  GRID-ID
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 ALL      HIGH  1ST HIGH VALUE IS     857.68994  ON 02070123: AT (     160.00,     200.00,      0.00,      0.00)
GC   GRD1


  *** RECEPTOR TYPES:  GC = GRIDCART
                       GP = GRIDPOLR
                       DC = DISCCART
                       DP = DISCPOLR
                       BD = BOUNDARY
1 *** ISCST3 - VERSION 02035 ***     ***  multiple source option                                                  ***
07/23/07                                ***                                                                     ***

16:20:18
 **MODELOPTs:
PAGE  14
 CONC                    RURAL FLAT          DFAULT


 *** Message Summary : ISCST3 Model Execution ***

  --------- Summary of Total Messages --------

 A Total of               0 Fatal Error Message(s)
 A Total of               1 Warning Message(s)
 A Total of             427 Informational Message(s)

 A Total of             427 Calm Hours Identified


    ******** FATAL ERROR MESSAGES ********
               *** NONE ***


   ********    WARNING MESSAGES   ********
 SO W320    31 PPARM :Input Parameter May Be Out-of-Range for Parameter       QS

    ************************************
    *** ISCST3 Finishes Successfully ***
    ************************************
```

Control

Title one = multiple source option
Pollutant = OTHER
Flat terrain
Averaging:
1 hour
Dispersion options:
Regulatory default option
Concentration
Rural
List file = C:\Documents and Settings\metramen\My Documents\Aruna\testv2.lst

Meteorology

Input file = C:\DOCUMENTS AND SETTINGS\METRAMEN\DESKTOP\PLAISANCE MET DATA.ASC.TXT
File format = ASCII
Anemometer height = 10
Surface station number = 61990
Surface station year = 2002
Upper air station number = 61990
Upper air station year = 2002
Start date = 01/01/2002
Start hour = 1
End date = 12/31/2002
End hour = 24

Source

Sources = 5
Min Elev: 0.0 m
Max Elev: 0.0 m
Groups = 1

Receptor

Grids = 1
Discrete receptors = 2
Min Elev: 0.0 m
Max Elev: 0.0 m
Boundary receptors = 0
Min Elev: 0.0 m
Max Elev: 0.0 m

Output

Receptor tables:
1 hour = first high
Maximum tables:
1 hour = 25

```
CO STARTING
CO TITLEONE  multiple source option
CO MODELOPT  DFAULT  CONC  RURAL
CO AVERTIME  1
CO POLLUTID  OTHER
CO TERRHGTS  FLAT
CO RUNORNOT  RUN
CO FINISHED

SO STARTING
SO ELEVUNIT  METERS
SO LOCATION  TRANS1  POINT  -52.3  1.4  0
SO LOCATION  TRANS2  POINT  -48.1  -1.8  0
SO LOCATION  REOP  POINT  1.6  -0.8  0
SO LOCATION  SONIW1  POINT  31.8  70.8  0
SO LOCATION  SONIA2  POINT  38.2  63.1  0
SO SRCPARAM  TRANS1  9.660000E-01  18  401  6.19  0.5
SO SRCPARAM  TRANS2  9.660000E-01  18  401  6.19  0.5
SO SRCPARAM  REOP  6.860000E-01  11  348  4.72  0.7
SO SRCPARAM  SONIW1  1.673000E+00  15  363  3.62  0.5
SO SRCPARAM  SONIA2  1.673000E+00  15  363  3.62  0.5
SO SRCGROUP  ALL
SO FINISHED

RE STARTING
RE GRIDCART GRD1 STA 0
RE GRIDCART GRD1 XYINC  -200.0  21  20.0  200.0  21  -20.0
RE GRIDCART GRD1 END
RE DISCCART  -164.8  16.8
** RCPDESCR  valentina 1
RE DISCCART  -111.9  65.5
** RCPDESCR  valentina2
RE FINISHED

ME STARTING
ME INPUTFIL  "C:\DOCUMENTS AND SETTINGS\METRAMEN\DESKTOP\PLAISANCE MET DATA.ASC.TXT"
ME ANEMHGHT  10  METERS
ME SURFDATA  61990  2002
ME UAIRDATA  61990  2002
ME STARTEND  2002  01  01  1  2002  12  31  24
ME FINISHED

OU STARTING
OU RECTABLE  1  FIRST
OU MAXTABLE  1  25
OU FINISHED

** PROJECTN  0 104 7 -177 0 0.9996 500000 0
** IMAGE2  "A:\VAL 1.TAB"
** OUTFILE  "C:\Documents and Settings\metramen\My Documents\Aruna\testv2.lst"
** RAWFILE  "C:\Documents and Settings\metramen\My Documents\Aruna\testv2.RAW"
** RAWFMT  2
** HILLBOUN  0 0 0 0
```

APPENDIX F

Proposal

Training Workshop on Air Quality Modelling

For

Ministry of Environment, Government of Mauritius

Prepared by

Dr Prasad Modak
Environmental Management Centre, India
Web www.emcenre.com

In cooperation with

Dr T Ramjeawon
University of Mauritius

December, 2004

1.0 Background

Air Quality Models (AQM) are used today for a wide variety of applications in environmental assessment and management. These applications include

- Siting/zoning of developmental projects
- Deciding on the buffer zones
- Setting emission and ambient air quality standards
- Deciding on stack heights
- Making choice of fuel
- Recommending air pollution control technology
- Preparing for emergency response due to leaks/accidental release
- Assessing impact on human life and natural resources

Application of AQMs requires knowledge about emissions and their characteristics, local meteorology and understanding of the underlying mechanisms of pollutant transport and dispersion. Since the computations involved are often intensive, AQMs are generally applied with the help of software packages. Several AQM software packages exist today, developed for various emission and meteorological conditions. It becomes necessary therefore that hands on training is provided to enable appreciation and use of some of the commonly used AQM software packages.

Unfortunately, the subject of AQM is often not covered in detail in the university programmes. Further, opportunities for hands on training on AQM software packages are not generally available. Given these limitations, the Ministry of Environment, Government of Mauritius considered operating a Training Workshop on AQM to benefit the Ministry Staff, Research and Academic Institutions and Professionals. This proposal is developed in response to such an interest.

2.0 Objective of the Training Workshop

The focus of the Training Workshop will be **Industrial Emission Source Modelling**[1]. Under this scope, the objectives of the proposed Training Workshop are as follows

a. Provide basic understanding of AQM – concepts, underlying theory, strengths as well as limitations
b. Illustrate practical applications of AQM in decision making
c. Provide coaching on one of the commonly used and broad based AQM software package through hands on work sessions
d. Provide guidelines on how to apply AQMs for regulatory applications
e. Provide resources (reading materials and software packages as available in the public domain)

[1] *EMC recommends a separate hands on Training Workshop to specifically address line and area sources of emissions (i.e. transportation corridors and urban areas) as a follow up event*

3.0 Proposed Structure of the Training Workshop

The workshop is designed for about 20 participants. It will be assumed that the participants do not have formal training in AQM. Participants with some basic environmental training and exposure will however be preferred.

All participants will receive the workshop materials including MS PowerPoint presentations, handouts to participants, case studies and group work session material and a resources CD-ROM. The CD-ROM will contain softcopies of all the workshop presentations, additional reading material on air quality modelling and free copies of some of the popularly used AQM software packages.

The Workshop is visualized in four modules. There are two possibilities of organizing these four modules.

Model A: The workshop will be conducted in four half day (morning) modules held over 4 working days. The modules will typically begin at 9 AM and end at 1230 PM.

Model B: The workshop will be conducted over two full days held on two consecutive days e.g. Friday/Saturday. The modules will typically begin at 9 AM and end at 1730 PM.

The Ministry of Environment can choose any of the two models. Model B may be more practical and effective than Model A.

The programme structure as visualized for Model B is detailed as below

Module A (Day One)		
L1 Why AQM?	0930 – 1000	Introduction to basic modelling concepts, use of AQM in decision making, advantages and limitations
L2 Understanding Emissions and Emission Characteristics	1000-1045	Emission factors, Point, Line and Area sources, Continuous and puff discharges
L3 Understanding basic concepts in meteorology	1045-1130	Winds, Mixing height, Monin-Obukov length, atmospheric stability, dispersion coefficients, plume rise etc
Tea/Coffee break		
L4 The Gaussian Plume based AQM	1200-1300	Introduction to Gaussian Plume based AQM, assumptions, governing equations, close form solutions for single source
Lunch break		
Module B		

W1 Application of AQM for single source point emission	1400 – 1530	Participants will work in groups on computers to apply a simple Gaussian Plume AQM for decision making
Tea/Coffee break		
L5 Introduction to ISC/AERMOD Software Package (Part 1)	1600 – 1700	Basic model structure, capabilities and input data requirements will be explained.
Discussions		Question/answer session
Module C (Day Two)		
L6 Introduction to ISC/AERMOD Software Package (Part 2)	0930-1100	Step by step instructions will be provided on how to set up input data for ISC/AERMOD.
Tea/Coffee break		
W2 Case study based group work session on ISC/AERMOD (Part 1)	1130-1300	Groups of participants will work on a hypothetical case study based on the ISC/AERMOD.
Module D		
W3 Case study based group work session on ISC/AERMOD (Part 2)	1400-1530	Participants will complete the group work and hold a discussion session on modelling experience
L7 Guidelines for AQM	1600 – 1700	Guidelines on how to choose, how to apply and how to interprete results of AQM will be provided
Concluding session and Workshop evaluation	1700-1730	Summarize outcomes of workshop, workshop evaluation and recommend next steps

Notes:

L indicates a Lecture session
W indicates a Group Work session
Choice of ISC or AERMOD will be made based on meteorological data generally available at Meteorogical Department at Mauritius.

MINISTRY OF ENVIRONMENT / UNIVERSITY OF MAURITIUS / MAURITIUS RESEARCH COUNCIL

Workshop
on

AIR QUALITY MODELLING

April 18 – 19, 2005

Jointly organized by

ENVIRONMENTAL MANAGEMENT CENTRE, INDIA

and

FACULTY OF ENGINEERING, UNIVERSITY OF MAURITIUS

List of Participants

No	Family Name	Other Name	Organisation	Position		
1	YADALLEE	Mohammad Aslam	ELD, DoE	Ag. Divisional Environment Off		
2	BEEDASSY	Rajiv	EA, DoE	Environment Officer		
3	BOODOO	Zyaad	ELD, DoE	Technical Officer		
4	ATCHIA	Mohammed Iqbal	NEL, DoE	Scientific officer		
5	Mrs SOOBRON	Soodevi	EA, DoE	Environment Officer		
6	DOSIEAH	Ashwin Kumar	NEL, DoE	Scientific Officer		
7	FANNY	Jean Yannick	NEL, DoE	Technical Officer		
8	DINDYAL	Devindranath	NEL, DoE	Scientific Officer		
9	Ms RAMPHUL	Nivedita Roshnit	Policy and Planning, DoE	Environment Enforcement Assistant		
10	CHAMILALL	Dinkar Sharma	PPC, DoE	Environment Officer		
11	MUNHURRUN	Girish	PPC, DoE	Technical Officer		
12	OH-SENG	Jaques Rudy	PPC, DoE	Technical Officer		
13	SURROOP	Dinesh	PPC, DoE	Technical Officer		
14	VITHILINGUM	Devarajen	PER, EA, DoE	Technical Officer		
15	Ms. PUDARUTH	Neermala	PER, EA, DoE	Technical Officer		
16	RUGHOOPUTH	Soonil Dutt	UoM	Prof of Physics		
17	SEEJORE	Om Prakash	UoM	Senior Lecturer, Faculty of Engineering		
18	SEMBHOO	Dharmendra	Central Electricity Board	Mechanical Engineer		
19	SOOKHRAZ	Sanjay	Central Electricity Board	Envirionmental Affairs Officer		
20	CHUTOORI	Chandansingh	Min. of Labour, Industrial Relations & Employment	Engineer		
21	HEERAMUN	Krishna	Mauritius Research Council	Research Officer		
22	BOONEEADY	Raj	Mauritius Meteorogical Services	Meteorologist		
23	RAMRACHEYA	Sharmeela Devi	Ministry of Local Government & SWM	Technical Officer		
24	DEELCHAND	Rajnish	Ministry of Health and QL	Sanitary Engineer		