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CAPE TOWN BROWN HAZE STUDY

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FOREWORD

CAPE TOWN BROWN HAZE STUDY

The seeds of the Cape Town Brown Haze study were planted at a meeting at the Cape Town Civic Centre on 1st November 1990. Under the auspices of the National Association for Clean Air (NACA), a gathering of local air pollution regulators and industrialists was addressed by Professor Judy Chow (Desert Research Institute, Reno Nevada) on the topic "Implications and uses of source apportionment receptor modelling for decision makers". A working group was formed to draft a proposal and to raise funds for a pilot source apportionment study. An early decision was that as far as possible local scientists and resources should be used and developed in this initiative. The outcome of this venture is now in your hands as the final report of the Cape Town Brown Haze Study.

Capetonians and visitors to the city have been eagerly awaiting an answer to the tantalising puzzle: What is the source of this all-too-apparent atmospheric blight - Cape Town's "brown haze"? The slightly surprising answer to this puzzle is contained in the body of this report (and I am sure the reader will already have cheated by turning immediately to the Executive Summary to find the answer). I would like to reflect on the processes leading up to this report.

It has been my privilege, as a member of the Steering Committee, of working closely with the Brown Haze scientific team, comprising Mark Wicking-Baird, Mark de Villiers and Professor Dick Dutkiewicz.

The initial learning curve through the Pilot Study Phase took the first hesitant steps through the pilot study phase, was very steep as the team developed the expertise in the Chemical Mass Balance (CMB) sampling and analytic techniques and began to develop the insights required to design the full scale study. This technology is significantly more exacting than the techniques then in current use in South Africa.

After presentation of the Pilot Study report, the team passed through a difficult intermediate stage, when an impatient audience expected definitive results immediately from the Pilot Study. Professor Dutkiewicz and his team, imperturbable (at least to public gaze!), pressed on with motivating the scientific and financial bases for the definitive full scale study. The team took the lead in developing the co-operative structure between regulators, local and international, local industry and the community which has been the hallmark of this study. In close collaboration with the scientists and technicians of the Cape Town City Council, they painstakingly executed the sampling phase. Selection of samples for analysis and analysis of the samples followed. This phase was not without its hiccoughs. I must commend the Brown Haze scientific team for its thoroughly professional attitude, especially during the difficult times. They never showed any compromise on the quality of their work and were prepared to face the impatience of the sponsors and the public rather than take short cuts.

The team was always self-critical, and receptive to even quite fierce outside criticism. Setbacks and delays were not met with despair, but determination to proceed. This approach accounts for the top-quality scientific report you now hold in your hands.

The wise counsel of the Steering Committee, in guiding and supporting the scientific team during the past three years, is also to be commended.

The process of the Brown Haze Study has also set new standards in South Africa, with regard to co-operation between scientists, local authorities, local industries, central government, and environmental organisations. On the technical side, this research project has fostered strong links between the scientific team at Energy Research Institute and the technical branch of the Cape Town Metropolitan Council, to the mutual advantage of both. The project has resulted in two higher degrees at the University of Cape Town.

Close involvement of the diverse parties at all stages of the project built up a high level of trust and co-operation between the scientific contractor and the community. As a result, these findings will be more readily understood and accepted, and debated on their substantive merits. This project will serve as an outstanding role model of how complex scientific projects can be managed with active community participation and inputs.

The release of this report is not the end of a process, but a step along the way. You, the reader, may well find the findings of this report surprising. Certainly, critical scrutiny of the methodology and results must now follow. If accepted after such examination, this report will form a powerful base for rational planning and air quality management strategy for the Greater Cape Town area.

In conclusion, I commend the work done by the Brown Haze scientific team on completion of a difficult task well done. I am confident that presentation of this Brown Haze report marks a significant mile stone in the science and the management of urban air quality in South Africa.

Harold Annegarn

Johannesburg
14 September 1997

EXECUTIVE SUMMARY

The Cape Town brown haze occurs mostly from April to September due to strong temperature inversions and windless conditions that can occur during these months, which leads to the build-up of pollutants emitted into the atmosphere. The haze extends over most of the Cape Metropolitan Area and is normally most intense in the morning and then lifts and disperses.

The haze has a strong degrading effect on visibility which is immediately apparent to the general public and to tourists. Capetonians are especially proud of the natural beauty of their city, and the haze is increasingly eroding this pride. Also of concern is the effect on the tourist industry which is projected to be Cape Town's most important economic growth area. Recent concern has been expressed about the increasing incidence and intensity of the haze.

The main objective of the Brown Haze Study was to determine the contribution of all major sources to the brown haze, and to obtain a better understanding of the mechanism of haze formation. The focus of the study was therefore on visibility, rather than health, although the two are closely related. It should be noted that localised air pollution problems were not addressed in this study.

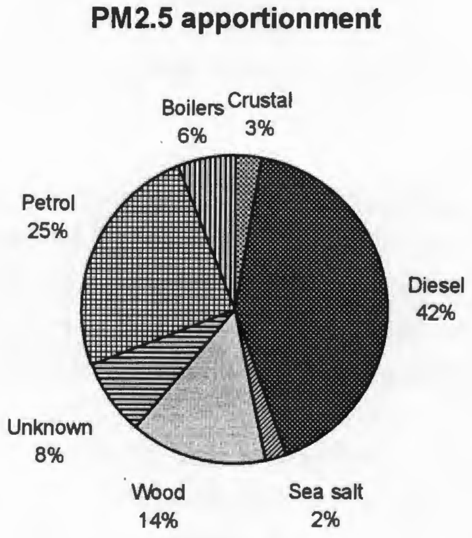
Generally, in urban areas, particles less than 2.5 microns in size (PM2.5) are the single largest cause of visibility impairment. They are also the most harmful size range of particles to human health. Because of the importance of PM2.5 in the haze the main focus of the study was a source apportionment of PM2.5. The apportionment used a receptor modelling approach that required chemical data about the main sources and the brown haze itself.

The brown haze was sampled over a one year period, from July 1995 to June 1996, using PM2.5 samplers situated at four sites (City Hall, Goodwood, Table View, Wynberg) in the Cape Town Metropolitan Area. This network was geared for optimum sampling during brown haze episodes. A single sample was also taken at Guguletu. In addition to the PM2.5 sampling there is ongoing continuous measurement of a number of air pollutants and meteorological parameters at the four sites. The Chemical Mass Balance Model, an accepted source apportionment tool of the United States Environmental Protection Agency, was used to determine the contribution of various sources to the brown haze.

Important sources of air pollutants were identified through an emissions inventory of the Cape Town Metropolitan area. Sources that were included in the modelling were various soils, road dust, sea salt, coal-fired boilers, oil-fired boilers, Caltex oil- and gas-fired equipment, Caltex's fluidised catalytic cracker unit, Kynoch's ammonium nitrate emissions, diesel combustion, petrol combustion, wood fires, grass fires, and tyre burning. Secondary sources for sulphates, nitrates, and carbon were also used in the modelling. In some instances the model could not distinguish different types of sources, in which case these sources had to be combined.

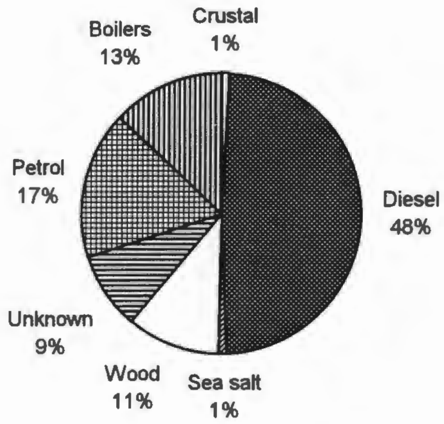
During the one year sampling period, internationally recognised health standards for nitrogen dioxide were exceeded during most brown haze episodes, for sulphur dioxide were very seldom exceeded, and for PM10 were never exceeded. The United States PM2.5 daily standard was not exceeded on the brown haze episodes measured, but is likely to be exceeded on the worst brown haze days. In general it can be said that, due to Cape Town's unique meteorology, Cape Town experiences strong pollution episodes for only a few hours per day on some days of the year. Pollution levels, and visibility, during these occasions are comparable with some of the worst polluted cities in the world, but they are not sustained. For this reason daily and annual air pollution standards are seldom exceeded.

Ambient sampling was carried out on 29 brown haze episodes at each of the monitoring sites. In order to satisfy a number of data quality criteria for modelling, only four to six brown haze episodes were modelled for each monitoring site. Average PM2.5 source apportionment of the brown haze episodes modelled is shown below.



PM2.5 apportionment was converted to visibility apportionment; that is contribution to the visual impact of the brown haze. Average visibility apportionment of the brown haze episodes modelled is shown below.

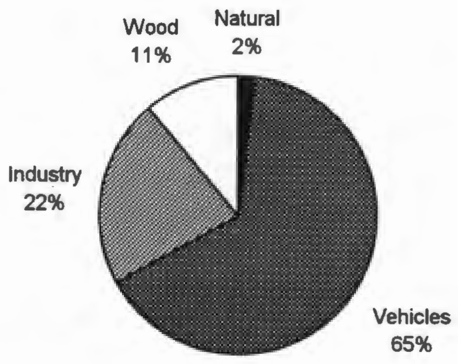
Visibility apportionment



The results show that the major source of the brown haze in Cape Town is diesel vehicles, with petrol vehicles, wood burning, and industrial boilers also being significant. A significant unknown source also exists, which comprises mostly organic carbon. It is likely that a significant portion of this organic carbon is derived from industrial process emissions. The Caltex refinery and the Athlone power station are included under boilers, together with other oil-fired and coal-fired boilers. Due to the emissions of the Caltex Refinery and the Athlone power station being above the inversion layer during the worst period of the brown haze, in the early morning, they are not expected to form a significant portion of the industrial contribution during brown haze episodes. The model indicated tyre burning and Kynoch Fertiliser Factory emissions to be insignificant. It must be emphasised that these results do not reflect on possible localised air pollution problems that may exist.

Assuming the unknown portion is attributed to industry, contributions to the brown haze can further aggregated as shown below.

Visibility apportionment



Primary PM2.5 emissions are the most important component of the brown haze, and in a business-as-usual scenario they are estimated to increase by 48% over the next decade. It is therefore likely that the intensity of the brown haze will increase by a similar amount. It is also likely, under the business-as-usual scenario, that PM2.5 health standards will be exceeded with increasing frequency over the next decade.

If Cape Town is serious about improving air quality and reducing the intensity of the brown haze, then both immediate action and longer term planning is required. Immediate attention should be focused primarily on diesel vehicles, the largest single contributor to the brown haze. Recommendations for authorities are:

- Enforce the diesel black smoke legislation.
- Introduce measures to reduce the number of smoking petrol vehicles.
- Enforce the industrial black smoke legislation.
- Initiate discussions with the oil industry about the potential benefits from fuel reformulation.
- Initiate the upgrading of air pollution control capacity in the Cape Metropolitan Council.
- Initiate the development of an air quality management system for Cape Town.
- Existing national air pollution legislation should be re-assessed, as much of it is outdated.

Responsibility for managing Cape Town's air quality lies primarily with the Health Department of the Cape Town Metropolitan Council. Presently this Department does not have the manpower, resources, or influence to adequately enforce current legislation, to adequately examine air quality data, or to ensure that air quality is optimally integrated within metropolitan planning. It is therefore recommended that:

- Manpower of the Air Pollution Division be increased.
- Adequately qualified and experienced manpower be taken on.
- The necessary budget for facilities to test and monitor emissions be allocated.
- The Air Pollution Division be given sufficient power to be able to enforce standards and have a say in metropolitan planning.

Immediate action should be complemented with the development of an integrated air quality management system for Cape Town. At the heart of the system will be an ongoing process of planning, implementing, and assessing emission reduction measures. Medium and long term air quality targets should be set, and revised periodically. The system should include setting of relevant ambient air quality standards, development and updating of an accurate emissions inventory, improving the air quality monitoring system, as well as a public awareness component.

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CONTENTS

Page

FOREWORD i
EXECUTIVE SUMMARY iii
ACKNOWLEDGEMENTS vii
CONTENTS ix

1. INTRODUCTION 1
1.1 Description of the brown haze in Cape Town 1
1.2 Background to this study 1
1.3 Objectives of this study 2
1.4 Management structure for the project 2
1.5 Basic methodology 3

2. LITERATURE REVIEW 4
2.1 Health effects of air pollution 4
2.2 Air pollution standards 6
2.3 Air pollution studies in Cape Town 7
2.4 Air pollution models 9
2.5 Source apportionment studies around the world 10
2.6 Visibility apportionment 12
2.7 Visibility apportionment studies 13

3. METEOROLOGY OF CAPE TOWN 15
3.1 Introduction 15
3.2 Overview of the meteorology of Cape Town 15
3.3 Meteorological zones of Cape Town 16
3.4 Meteorology and brown haze episodes 18

4. METHODOLOGY 19
4.1 Emissions inventory 19
4.2 Source sampling 20
4.3 Ambient particulate sampling 20
4.4 Brown haze episode prediction 22
4.5 Other ambient data 23
4.6 Analytical methods 23
4.7 Apportionment 23
4.8 Validation 24

5. EMISSIONS INVENTORY 26
5.1 Geographical area covered by the emissions inventory 26
5.2 Sources of information 27
5.3 Accuracy of the inventory 27
5.4 Uses and limitations of the inventory 27
5.5 Cape Town emission inventory 28

6. SOURCE PROFILE 31
6.1 Oil-fired boilers 31
6.2 Crustal material 32
6.3 Caltex Refinery catalyst dust 32
6.4 Wood burning 32
6.5 Grass and tyre burning 32
6.6 Diesel vehicles 33
6.7 Leaded petrol vehicles 33
6.8 Miscellaneous profiles 34
6.9 Modelling 34

7. AMBIENT CONDITIONS 36
7.1 General trends 36
7.2 Ambient conditions during particulate sampling 38
7.3 PM2.5/PM10 ratio 40

8. RESULTS OF THE APPORTIONMENT OF THE BROWN HAZE 42
8.1 Data validation 42
8.2 Modelling results 45
8.3 Comparison with other cities 54
8.4 Discussion of modelling results 54

9. PROJECTED EMISSIONS FOR CAPE TOWN 59
9.1 Transport 59
9.2 Industry 60
9.3 Households 60
9.4 Business as usual scenario for Cape Town 62

10. OPTIONS FOR REDUCING EMISSIONS 64
10.1 Transport 64
10.2 Industry 68
10.3 Domestic fires and tyre burning 69

11. RECOMMENDATIONS 70
11.1 Immediate action 70
11.2 Allocation of resources for air quality management 70
11.3 Air quality management system 71

12. REFERENCES **75**

APPENDICES **79**
A: Emission inventory A1-A17
B: Source sampling B1-B8
C: Ambient sampling C1-C3
D: Filter handling D1-D6
E: Detailed maps of each sampling site E1-E5
F: Analytical methods F1-F3
G: The Chemical Mass Balance Model G1-G3
H: Visibility apportionment H1-H3
I: Source profiles I1-I17
J: Chemical Mass Balance Model performance measures J1-J2
K: Ambient meteorological and gaseous data K1-K8
L: Ambient filter concentrations L1-L6
M: Chemical Mass Balance Model results for each episode M1-M23
N: Apportionment results for each episode N1-N5

1. INTRODUCTION

1.1 Description of the brown haze in Cape Town

"Brown Haze" is a term used to describe a brown-coloured smog found predominantly in the wintertime in the Cape Town region. It occurs mostly from April to September due to strong temperature inversions and windless conditions that can occur during these months, which leads to the build-up of pollutants emitted into the atmosphere. The haze extends over most of the Cape Metropolitan Area, but does not appear, by visual observation, to be of uniform intensity. It shifts, depending on the direction of any light wind. The haze is normally most intense in the morning and then lifts and disperses as the day continues.

The haze has a strong degrading effect on visibility which is immediately apparent to the general public and to tourists. Capetonians are especially proud of the natural beauty of their city, and the haze is increasingly eroding this pride. Also of concern is the effect on the tourist industry which is projected to be Cape Town's most important economic growth area.

The haze is also cause for concern to residents because of health risks that may accompany the visible air pollution. Small particles, largely responsible for the haze, can also have serious respiratory effects if their concentration is sufficiently high. The same conditions that are conducive to the formation of a haze are also conducive to the accumulation of gases which are invisible, but if sufficiently concentrated can have unpleasant health and odour effects.

1.2 Background to this study

The problems of inadequate air quality are not new to Cape Town. By the late sixties Cape Town was experiencing a thick smog caused by the three power stations in the area, coal-burning locomotives and tugs, industrial incinerators, and heavy fuel burning appliances. In 1968 the City Council initiated a programme of air pollution control and within a decade Cape Town had significantly reduced pollutant levels. This was achieved through measures such as termination of the use of coal-burning locomotives and tugs, the closure of two power stations, and enforcement of standards for fuel burning appliances. However, since then another form of air pollution, termed the brown haze, began to emerge. The haze prompted local authorities to begin installing a sophisticated pollution monitoring network in Cape Town from the mid-eighties. The monitoring equipment targeted pollutants mostly associated with motor vehicles as this was thought to be the major cause of the problem. Although significant pollutant levels were measured little was known of the contribution of each potential source to the brown haze.

It has been difficult to determine quantitatively whether the number of incidents of haze are increasing since no measurements have been made of the severity of the haze. However the City Council measure the haze daily by visual observation and they are convinced that the haze problem is intensifying. The problem has also been highlighted by the local press, and was further highlighted by the comments of a number of overseas researchers who claimed that the haze urgently required investigation.

In view of the concern over the brown haze, it was decided that it had become necessary to analyse its constituents and determine its sources. Authorities in Cape Town made a plea to the National Government for assistance, but insufficient funds were available. The Cape Town Branch of the National Association of Clean Air then undertook to raise funds for a pilot study of the haze. A total of R30 000 was raised.

The pilot study was carried out in 1992 by the Energy Research Institute, and its objective was to investigate research requirements to understand the nature and causes of the brown haze. The pilot study concluded that based on comparisons with other cities Cape Town does have a serious air pollution problem, and that air quality is likely to get worse. It was estimated that a major study, costing about R400 000, would be required to identify the causes of the haze. The pilot project concluded that a source apportionment study, focusing on particulates and to a lesser extent gases, was necessary and that such a study was possible with local resources.

The Energy Research Institute then approached all potential funders of the brown haze project including local industry, associations, the Department of National Health, and local municipalities. By the end of 1994 sufficient funds had been raised to begin the study.

1.3 Objectives of this study

The main objective of the second phase of the brown haze study was to determine the contribution of all major sources to the brown haze, and to obtain a better understanding of the mechanism of haze formation. The focus of the study was therefore on visibility, rather than health, although the two are closely related. Identifying contributions to the haze will indicate the most important areas where authorities should focus their activities, and will enable the effects of possible measures to be assessed. The study also examined where Cape Town is heading in terms of air quality and the options available to improve air quality. The study did not examine any localised air pollution problems that may exist.

1.4 Management structure for the project

At the outset of the project a project management structure, shown in Figure 1.1, was agreed upon by the sponsors and main stakeholders:

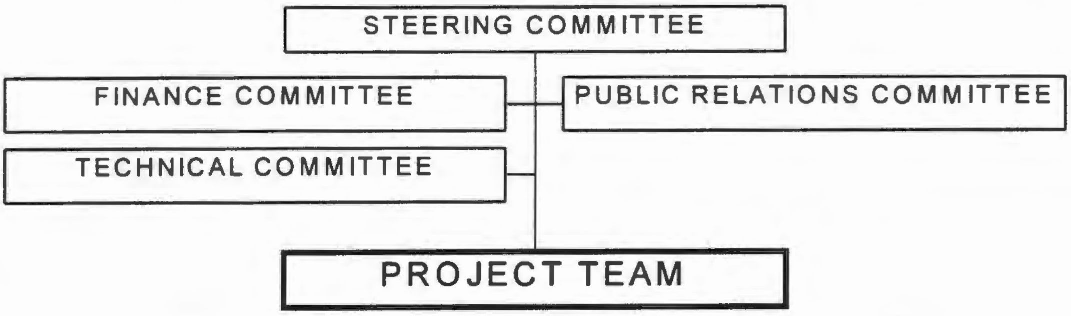


Figure 1.1 Management structure for the brown haze project

The Project Team was responsible for the carrying out of the research. It was provided with technical guidance from the Technical Committee. The Steering Committee, comprising sponsors and persons with specialist knowledge, was responsible for overseeing the entire project. The Finance Committee audited the project balance sheet. The Public Relations Group ensured that the general public was informed about the research both during and after the project.

1.5 Basic methodology

Visibility impairment of the brown haze is caused by the scattering and absorption of light by particles and gases. Generally, in urban areas, particles less than 2.5 microns in size (PM2.5) are the single largest cause of visibility impairment. They are also the most harmful size range of particles to human health. Because of the importance of PM2.5 in the haze the main focus of the study was a source apportionment of PM2.5. The apportionment used a receptor modelling approach that required chemical data about the main sources and the brown haze itself.

The brown haze was sampled over a one year period using an ambient sampling network that consisted of PM2.5 samplers situated at four sites in the Greater Cape Town area. This network was geared for optimum sampling during brown haze episodes. In addition to the PM2.5 sampling there was continuous measurement of PM10, NO_2, NO, SO_2, ozone, non-methane hydrocarbons, and meteorological parameters at the four sites. The results of the source apportionment, chemical analyses, and ambient gaseous and meteorological data were integrated to evaluate the role of the main contributors to haze formation.

2. LITERATURE REVIEW

2.1 Health effects of air pollution

The effects of air pollution on health has attracted the attention of many regulatory bodies(11,13,16,18). This is because pollutants such as oxides of nitrogen, sulphur dioxide, volatile organic compounds, ozone and particulates have been correlated with changes in mortality, instances of respiratory complaints and cardiovascular illnesses, as well as carcinogenicity. Health effects of pollutants are determined in a number of ways. Laboratory experiments determine the threshold effects of pollutants, while epidemiological studies attempt to link changes in ambient pollutant levels with health effects in communities.

2.1.1 Nitrogen dioxide

Of the oxides of nitrogen (NO_x), nitrogen dioxide (NO_2) is linked with health effects. NO is emitted from high temperature combustion, and later partially converted to NO_2 by photochemical reactions. Sources of NO include motor vehicles and fossil fuel burning power plants. Nitrogen oxides are less soluble in water than sulphur dioxide and are therefore associated with deep lung penetration as scrubbing of the gas in the nasal passages is not efficient(11). Animal experiments have shown that NO_2 causes alteration in lung metabolism, structure and function, and an increase in the susceptibility to pulmonary infections. Studies on humans have shown that, with asthmatics in particular, NO_2 has a bronco-constricting effect.

In a paper by Özkaynak(8) reviewing epidemiological studies into the health effects of ambient NO_2, no conclusive association was made between ambient NO_2 and respiratory illness although it was suggested that high levels of this pollutant could cause the prolonging of respiratory complaints.

2.1.2 Sulphur dioxide

Sulphur dioxide (SO_2) is a colourless gas that is soluble in water and can be readily oxidised by coming into contact with water droplets in the atmosphere. Therefore the health effects of the gas are often associated with the secondary aerosol pollutants such as ammonium sulphate [$(NH_4)_2SO_4$] which is linked to atmospheric visibility degradation(12). Atmospheric SO_2 results mainly from the combustion of fossil fuels such as in power stations, motor vehicles and industrial boilers.

Due to its high solubility in water SO_2 is readily absorbed in the mucous membranes of the nose and the upper respiratory tract(13). High occupational exposures (more than 10000 $\mu g/m^3$) to the gas give rise to severe brochoconstriction, chemical bronchitis and tracheitis. Lower concentrations (500-2700 $\mu g/m^3$) cause bronchospasm in asthmatics. Typical ambient levels are much lower than this (less than 100$\mu g/m^3$). SO_2 also oxidises in the atmosphere to form sulphate particles. These have been correlated with changes in mortality(13) and these effects will be discussed in more detail later in the chapter when particulates are discussed.

2.1.3 Volatile organic compounds

Volatile organic compounds (VOC's) are described by the United Nations Economic Commission for Europe(14) as "all organic compounds of anthropogenic nature other than methane that are capable of producing photochemical oxidants by reactions with oxides of nitrogen in the presence of sunlight". Most VOC's do not occur in appreciable enough concentrations in the atmosphere to constitute a health risk, but the ones that do are: benzene, aldehydes, 1,3-butadiene, n-hexane, and some chlorinated hydrocarbons. The sources of these VOC's are vehicle exhausts, petroleum fuel evaporation from refineries and vehicles, and industries that use solvents such as the paint or plasticizer industry.

Health effects of VOC's differ from compound to compound, but in general they have one of the following effects: carcinogenicity, neurobehavioural or nephrotoxic. Benzene is a well known carcinogen(15) and has been linked to incidences of leukemia(13,14) as has 1,3-butadiene(45). Aldehydes such as formaldehyde have been linked with irritation of the eyes, nose, throat and upper respiratory tract(13). n-Hexane effects respiratory and cardiovascular function.

2.1.4 Ozone

Ozone in the urban atmosphere is a photochemical oxidant whose formation is the result of interactions between oxides of nitrogen and hydrocarbons in the presence of sunlight. Motor vehicles are primarily associated with these precursor pollutants, although stationary sources burning fossil fuels also contribute to nitrogen oxide emissions. The atmospheric concentrations of ozone are a strong function of the amount of solar insolation and the precursor loading in the atmosphere(8).

Ozone exposure causes irritation to the airways resulting in inflammation, increased permeability in lung tissue, and destruction of pulmonary macrophages(9). Large or intermittent chronic exposures can cause thickening of airways and alveoli membranes with eventual loss of function. High ambient ozone concentrations have been associated with restricted activity, asthma symptoms, and respiratory admissions to hospitals(10).

2.1.5 Particulates

Particulate air pollution and its health effects are associated with complaints of the respiratory system(1). More specifically researchers have shown that particulates are linked to increased mortality and an increase in the hospital admissions for respiratory and cardio-vascular illnesses(1,2,3,5). Furthermore particulates are associated with mutagenic activity(4,6) which in turn indicates their cancer causing potential.

In many countries the primary health standard for particulates is PM10, which refers to particles of aerodynamic diameter less than 10μm. This standard was chosen as representing the particulate size that has the potential to penetrate the upper airways of the respiratory system(7). PM10 can be subdivided into three categories, based on the methods of formation of particles:(1)

(a) Nucleation Mode Particles (10 - 200 nanometres) which are formed by the condensation of hot gases. The ratio of the number of particles to the total mass of particles in this mode is high, and have a short lifetime in the atmosphere.
(b) Accumulation Mode Particles (0.2 - 2 microns) which are formed by the coagulation and growth of Nucleation Mode Particles. These have a long atmospheric lifetime and make up the bulk of the atmospheric airborne particles. These are also primarily associated with emissions from combustion sources.
(c) Coarse Mode Particles (2-10 microns) which are mechanically generated and have a short atmospheric lifetime due to their high deposition rate. Relative to the Nucleation Mode, the ratio of the number of particles to the total mass of the coarse mode is low.

These three categories are, however, generally simplified to a coarse fraction (2.5 to 10 microns) and a fine fraction (less than 2.5 microns). Coarse particles are associated with particulate deposition in the bronchial region while fine mode particles are deposited further into the respiratory system resulting in their slower clearance from the lung(5).

This had lead to separate research into the health effects of the fine mode and coarse mode of particulates. Researchers have shown that PM2.5 has a much stronger correlation to health effects than PM10(1,2,5). It is postulated that this is due to the greater penetration into the lung; the fact that fine particles readily infiltrate buildings cause indoor and outdoor levels to be similar and thus exposure times longer; and the larger number of particles in the fine mode may effect the ability of the respiratory system to clear out the particles efficiently.

2.2 Air pollution standards/guidelines

Due to the adverse health effects of the pollutants mentioned in the previous section, certain ambient air quality standards/guidelines have been set to protect the general public against adverse health effects(16). The difference between standards and guidelines lies in their enforcement. Whereas standards are pollutant levels that can, by law, only be exceeded a set number of times over a given period, guidelines are concentrations of pollutants that an organisation recommends should not be exceeded in the interests of public health. The United States Environmental Protection Agency (EPA) and the World Health Organisation (WHO) are the primary bodies for the publishing of air quality standards/guidelines. Table 2.1 shows the standards/guidelines proposed by these bodies along with the South African recommendations proposed by the Department of Environmental Affairs and Tourism (DEAT).

Table 2.1 Air Pollution Standards ($\mu g/m^3$)

POLLUTANT	AVERAGING TIME	EPA[17] STANDARD	WHO[13] GUIDELINE	DEAT[18] GUIDELINE
Nitrogen Dioxide	1 year	100	40-50	94
	1 hour		200	376
Ozone	1 hour	235		235
	8 hour		120	
Sulphur Dioxide	1 year	80	50	86
	24 hours	365	125	286
	10 minutes		500	1716
PM10	1 year	50		60
	24 hours	150		180
PM2.5	24 hours	65		
	1 year	15		

Table 2.1 shows that there are both short term and long term standards/guidelines for some pollutants. This is aimed at protecting the public from the risks associated with both acute and chronic exposure to pollutants[13,16].

Air pollution standards/guidelines are constantly being reassessed and modified due to new information on air pollution health effects, and because of improvement in the technologies available for measuring the pollutants. The US EPA is presently involved in the revision of particulate and ozone standards[19,20]. The proposed new ozone standard is 157$\mu g/m^3$ averaged over 8 hours as opposed to the previous 1 hour averaging time. It is anticipated that this standard will be implemented by the year 2000[20]. The proposed particulate matter standard involves a new measurement range. The original standard was based on particles less than 10μm (PM10), and while this is to be kept, a further standard based on particles less than 2.5μm (PM2.5) was recently introduced. The reason for the emphasis on PM2.5 is that it has a strong relationship with health effects[1]. This size fraction is associated with emissions from combustion sources and therefore the PM2.5 standard will place more emphasis on the impact of these emissions[19].

2.3 Air pollution studies in Cape Town

2.3.1 Pollution problems in the Cape Town Metropolitan Area

Monitoring of pollutants has taken place at some sites in Cape Town since the sixties. The pollutants measured were SO_2 and particulates by the soiling index method. In 1975 a study was commissioned by the Cape Town City Council to carry out an air pollution study of Greater Cape Town[21]. The study found that the levels of the pollutants SO_2, NO_x, particles and ozone were within international air quality standards although concern was expressed over high episodic concentrations of ozone, NO_x and particulates.

As a result of this the report recommended the implementation of an air quality management programme in the area. This would include the measurement of ambient air pollutant concentrations as well as the setting and enforcement of air pollution standards for emitters and for ambient pollutant concentrations.

2.3.2 Brown Haze Pilot Study

Due to the occurrence of a brown haze on calm days in the winter months a pilot study was carried out in Cape Town from June to August 1992 whose objectives were(21):

- to develop a methodology to sample and analyse the haze
- assess local analysis potential
- determine the constituents of the haze
- attempt to determine the major sources of the haze
- compare the results of the study with other cities and pollution standards
- determine requirements for the next phase of the brown haze study.

From the study it was concluded that during brown haze episodes particulate levels were comparable to other heavily polluted international cities, and that there was the possibility of particulate concentrations exceeding international guidelines. Further, the infrastructure existed in Cape Town for a more comprehensive source apportionment study to be carried out.

2.3.3 Milnerton Air Quality Study(23)

An air pollution study focusing on exposure assessment followed by health risk assessment was undertaken by the CSIR between October 1994 and October 1995. This was as result of widespread complaints from the communities of Milnerton and surrounding areas. The study included continuous gaseous and particulate sampling as well as passive volatile organic compound monitoring using resin badges, and pollen and fungal monitoring.

The study identified benzene, oxides of nitrogen, fungal spores and pollen as health risks. There were also exceedences of the WHO SO_2 10 minutes-exposure guideline on 17 February 1995 at Table View. It was recommended that monitoring in the area continue with a more detailed benzene study being suggested. The study also recommended that the public be informed of air pollution levels.

2.3.4 Dispersion modelling in the Greater Cape Town Region

A dispersion modelling study for SO_2 was undertaken in 1993/94 by Dracoulides(24). It was aimed at modelling the dispersion of SO_2 throughout the area and to assess the accuracy of the model by comparing the predicted ambient levels with those measured at Cape Town City council sampling sites. This was important as dispersion models are useful for the evaluation of future air pollution control strategies and their potential controls.

Emissions for the years 1991 and 1992 were modelled, and the model predicted accurately for the Bellville area, but under-predicted concentration by a factor of 2 or 4 at Goodwood and the Cape Town CBD. The study concluded that the model was able to predict adequate air pollution concentrations at locations away from Table Mountain.

2.4 Air pollution models

Air pollution models are mathematical representations of the atmosphere and so can be used by researchers and scientists to attempt to manage air quality. The first step to air quality management is to have knowledge of the contributions of emission sources to the ambient air pollution levels. Dispersion and receptor models are commonly used.

The route by which the two models assess source impacts are different and thus give each model advantages in certain situations. Dispersion models take emission inventories and meteorological data and hence assess the impacts of sources on a chosen receptor. Receptor models require information about ambient and source pollution chemistry to assess source impacts at a receptor.

Air pollution receptor models are based on the following mass conservation expression:

$$C_i = \sum_{j=1}^{p} a_{ij} S_j \quad \text{...} (1)$$

Where:

S_j = estimated contribution of source j to the receptor.
C_i = concentration of chemical species I measured at the receptor
a_{ij} = the fractional contribution to the receptor of chemical species I from source j
p = the total number of independent contributing sources

Dispersion models require absolute emission rates while receptor models require relative chemical compositions of sources as inputs. Source data for receptor models is more robust and easier to obtain. In a receptor modelling workshop manual series Watson(29) states that dispersion models are limited in that they are unable to quantify source impacts over short episodes and in complex terrain. This is because emission inventories are unable to reflect hourly and daily emission variations. Receptor models do not need meteorological data inputs and so are more accurate in complex terrain. According to Watson(29) they are far more applicable to the assessment of 24 hour pollution episodes. Receptor models are thus more suited to an episodic sampling study such as the brown haze. Further, particularly in the Cape Town central business district (CBD), dispersion modelling becomes inaccurate(24).

There are a number of receptor modelling techniques. These range from statistical techniques such as factor analysis to chemical mass balance models, to microscopic techniques. A chemical mass balance model approved by the US EPA has been chosen for this study(30).

This type of model has been extensively used in studies in the USA(31,32,33,34,35) and there are well documented procedures for performing such a study including extensive quality control procedures(32,35).

2.5 Source apportionment studies around the world

Source apportionment studies have been performed since the late 1970's. These have been carried out as a result of perceived high particulate loadings in the atmosphere. Table 2.2 summarises some studies and gives results of apportionment, where available, as well as the type of model used and the date when the study was performed.

Table 2.2 Source apportionment studies

	Receptor Model	Date Performed	Particle Measure	Sources and Contribution
San Francisco Bay(31)	Chemical Mass Balance	1991-1992	PM10	Geological Dust 18% Vehicles 13-18% Wood/Veg Burning 40% Sulphate 3-4%
Duarte California(36)	Principal Component Analysis	1983 and 1987-1988	PM3.5	Soil 23% Sulphate 16% Vehicles 10% Organic Carbon 12%
San Joaquin California(37)	Chemical Mass Balance	June 1988 - June 1989	PM10	Soil 54% Nitrate 15% Vehicles 10% Construction 8%
Denver Colorado(33)	Chemical Mass Balance	1978	PM2.5	Vehicles 26% Coal Combustion >20% Wood Burning 12%
Shanghai(38)	Chemical Mass Balance	1990	PM10	Area Sources 53% Construction 6.2% Road Soil 8.5% Sulphate 8.3% Open Sources 6.4% Soil 4.9%
Milan(39)	Factor Analysis	1988	PM15	Metal Smelting Crustal Material Potassium Rich Source Vehicles Regional Crustal Material Sulphate
Philadelphia(34)	Chemical Mass Balance / Multiple Linear Regres.	1982	PM10	Sulphate 49-55% Crustal Material 17-24% Vehicles 4-6%
Copenhagen(40)	Chemical Mass Balance	1983	TSP	Crustal Dust 20-34% Traffic 37% Fuel Oil Combustion 20% Combined Source 28-50%
Japan(41)	Chemical Mass Balance	1977-1985	PM10	Soil 17.7-28.9% Marine 1.6-8.0% Refuse Burning 4-7.9% Oil Burning 1.5-4.0% Iron Smelting 0.5-6.8%
Hong Kong(42)	Factor Analysis	1986-1987	PM10	Construction 6.48 mg.m^{-3} Vehicles & incineration 1.93 mg.m^{-3} Wind blown Dust 7.14 mg.m^{-3} Coal-fired Power Plant 4.92 mg.m^{-3} Oil Combustion 8.15 mg.m^{-3}
Tuscon(43)	Chemical Mass Balance	1989-1990	PM2.5	Motor Vehicles 50-62% Geological Material 25-31% Ammonium Sulphate 5-11% Volatile Nitrates 8% Ammonium Nitrate 0-1%
Vaal Triangle(47)	Chemical Mass Balance	1994	PM10	Arc Furnaces 11-26% Soil Dust 0-35% Domestic Coal Fires <10-35%

2.6 Visibility apportionment

The Brown Haze Study focused on the degradation effects of the haze on visibility. Visibility or visual range of an observer is linked to the transmission of light through the atmosphere by a light extinction coefficient. Light extinction is made up of the following independent components:(35)

(a) Scattering by gases (Rayleigh Scattering) which is a constant value for a given temperature and pressure. Molecules of gas in the atmosphere divert light from a sight path.
(b) Gases absorb light and transform it into molecular energy. Nitrogen dioxide concentration is associated with light absorption by gases because absorption by other gas molecules is negligible.
(c) Absorption of light by particles occurs when black or coloured particles transform light into heat. Absorption is linked to the concentration of elemental carbon in the atmosphere.
(d) Particles scatter light in a similar way to gases. Scattering is a function of the wavelength of light, particle size and the index of refraction for the particles. Particles of 0.5µm in diameter are the most efficient at scattering light.

A number of studies(25,26,27) have shown that different chemical species have differing effects on visibility degradation. These visibility effects are normally split amongst six main groups which are:

- fine ammonium sulphate (S)
- fine ammonium nitrate (N)
- fine organic carbon (C_{ao})
- elemental carbon (C_{ae})
- remainder of fine particles (R)
- gaseous NO_2

A number of empirical models have been developed to determine the effect of the above chemical species on the visibility. These models usually assume that:

- all components contributing to scattering are included as independent variables
- the components are externally mixed
- sufficient samples have been taken to provide stable solutions
- scattering efficiency for each component is constant
- chemical concentrations are uncorrelated in time

High humidity has been found to significantly enhance the visibility effect of sulphates and nitrates.

2.7 Visibility apportionment studies

Previous visibility apportionment studies(26,43,44) have given results in one of two formats depending on the detail required from the study. The basic approach would be to apportion light extinction to the six visibility affecting species mentioned above. Studies in Denver (1981(26) and 1987-88(44)) did this and their findings are summarised in Table 2.3.

Table 2.3 Visibility apportionment in Denver

Species	**Denver 1981** **% contribution to extinction**	**Denver 1987-88 (electrical utilities burning gas)[a]** **% contribution to extinction**	**Denver 1987-88 (electrical utilities burning coal)[a]** **% contribution to extinction**
Ammonium Sulphate	20.2	6	6
Ammonium Nitrate	17.2	16	8
Organic Carbon	12.5	21	21
Elemental Carbon (absorption)	31.2	25	30
Elemental Carbon (scattering)	6.5	3	4
Remaining Particulate Mass	6.6	15	15
Rayleigh Scattering	-	6	6
NO_2	5.7	8	10

[a] During the 1987-88 Denver study the electrical utility in the town was alternating between gas and coal as fuel. An apportionment was carried out under these two conditions.

Another approach to visibility apportionment is to apportion visibility to pollution sources. This requires the combination of a model to apportion extinction to the six visibility affecting species, and a receptor model such as the Chemical Mass Balance Model. This approach was used in the Tuscon Urban Haze Study(43). Table 2.4 shows the range of values obtained for apportionment of the morning and afternoon hazes. The table also shows apportionment of hazes with b_{ext} ranging from 100-200 Mm^{-1} (haze with 40 to 20 km visual range) and for 200-250 Mm^{-1} (strong haze with 20 to 16 km visual range). The report also mentions that California and Colarado have visibility standards. California's is that visibility should be greater than or equal to 16 km (100 Mm^{-1}) and Colarado's is 50 km (76 Mm^{-1}).

Table 2.4 Visibility source apportionment in the Tuscon Urban Haze Study (%)

Source	morning haze	afternoon haze	strong morning haze
Primary Geological Material	10-25	10-50	<10-50
Primary Motor Vehicles	25-50	25- >50	>50
Primary Wood Combustion	<10	<10	<10
Primary Smelter	<10	<10	<10
Primary Limestone	<10	<10	<10
Secondary Sulphate	<10	<10	<10
Secondary Nitrate	<10-50	<10	<10-25
Secondary Organic Carbon	<10	<10	<10
NO_2	<10	<10	<10
Rayleigh Scattering	<10-25	10-25	<10

3. METEOROLOGY OF CAPE TOWN

3.1 Introduction

Ambient pollutant concentrations are strongly dependent on the atmosphere into which they are emitted. Ambient measurements are taken at low levels (3-18m) in this study so it is the characteristics of the first 500m of the atmosphere (called the planetary boundary layer) that are important. The meteorological factors that effect air pollutant concentrations in the lower atmosphere are(48):

- wind velocity
- vertical temperature profile
- mechanical turbulence

These, with rate and height of emissions govern, the ambient pollutant concentrations.

3.2 Overview of the meteorology of Cape Town

In general Cape Town meteorology can be summarised by four typical synoptic maps(49) for the Southern African subcontinent (Figure 3.1).

The summer months are characterised by a high south-easterly air flow (Figure 3.1a) this is caused by a ridging anticyclone over the south Atlantic. This means high wind velocity and consequently high atmospheric turbulence which dilutes and disperses pollutants efficiently.

During the winter months the wind is generally from the north-west (Figure 3.1b). This is caused by a pre-frontal system that also causes low temperatures and overcast conditions. The high wind velocity again performs a diluting function on pollutants in the area. Figure 3.1c shows conditions that occur mainly in early spring and late winter. These are associated with brown haze episodes in the Cape Town region(50). Strong overnight temperature inversions are associated with light föhn wind (berg wind) conditions, ahead of migrating coastal lows.

Figure 3.1d depicts stagnant conditions over the region caused by an anti-cyclone. This causes light variable winds and an elevated temperature inversion. This situation also has the potential to result in pollution episodes as there is insufficient air flow to dilute pollutants.

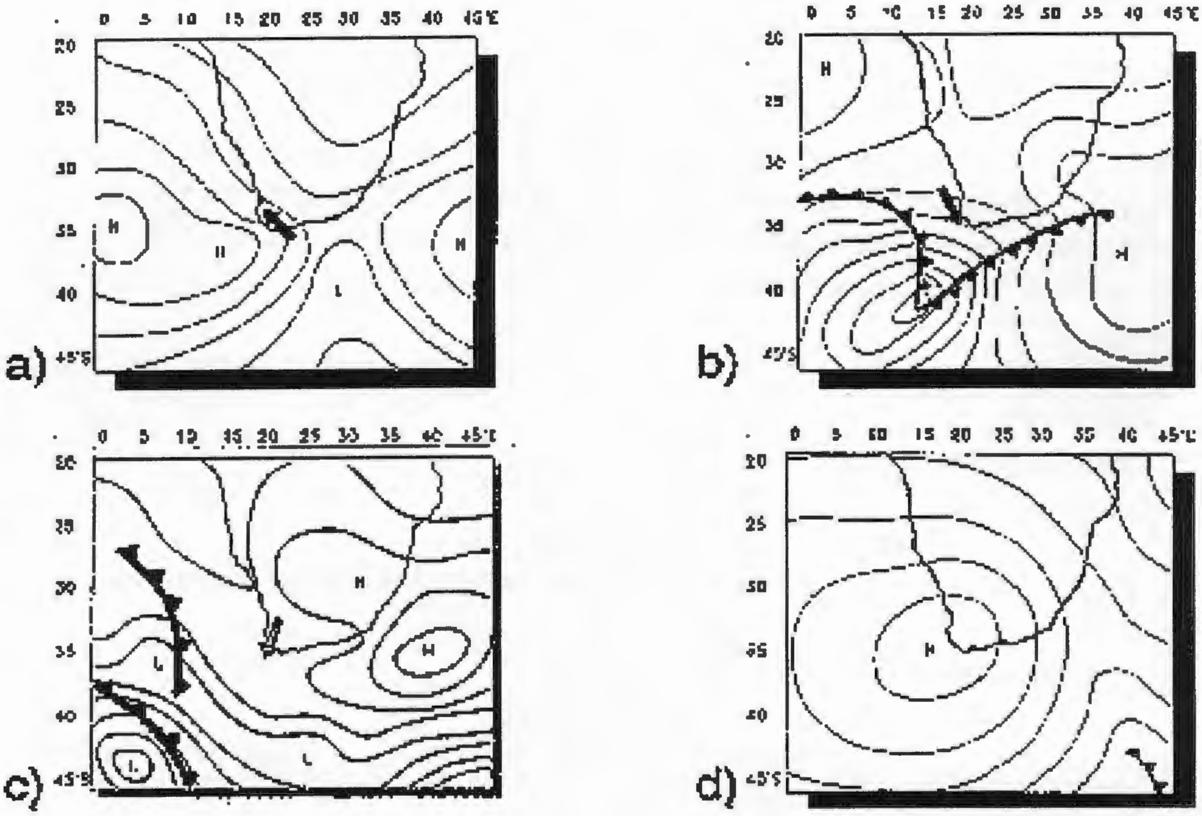


Figure 3.1 Typical synoptic maps for the Southern African subcontinent(49)

3.3 Meteorological zones of Cape Town

Due to the effect of Table Mountain and False and Table Bays the meteorology of Cape Town is complex and has been divided into six zones(51) (Figure 3.2) that show different wind patterns and potentially different pollutant loadings.

Zone 1 includes the Central Business District (CBD) of Cape Town. The meteorology here is complex due to the effect of Table Mountain. This causes southerly airflow to have a re-circulating effect rather than a ventilation effect, as in other areas. Temperature inversions are also persistent in the winter months. North-westerly airflow provides the best ventilation for pollution in the area.

Zone 2 runs parallel to the Peninsula mountain chain and includes the Wynberg monitoring site. This zone is the highest rainfall region in the Cape Town Metropolitan Area due to effects of the mountains. Inversions are persistent here too, but tend to break up more quickly than in zone 1 due to the mountain slopes facing the rising sun. This causes increased convective activity. Topography also causes downdrafts so pollution is often dispersed downwards. Ventilation is typically by south-easterly and north-westerly air flow.

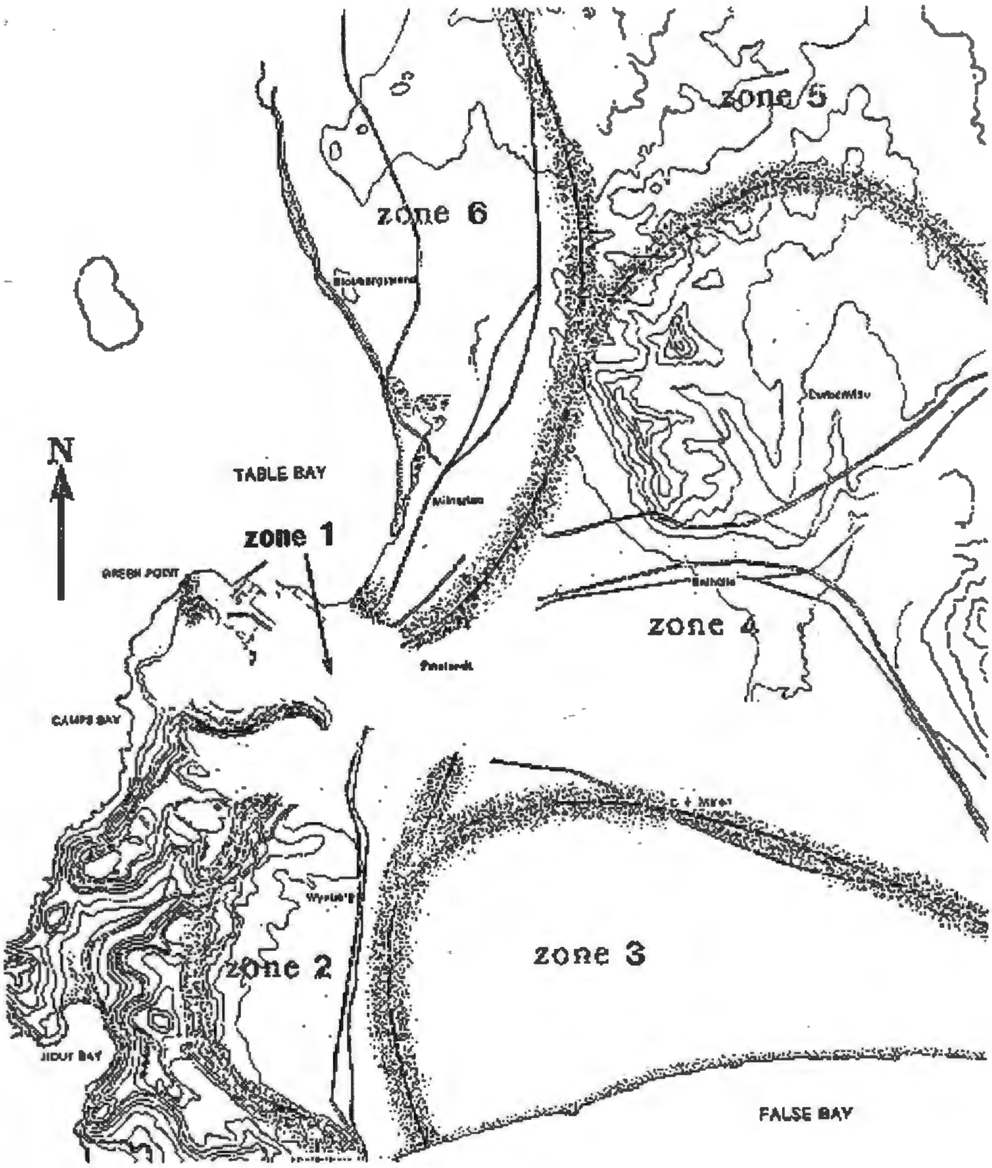


Figure 3.2 Meteorological zones of Cape Town.

Zone 3 represents the Southern Cape Flats area. There is no sampling site in this area. Although inversions do occur here in winter they are generally short lived since from about 10am the zone starts to experience strong air flows either from the south or the north depending on the weather system.

Zone 4 consists of the central Cape Flats area. Most of the industrial areas in the region are found here and the Goodwood sampling site is situated in this zone. In winter, under stable conditions this area experiences low level temperature inversions. These persist well into the morning as this area does not experience the ventilation effects of zone 3. Under unstable conditions, drainage flows are from the north-west or south-east.

Zone 5 is situated north of zone 4 and is considered a background area for this study. There is no sampling site in this area. In general the area shows strong daytime winds with a westerly component and weaker night-time winds predominantly from the east.

Zone 6 is the coastal belt from Paarden Eiland to Koeberg. There is a sampling site at Table View in this area. As with the other zones southerly and northerly drainage flows dominate in this area. Under stable conditions, however, low level inversions are formed with light sea breezes re-circulating pollutants in the area. The occurrence of the thermal internal boundary layer (a feature of coastal climatology) causes pollutants emitted in this area to be mixed to the ground. This effect can impact on pollutant concentrations some distance inland.

As shown Cape Town can be divided up in to six micro-climatic zones. Of the six zones, ambient pollutant measurements were taken in zones 1, 2 ,4 and 6 during this study.

3.4 Meteorology and brown haze episodes

Most brown haze episodes are associated with weather conditions depicted in Figure 3.1c. According to Jury et al(52) the atmospheric characteristics that are associated with pollution episodes are:

- local berg winds from NNE
- a temperature increase of about 11°C from ground level to 500m above the earth's surface.

The latter represents temperature inversion conditions in the atmosphere. The warm berg winds cause dry night-time conditions in the lower atmosphere. Night-time radiative heat loss and sinking motion from the upper atmosphere combine under these conditions to form a strong ground based inversion. The conditions in the inversion are generally calm and so there is little dilution of emitted pollutants. Emitted pollutants will rise until their "initial buoyancy and vertical momentum are dissipated"(53,54). Further the layer prevents mixing from the atmosphere above. This effectively means that pollutants are being emitted into a smaller airmass where the air velocity is insufficient for dilution. This results in higher than normal pollutant concentrations.

4. METHODOLOGY

As mentioned previously, this is a source apportionment study using a receptor modelling approach. Source apportionment is the quantification of the relative contribution of each emission source to the pollutants collected at an ambient site (or receptor). To perform a source apportionment it is necessary to collect data about the sources of emissions and about the ambient pollutant levels. The data includes a breakdown of the chemical species making up the particles from the sources and the ambient locations.

The source apportionment is based on PM2.5 due to its importance in terms of visibility degradation and health (see Chapter 2). The basic methodology of the brown haze study was to collect PM2.5 samples on filters from various emission sources (identified by performing an emissions inventory) and ambient sites, have the filters analysed chemically, insert the chemical data into a receptor model to obtain a source apportionment of PM2.5, convert the PM2.5 source apportionment to visibility apportionment, and investigate the mechanisms by which the brown haze is caused.

4.1 Emissions inventory

An emission inventory provides an inventory of primary emissions from the most important sources for a particular area. Emission inventories can be divided into three classes:

(i) **Gross estimation inventory** - Emission estimates are based on summary statistics for fuel consumption, industrial processing, etc. It is not very accurate and mainly used for nation-wide estimates.

(ii) **Rapid survey inventory** - The inventory is compiled for large point sources and through the use of reference documents for area sources. The inventory areas are often divided into zones. The method is reasonably accurate.

(iii) **Detailed source inventory** - The method was developed for use in mathematical atmospheric dispersion modelling. All point sources down to a certain emission level are included. Sources below this emission level are treated as area sources, and mobile sources are treated as a special category of area sources. All emissions are reported on a grid square basis.

The emission inventory chosen for this study lies somewhere between the first and second class of inventory. The inventory covers the Cape Town Metropolitan Area and is not divided into zones. The emission inventory was compiled for 1995. Emissions investigated were SO_2, NO_x, volatile organic compounds (VOCs), PM10 and PM2.5. SO_2, NO_x, and VOCs are precursors for secondary particulates and were thus included in the inventory. The emission inventory was used to identify the most important emitters. It was these emitters that were used in source apportionment. A detailed description of the source inventory is given in Appendix A.

4.2 Source sampling

The methodology for source sampling was based on the work done by Mintek(10) and by the Desert Research Institute(11). Details of the methodology are shown in Appendix B. Essentially sources were sampled using the techniques of either isokinetic sampling, resuspension sampling, or controlled combustion in a chamber. Sources that were characterised were:

various soils
road dust
sea salt
coal fired boiler
oil fired boiler
Caltex oil fired boiler
Caltex gas fired boiler
Caltex furnace
Caltex fluidised catalytic cracker unit
Kynoch Ammonium Nitrate emissions
diesel combustion
petrol combustion
wood fires
grass fires
tyre burning

4.3 Ambient particulate sampling

Procedures used for ambient sampling are outlined in Appendix C and Appendix D.

4.3.1 Description of ambient sampling sites

Ambient particulate sampling took place at four sites. They are Wynberg, Goodwood, Table View and the Central Business District, and their location is shown in Figure 4.1. Detailed maps of the sampling sites are shown in Appendix E. The sites were chosen on the basis of there being existing air monitoring equipment at those sites, as well as all the necessary infrastructure, such as security and electricity. As indicated in Chapter 3, the sites also fall in four of the six meteorological zones identified in the Cape Town Metropolitan Area. A single sample was also taken in Guguletu, which is located near informal settlements.

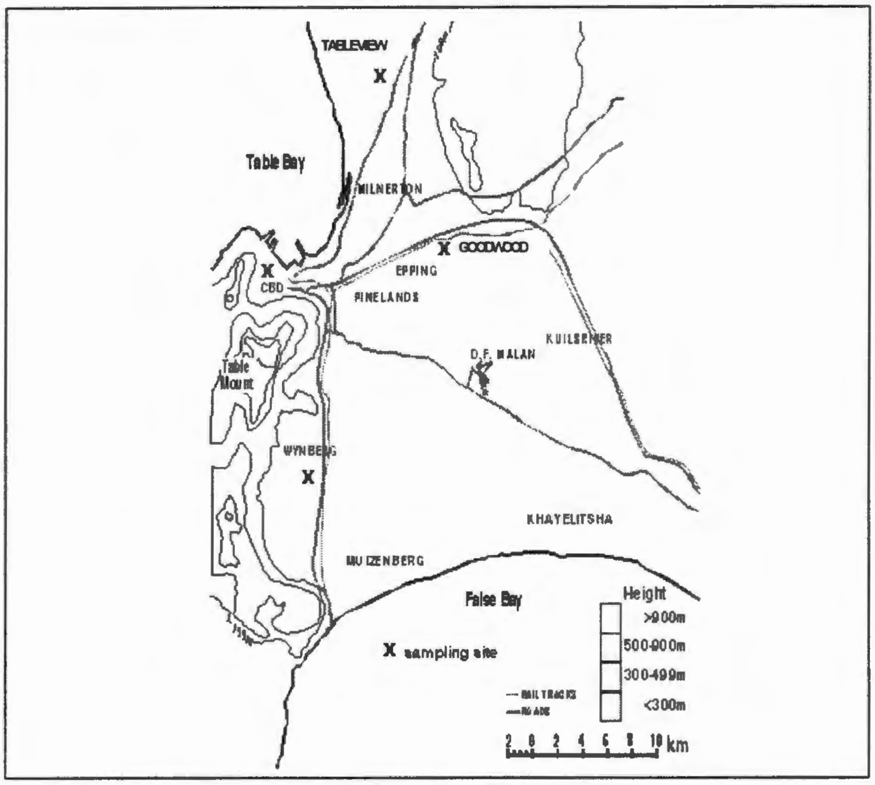


Figure 4.1 Location of the ambient sampling sites

A description of each site is given as follows:

Wynberg

Is located in a residential area a few hundred metres from a main road. Monitoring equipment at the site includes:

- PM10 continuous monitor
- PM2.5 Automated Cartridge Collection Unit (ACCU)
- NO_x monitor
- Ozone monitor

CBD

There are two monitoring sites which are located 100 metres from each other. The sites are at the City Hall and at the Drill Hall. Equipment at these sites include:

- PM10 continuous monitor
- PM2.5 ACCU
- NO_x monitor
- Non-methane hydrocarbon analyser
- Meteorological station

Table View

Is located in a residential area next to an infrequently used road. It is about a kilometre from the sea and is about two kilometres on the prevailing wind side (north-west) of a large refinery (Caltex) and fertiliser factory (Kynoch). Monitoring equipment at this site includes:

- PM10 continuous monitor
- PM2.5 ACCU
- NO_x analyser
- SO_2 analyser
- Meteorological station

Goodwood

It is located in a residential area. The equipment at this site includes:

- PM10 continuous monitor
- PM2.5 ACCU
- NO_x analyser

4.3.2 Sampling frequency and duration

Sampling was carried out for a period of one year from July 1995 to June 1996. Sampling was predominately during brown haze episodes which are characterised by temperature inversions and windless conditions occurring predominantly between April and September. A few samples were collected on clear days for comparison.

Sampling was 12-hourly during haze episodes, but in some instances was extended to 24 hours if there was insufficient filter loading on the filters to be able to perform chemical analysis. Sampling was from midnight to midday and/or midday to midnight. During clear days sampling was allowed to continue until the filters had been loaded enough for analysis. Filter loading was estimated from the continuous PM10 readings.

4.4 Brown haze episode prediction

There are a number of factors that are considered in predicting an episode:

- The Weather Bureau at Cape Town International Airport predicts a temperature versus height profile in the atmosphere a day in advance. This gives a prediction for the temperature inversions which characterise the haze.
- The Weather Bureau also gives six hourly predictions of wind speed and direction from 00h00 for three days at a time. This is important because calm conditions are important for haze formation. Wind tends to blow away pollutants and break up the temperature inversion.
- Synoptic charts also give an indication of the weather patterns. Generally a coastal low pressure system over the peninsula gives an indication of calm conditions in winter months.

It was arranged that the Cape Town Weather Bureau send daily weather prediction reports to brown haze researchers. Taking into account the above factors it was possible to predict brown haze episodes with reasonable success.

4.5 Other ambient data

Each of the sampling sites not only measures particulates but also gives ambient data for a variety of gases, and there is also measurement of wind speed and direction, and temperature. This data was received in hourly average form from the Cape Town City Council. A rigorous calibration process based on EPA procedures is followed at the sampling sites. This consists of a multi-point calibration every three months on all analysers and a level 2 single point calibration every second week. Calibration equipment and gases are audited and accredited by ESKOM.

4.6 Analytical methods

Samples were collected on three types of filters determined by the type of analysis that was required. In all instances sampling was carried out on teflon filters and quartz filters (on 16 occasions polycarbonate filters were used instead of Teflon filters due to a supply delay). In some instances sampling was also carried out on polycarbonate filters. Qualitative Scanning Electron Microscope (SEM) analysis was performed on some polycarbonate filters. Table 4.1 summarises the types of filters used.

Table 4.1 Analytical techniques applied to filter substrates

Filter Type	Analytical technique	Resulting information
Teflon	X-Ray Fluorescence (XRF) Weighing	Concentrations of elements from Mg to Pb in the periodic table
Quartz	Ion Chromatography	Water soluble SO_4^{2-}, Cl^-, NO_3^-, Ca^{2+}, K^+, Mg^{2+}, Na^+, NH_4^+
	Thermal Optical Reflectance	Organic and elemental Carbon
Polycarbonate	Electron Microscopy	Particle size distribution, qualitative particle by particle analysis
	X-Ray Fluorescence (XRF)	Concentrations of elements from Mg to Pb in the periodic table

These analytical techniques are discussed in Appendix F.

4.7 Apportionment

Apportionment was carried out using the Chemical Mass Balance Model (described in Appendix G). This Model was originally developed by John G. Watson at the Oregon Graduate Centre(46). It has since been refined and accepted as a source apportionment tool by the United States Environmental Protection Agency. It has been used extensively in studies in the United States (Table 2.2). Furthermore, as discussed in Chapter 2, this model is suitable for the episodic sampling carried out in this study.

The output of the model is the contribution of each source to the PM2.5 chemical species sampled over a certain period at a certain ambient site. The source apportionment of PM2.5 for a particular ambient site will vary from day to day due to changes in the meteorology. The apportionment was therefore averaged over the episodes measured. The source apportionment of PM2.5 was then converted to a source apportionment of visibility degradation. Light scattering and absorption by gases also had to be taken into account. The model used to predict visibility degradation is described in Appendix H.

4.8 Validation

An important aspect of the study was the data validation process. The objective of data validation was to identify deviations from measurement assumptions and procedures during data collection and processing. This applies to the entire study so data validation was carried at each of the major steps in the source apportionment. These are sample collection, chemical analysis and modelling.

The first assumption of sample collection in this study was that only PM2.5 was collected on to the filters when samples were taken. To make sure this was true the flowrate through the PM2.5 impactor needed to be checked. The TEOM unit had a built in flow controller and it recorded the total volume flow rate through the filters. Samples where this flowrate deviated from 13.7 l/min were flagged as being suspect. PM10 was measured at the same time that filter samples were being taken. Filter samples were flagged as suspect if the calculated PM2.5 concentration was greater than the PM10 concentration.

Chemical data was validated by the different organisations carrying out chemical analysis. This was done mainly by repeat tests. Once all the data from the chemical analysis was received some tests were performed on the data to further check its validity. These were:(47)

- The chemical species masses from chemical analysis were compared against the gravimetric mass of the filter. The check was passed if the gravimetric mass was within acceptable limits.
- The SO_4^{2-} measured by ion chromatography (IC) should be less than the Sulphur element measured by XRF. The potassium ion should be less than potassium measured by XRF, the same for the calcium ion and the calcium element. This is because the water soluble concentration measured by IC is less than the total elemental concentration measured by XRF (which includes both soluble and insoluble species).
- A linear relationship should exist between lead and bromine.

Data validation for the modelling apportionment was based on the seven steps proposed by the EPA(46) these are:

(a) Determine the general applicability of the CMB model to the application at hand.

(b) Set up the model by identifying and assembling the source types, source profiles, and receptor concentrations for model input. Make a preliminary application of the model to these data.

(c) Examine the model's statistics and diagnostics to identify potential deviations from the model assumptions.

(d) Evaluate problems that might result from problems with model input data deviations from model assumptions.

(e) Make any model input changes which can be justified to resolve the identified problems.

(f) Assess the stability of the model results and their consistency with the preliminary analyses.

(g) Evaluate the model results by comparing them with other receptor or dispersion model results and reconcile any differences.

5. EMISSIONS INVENTORY

5.1 Geographical area covered by the emissions inventory

Figure 5.1 shows the area covered by the inventory. It represents the boundaries of the newly formed Cape Metropole (with its 6 municipalities).

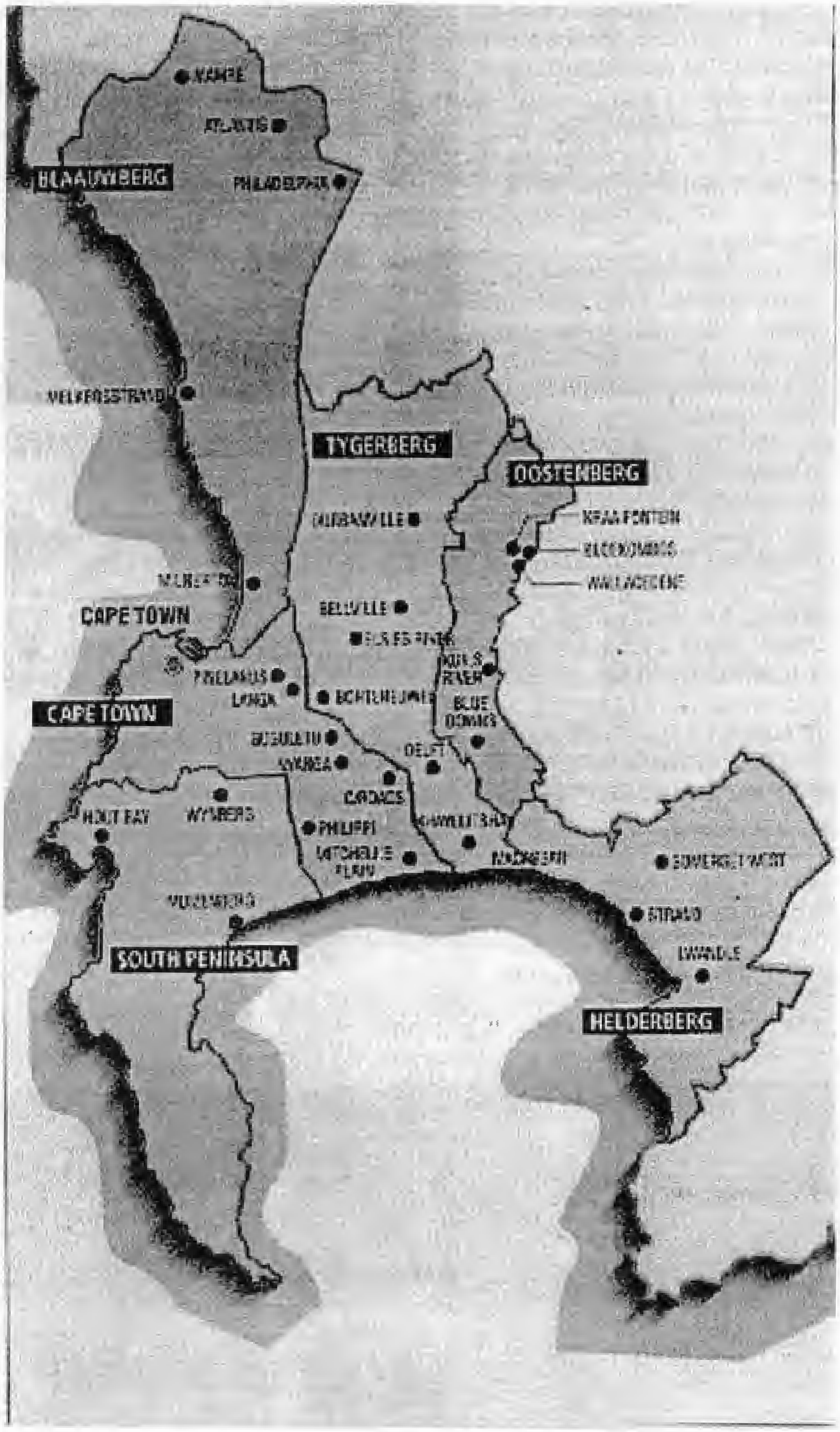


Figure 5.1 Boundaries of the emission inventory

5.2 Sources of information

Generally emissions were determined by multiplying fuel consumption by emission factors. Fuel consumption data for the entire area was obtained from various sources, and sometimes estimated from other parameters. Emissions from large point sources were sometimes obtained directly from the industries.

Emission factors for PM10 were derived from van Nierop (1995)(55) who compiled a detailed PM10 emission inventory for the Vaal Triangle. Where these were felt to be inappropriate or inadequate PM10 emission factors were derived from the US Environmental Protection Agency (EPA)(56). PM2.5 emission factors were estimated as percentages of PM10. The EPA has compiled a report, in five volumes, with instructions on how to compile an emission inventory and provides emission factors for most point, mobile, and area sources. Emission factors for SO_2 and NO_x were derived from Dracoulides (1994)(49) who recently conducted a modelling study in the Cape Town Metropolitan Area. Where these were felt to be inappropriate or inadequate SO_2 and NO_x emission factors were derived from the US EPA.

5.3 Accuracy of the inventory

Because of the wide range of sources considered and the wide range of sources of information, it is impossible to generalise about the accuracy of the emission inventory. Appendix A does, for the more uncertain data, give an indication of discrepancies in data between different sources of information. Many of the emission factors were derived from international sources rather than from research on local conditions, and it can therefore be expected that these values used are not accurate. Much of the fuel use data is also uncertain because of the assumptions that had to be made in order to reach a 'best estimate'. For instance it is impossible to determine the mass of vegetation burnt in the Cape Town Metropolitan Area with any degree of accuracy. Appendix A gives an indication of the accuracy of the information used to compile the inventory.

Emissions were accounted for as far as possible. However the VOCs emissions inventory is not exhaustive in that there a number of small sources of VOCs which are difficult to identify. Very large wild fires, which occur infrequently (once or twice a year) but produce enormous emissions, were also not included because of their variable nature and the difficulty of quantifying the emissions.

5.4 Uses and limitations of the emission inventory

The emission inventory is useful for identifying potential significant sources of the brown haze. It can also be used to qualitatively verify the results of source apportionment by examining wind direction and the time, height and location of emission sources. In addition the receptor model is unable to distinguish sources of secondary sulphates and nitrates and the emission inventory can assist in this regard. However it should always be noted that primary emissions given by the source inventory will not be proportional to their contribution to visibility impairment or health risks since:

(i) Primary emissions will have differing dispersion mechanisms from each source since they are released at different heights, times, and positions. The height of emissions is particularly important as those emitted above the inversion layer will take some time to reach ground level.

(ii) Most primary emissions will undergo phase changes and/or chemical transformations, the rate of which depend on factors such as humidity, temperature, light, and the presence of other chemical species and catalysts. Examples of transformations are SO_2 converting to sulphates and NO_x converting to nitrates.

(iii) Differing chemical species have differing effects on visibility impairment and health. For instance carbon particles have a far greater visibility impairment effect than silica particles.

(iv) Visibility impairment and health risk depends on particle size distribution which is not indicated in the inventory.

(v) Certain emissions are seasonal in nature and therefore may only contribute significantly to the haze during certain periods of the year, for instance wild fires rarely occur in winter.

5.5 Cape Town emission inventory

Table 5.1 shows the emission inventory for the Cape Town Metropolitan Area in physical units and Table 5.2 shows the emission inventory in percentages. All sources of information are shown in Appendix A.

Table 5.1 Summary of primary atmospheric emissions in Cape Town (tons/year)

	EMISSION RATES (tons/year)				
	SO_2	NO_x	VOCs	PM10	PM2.5
Residential					
Coal	185	15	49	40	16
Paraffin	344	61	4	8	8
LPG	0	31	11	2	2
Wood	1	542	2387	1877	1314
Transport					
Petrol vehicles	1591	16848	33696	562	472
Diesel vehicles	2716	1781	460	1927	1773
Brake and tyre wear				86	0
Paved roads				2129	213
Unpaved roads				1391	139
Aviation fuel	46	576	470	33	30
Ship diesel	69	739	31	52	47
Ship bunker oil	1145	582	109	67	60
Industry and commerce					
Coal	4750	1875	6	975	390
HFO	7686	695	4	451	406
FFS fuels	146	154	1	100	90
Diesel	84	900	38	64	59
Power paraffin	39	7	0	1	1
Caltex	10880	1643	1700	432	302
Kynoch		888		135	122
Athlone power station	2261	893	3	464	186
Other					
Tyre burning	241	13	107	335	168
Medical incineration	1	2	0	3	3
Wildfires	40	107	647	460	322
Other VOCs			15618		
Total	32225	28352	55341	11594	6123

Table 5.2 Summary of primary atmospheric emissions in Cape Town (%)

	EMISSION %				
	SO_2	NO_x	VOCs	PM10	PM2.5
Residential					
Coal	0.6	0.1	0.1	0.3	0.3
Paraffin	1.1	0.2	0.0	0.1	0.1
LPG	0.0	0.1	0.0	0.0	0.0
Wood	0.0	1.9	4.3	16.2	21.5
Transport					
Petrol vehicles	4.9	59.4	60.9	4.9	7.7
Diesel vehicles	8.4	6.3	8.3	16.6	29.0
Brake and tyre wear	0.0	0.0	0.0	0.7	0.0
Paved roads	0.0	0.0	0.0	18.4	3.5
Unpaved roads	0.0	0.0	0.0	12.0	2.3
Aviation fuel	0.1	2.0	0.8	0.3	0.5
Ship diesel	0.2	2.6	0.1	0.4	0.8
Ship bunker oil	3.6	2.1	0.2	0.6	1.0
Industry and commerce					
Coal	14.7	6.6	0.0	8.4	6.4
HFO	23.9	2.5	0.0	4.0	6.6
FFS fuels	0.5	0.5	0.0	0.9	1.5
Diesel	0.3	3.2	0.1	0.5	1.0
Power paraffin	0.1	0.0	0.0	0.0	0.0
Caltex	33.8	5.8	3.0	3.7	4.9
Kynoch	0.0	3.1	0.0	1.2	2.0
Athlone power station	7.0	3.2	0.0	4.0	3.0
Other					
Tyre burning	0.7	0.1	0.2	2.9	2.8
Medical incineration	0.0	0.0	0.0	0.0	0.0
Wildfires	0.1	0.4	1.2	4.0	5.3
Other VOCs	0.0	0.0	28.2	0.0	0.0
Total	100.0	100.0	100.0	100.0	100.0

6. SOURCE PROFILES

Source profiles were measured for the major air pollution sources in the Cape Town Metropolitan Area, based on the emission inventory. Source sampling was carried out using a number of methods ranging from isokinetic stack sampling to the resuspension of dust samples. Once modelling was carried out, however, it became evident that results of the apportionment could have been improved by producing multiple source samples. This was largely not possible in the study due to budgetary constraints. Multiple samples could have given a better understanding of the variability of sources and therefore a more accurate assessment of the uncertainties of the source profiles.

Total particulate masses were calculated for each source sample by:

- summing organic carbon, elemental carbon, anions not measured by XRF, cations, and all the elements measured by XRF.
- multiplying the organic carbon mass by 1.2 to take into account organic hydrogen and organic oxygen.
- assuming that silicon, aluminium, iron, vanadium, and calcium exist as oxides.

A source can be regarded as acceptable if the ratio of calculated to weighed mass ranges from 75% to 135%. For those sources which do not lie in this range, a larger degree of uncertainty was taken into account in the modelling.

Appendix I contains a graphical representation of the mass fraction of each chemical species in the source profiles. Each of the groups of source profiles are discussed in the sections that follow.

6.1 Oil-fired boilers

Samples were taken from two oil fired boilers in this study. The first was at African Products and was of moderate output. The second sample was from a boiler firing oil at the Caltex Petroleum Refinery. For the African Products boiler the calculated mass was 56% of the weighed mass. This ratio is low and was cause for concern in modelling. For the Caltex boiler the calculated mass was 90% of the weighed mass, which is within acceptable mass validation limits. The composite of these two profiles was also generated for modelling purposes by taking the arithmetic mean of the two profiles.

Heavy Fuel Oil boilers are expected to show significant proportions of aluminium, silicon, nickel, vanadium, sulphur, organic carbon and elemental carbon, with vanadium being a recognised trace element for oil firing. The two profiles show differences in the proportions of these main constituents. These differences are expected as Caltex fires fuel oil that is slightly different in composition to commercially available fuel oil. The firing conditions of the two boilers were also different, with the Caltex boiler firing the fuel oil at a higher temperature. The Caltex boiler seems to have better combustion as it produces a lower proportion of elemental carbon.

6.2 Crustal material

Crustal samples of Wynberg dust, Table View dust and city road dust were taken in the study and resuspended onto filters. These were taken to represent the crustal material in the vicinity of the sampling sites. For the three crustal material samples the calculated masses were all between 80% and 100% of the weighed masses.

Crustal material shows high proportions of aluminium, silicon, calcium and iron. The three crustal profiles measured, show differences in the proportions of these elements. The aluminium to silicon ratio varies for the three samples. Table View soil has an appearance similar to beach sand which is why it has the highest silicon value of the samples. The Road dust sample has the highest aluminium value, which can be attributed to wear and tear of motor vehicles. Other trace metals such as zinc, nickel, iron, copper and lead are high in this profile due to the motor vehicle influence. The Wynberg sample also shows a high iron content which is expected because the soil found here is a reddish colour indicating the presence of iron oxide.

6.3 Caltex Refinery catalyst dust

Besides the crustal material mentioned above, a resuspension sampling method was used to gain a profile of the catalyst dust from the Caltex oil refinery. The calculated mass for this source was 75% of the weighed mass.

This profile was similar to the crustal material in that it had a large proportion of aluminium and silicon. A trace element for catalyst dust is lanthanum which is higher in this profile than in other source profiles.

6.4 Wood burning

Wood burning profiles were generated for Port Jackson and Rooikrantz wood burning. The calculated mass for both samples was between 90% and 100% of the weighed mass.

The wood profiles show a high mass fractions for potassium, chlorine, and organic and elemental carbon. High potassium and chlorine are generally associated with wood burning and the high carbon values are as a result of the fact that wood is an organic fuel. In comparing the two profiles it is noticeable that the Rooikrantz profile generally has higher mass fractions of metals. In particular the red colour of Rooikrantz wood can be explained by the high iron content.

6.5 Grass and tyre burning

Source profiles were also generated for grass and tyre burning. Grass burning is mainly a summer phenomenon and is not expected to effect the winter ambient samples much while tyres are burnt in the Cape Town Metropolitan Area for warmth and for scrap metal. The calculated tyre mass is over 90% of weighed mass, which is acceptable under the mass validation criteria. The calculated mass for grass burning is 143% of the weighed mass, which may mean that the filter sample was contaminated in some way.

The tyre profile is high in aluminium, silicon, iron, and organic and elemental carbon. Tyre burning does not appear to produce as much chlorine as vegetative burning, but does have a large high-temperature elemental carbon component which is consistent with the black smoke observed from a tyre fire, and the high calorific value of tyres as a fuel.

The grass burning profile is similar to the wood burning profiles discussed above but with a lower potassium value.

6.6 Diesel vehicles

The diesel vehicle profile represents the emissions from the tail pipe of a diesel vehicle driving on an ECE urban driving cycle. The calculated mass of the diesel vehicle sample was 90% of the weighed mass.

The diesel profile is significant in sulphur, organic and elemental carbon. Diesel vehicles are often associated with emitting "black soot" and thus it is expected that there will be elemental carbon in the profile. The diesel vehicle sampled in the study was a well maintained vehicle that did not smoke badly. The Diesel2 profile seen in Appendix I was used in modelling to assess the effect of small changes in the elemental carbon values on modelling. The high sulphur mass fraction is as result of the sulphur found in diesel fuel.

6.7 Leaded petrol vehicles

Petrol vehicle profiles were generated using the same methods as for diesel vehicles. The vehicle profiles analysed in the study had calculated-to-weighed mass percentages of 91% and 78%.

Petrol vehicles show high mass fractions for lead, bromine, organic and elemental carbon. In the study a well maintained and a poorly maintained vehicle profile was produced. The main differences between them is the amount of organic and elemental carbon emitted relative to lead and bromine. The poorly maintained vehicle emits more of the carbon species due to poor combustion conditions or the combustion of small amounts of oil. Furthermore oil combustion produces trace metals which, however, are not seen here as they appear to be overshadowed in the profile by the high carbon species. The high values for the carbon species for the poorly maintained vehicle also cause a smaller mass fraction of bromine and lead in the poorly maintained vehicle. A composite profile of the two was made for modelling purposes.

6.8 Miscellaneous profiles

Ammonium nitrate, Portland Cement and marine profiles were used from the EPA source profile database to supplement the profiles measured in the study. These were profiles that were expected to be needed in modelling. A coal flyash sample from the Vaal Triangle study was also used as this was also expected to be necessary.

In addition to these profiles secondary sulphate, nitrate, organic and elemental carbon were used.

6.9 Modelling

The profiles mentioned above were generated for input into the chemical mass balance model. The profiles used can be split into three types, namely: primary, secondary and composite. Primary profiles are profiles that represent the primary emissions from sources discussed above and include the various vehicles, oil boilers, wood burning and the like. Composite profiles were also generated using the arithmetic means of similar primary profiles and these include composite profiles of petrol vehicles, wood burning, oil boilers and crustal material. These are useful in modelling when it becomes difficult to separate like sources. Very often it is easier to model average (or composite) profiles. Secondary source profiles are the profiles for sulphate, nitrate and organic carbon. These represent profiles for particulates that are not directly emitted but are formed from the reactions of gasses in the atmosphere. Table 6.1. shows the various profiles giving their type and the code used for the profile when modelling.

Table 6.1 Source profile codes for modelling

Modelling Code	Description	Profile Type
APOBL	African Products oil fired boiler	Primary
CALOB	Caltex oil fired boiler	Primary
WBDST	Crustal material from the Wynberg sampling site	Primary
TVDST	Crustal material from the Table View sampling site	Primary
RDUST	Crustal material from paved roads	Primary
CALCT	Catalyst material from Caltex	Primary
RKBRN	Burning of Rooikrantz wood	Primary
PJBRN	Burning of Port Jackson wood	Primary
TYBRN	Burning of Tyres	Primary
GRBRN	Grass Burning	Primary
DIVEH	Diesel vehicles	Primary
SO4	Sulphate	Secondary
NO3	Nitrate	Secondary
MARI1	Sea Salt	Primary
KYLAN	Ammonium Nitrate	Primary
SASFA	Fly Ash from coal burning	Primary
PCEMT	Portland Cement	Primary
CRUST	Crustal Material	Combined
WBURN	Wood Burning	Combined
CRUSTC	Crustal Material and Fly Ash	Combined
OHC	Organic High Temperature Carbon	Secondary
OLC	Organic Low Temperature Carbon	Secondary
EHC	Elemental high temperature carbon	Primary
VEH1	Leaded petrol vehicle (well maintained)	Primary
PETVH	Leaded petrol vehicle (poorly maintained)	Primary
VEH2	Leaded petrol vehicle (average)	Combined
DIES2	Diesel vehicle	Primary
COMPB	Oil fired boiler	Combined

7. AMBIENT CONDITIONS

7.1 General trends

At the four sites used by the Brown Haze Study for sampling particulates, various meteorological and air pollutant levels are continuously monitored and 5-minute average values are recorded. The monitoring, recording, and validation of this data is maintained by the Scientific Services Branch of the Cape Town Municipality. The Municipality provided validated hourly data for each of the sites for the one-year particulate sampling period (July 1995 to July 1996). Table 7.1 summarises the meteorological and air pollutant data collected during the sampling period.

Table 7.1 Monitoring Equipment at Ambient Sampling Sites

	Goodwood	CBD	Table View	Wynberg
NO_2	yes	yes	yes	yes
NO_x	yes	yes	yes	yes
PM10	yes	yes	yes	yes
SO_2	no	no	yes	no
Hydrocarbons	no	yes	no	no
Ozone	no	no	no	yes
Relative Humidity	no	yes	yes	no
Wind speed	no	yes	yes	no
Wind direction	no	yes	yes	no

Table 7.2 indicates average hourly pollution levels for each of the monitoring sites. It is clear that the CBD has the highest average NO_x and NO_2 levels, but Goodwood has the highest PM10 average, although the variation from site to site is not great.

Table 7.2 Average hourly pollutant concentrations (July 1995-July 1996)

	Goodwood	CBD	Table View	Wynberg
NO_2 [$\mu g/m^3$]	37	69	21	8
NO_x [$\mu g/m^3$]	88	272	31	14
PM 10[$\mu g/m^3$]	29	26	23	21
SO_2 [$\mu g/m^3$]			13	
Hydrocarbons [$\mu g/m^3$]		136		
Ozone [$\mu g/m^3$]				26

Table 7.3 indicates the number of exceedences of the US EPA and health standards (WHO guidelines for NO_2 1-hour and SO_2 10-minute) over the one-year period. High NO_2 levels, especially at the CBD, are once again evident. The high CBD values are due to high vehicle densities in the CBD. It is interesting to note that the PM10 daily standard was never exceeded at the monitoring sites. SO_2 guidelines were only exceeded on three occasions, excluding an abnormal sulphur fire incident.

Table 7.3 Number of health standard exceedences per pollutant (July 1995-July 1996)

Pollutant	Duration	Standard	Goodwood	CBD	Table View	Wynberg
NO_2	annual	100 μg/m³	0	0	0	0
	1-hour	200 μg/m³	21	87	0	0
SO_2	annual	80 μg/m³			0	
	24-hour	365 μg/m³			0	
	10 min.	500 μg/m³			3	
PM10	annual	50 μg/m³	0	0	0	0
	24-hour	150 μg/m³	0	0	0	0

Of particular interest is PM2.5 levels in Cape Town, over the sampling year, compared with the newly introduced US EPA PM2.5 standards. PM2.5 is not measured continuously, but was only measured on particular episodes. However during the episodes measured, the EPA PM2.5 standard of 65 $\mu g/m^3$ was never exceeded. Based on the average PM2.5:PM10 ratio for Goodwood during brown haze episodes (60%±17%), and the maximum daily PM10 levels in Goodwood (>100 $\mu g/m^3$), statistically it is likely that the EPA PM2.5 daily standard has been exceeded at Goodwood. The yearly PM2.5 standard set by the USEPA is $15\mu g/m^3$. Insufficient PM2.5 sampling data on non-haze days was available to be able to draw any clear conclusions on Cape Town's exceedence of the EPA annual PM2.5 standard.

Analysis of the hourly data over the one-year period indicates trends which may help explain the causes of the brown haze:

- In the CBD PM10 often peaks around 11-12 am, about one to two hours later than the NO_x peak. At the other sites PM10 peaks around 8-11 am, at the same time as the NO_x peak (which is considerable lower than the CBD NO_x peak). This indicates that there may be secondary particulate formation in the CBD.
- Smaller PM10 peaks also often occur in the evening at 7-10 pm. This could be due to the afternoon traffic and/or the starting of domestic fires. The Goodwood site peaks can be attributed to late night shopping at the N1 City shopping centre.
- High pollution levels are usually associated with low wind speeds, but on a number occasions, under strong southerly winds, the Goodwood and Table View sites experience high PM10 levels (but low NO_x levels). This is thought to be wind-blown dust from the Cape Flats.
- There is no observable correlation between humidity levels and pollution or particulate levels.

7.2 Ambient conditions during particulate sampling

During the sampling period of the Brown Haze Study, one of the objectives was to sample as many brown haze episodes as possible. Table 7.4 shows the twenty days during the study with the highest PM10 daily average at the Goodwood site. This site was chosen because it registered the highest PM10 daily average of the three sites over the sampling period. Table 7.4 also indicates that filter samples were taken on six of these days including three of the five days with the highest daily averages.

Table 7.4 Highest twenty PM10 daily averages at Goodwood (July 1995-July 1996)

Date	PM10 Daily Average [μg/m^3]	PM10 Hourly Maximum [μg/m^3]	Filter Sample Taken
29-Oct-95	97.50	366	N
30-Apr-96	91.92	304	Y
27-May-96	89.71	224	Y
21-Jun-96	80.17	224	Y
26-Apr-96	77.67	158	N
14-Jul-95	75.13	283	Y
8-May-96	73.58	165	Y
5-Jun-96	69.46	180	N
30-Oct-95	64.13	111	N
28-Oct-95	63.25	145	N
18-Jan-96	60.79	171	N
17-Nov-95	60.17	117	N
19-Jun-96	57.38	206	N
19-Sep-95	56.63	105	N
15-Aug-95	55.25	175	N
17-May-96	52.75	115	Y
16-May-96	52.63	110	N
19-May-96	52.63	173	N
22-Sep-95	52.58	104	N
28-Mar-96	52.00	108	N

Sampling was performed on 29 occasions at Goodwood during the study. Figure 7.1 and Figure 7.2 show plots of daily average and daily maximum PM10 for the sampling period. The symbols indicate days on which filter samples were taken.

The figures also show that the period from April to October is when elevated PM10 values occur. The noticeable peaks in PM10 daily average and maximum shows that pollution in the Cape Town Metropolitan Area is episodic rather than continuous. This supports the assertion made in Chapter 3 that high pollutant levels are caused by favourable meteorological conditions.

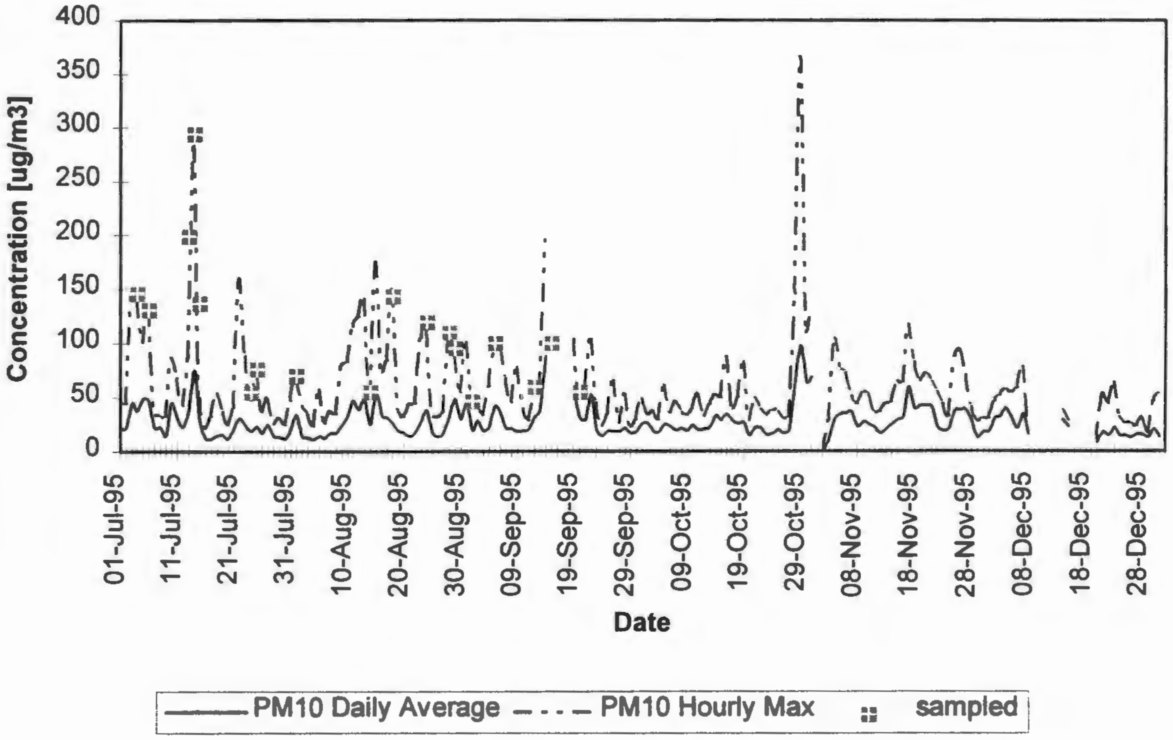


Figure 7.1 Hourly PM10 concentrations for Goodwood for July - December 1995

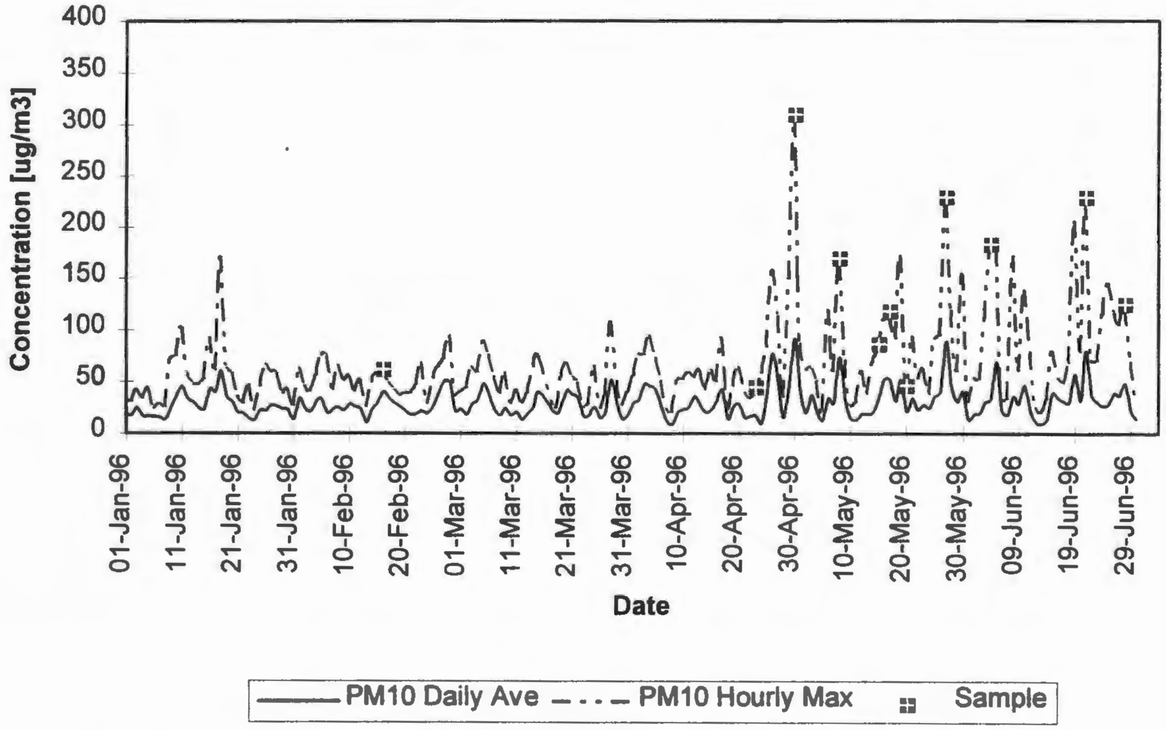


Figure 7.2 Hourly PM10 concentrations for Goodwood for January - June 1996

7.3 PM2.5/PM10 ratio

In Chapter 4 a description was given of the monitoring equipment at each of the four ambient sampling sites. The particulate sampling capabilities at the sites included both continuous PM10 monitoring and the sampling of PM2.5. When brown haze episodes were sampled PM2.5 was collected onto filters which were later weighed. Weight of the filter samples divided by air drawn through the filter gave time-averaged PM2.5. Generally PM2.5 was averaged over 12 or 24 hours. These could be directly compared with continuous PM10 data by averaging PM10 data for the same time as filter samples were taken.

Table 7.5 shows the mean PM2.5 to PM10 ratios for the four sampling sites along with the standard deviations of the data.

Table 7.5 Mean and standard deviations of the PM2.5:PM10 Ratio at the sampling sites (July 1995-July 1996)

Sampling Site	Mean PM2.5:PM10	Standard Deviation
Goodwood	0.60	0.17
CBD	0.57	0.21
Wynberg	0.59	0.22
Table View	0.61	0.14

The PM2.5 to PM10 ratio indicates what proportion of PM10 is made up by PM2.5. As was mentioned in Chapter 2. PM2.5 is associated with emissions from combustion sources so a high PM2.5:PM10 ratio indicates that a large proportion of the ambient PM10 is due to contributions from combustion sources. The large standard deviations of the data indicate that the ratios vary considerably from day to day.

An analysis of this data can give an indication of the mechanisms of different haze episodes. For instance on 30 April 1996 (the day with the highest PM10 daily average on which a filter sample was taken according to Table 7.4) the PM2.5:PM10 ratio was 0.27 at both Goodwood and the CBD, and 0.39 at Wynberg. These ratios are low and indicate that the particulate pollution consisted of mainly coarse particles (indicating geological material). This episode had shown characteristics differing from the norm for a brown haze episode as the PM10 had peaked at midday and the NO_x values had remained low. This further indicated that the high particulate levels were not caused by emissions from combustion sources. The high pollutant values were probably caused by geological dust transported by berg winds.

In contrast to this a sample taken form 00h00 to 12h00 on 25 July 1995 gave the high values for PM2.5:PM10 with all sites except Table View recording above 0.80. This indicates that PM10 concentration was made up mainly of PM2.5 or contributions from combustion sources. Appendix K shows that during the sampling period there was a typical morning peak particulate associated with pollutants being trapped under a strong temperature inversion. The high NO_x values at the same time indicate that combustion sources were contributing significantly to pollutant concentrations.

Thus this ratio can be used as a validation tool when assessing the outputs of the Chemical Mass Balance model. From this qualitative analysis one would expect a large proportion of particulates to be apportioned to geological material on 30 April 1996 and a small proportion on 25 July 1995.

8. RESULTS OF THE APPORTIONMENT OF THE BROWN HAZE

8.1 Data validation

Data validation was carried at each stage of the research process. Validation included:

(a) Independent calculation of the source and ambient profiles to be used for the modelling.
(b) Comparing the calculated and weighed masses on each filter.
(c) Checking known ratios of elements, known tracer elements, and duplicate analysis results.
(d) Checking statistical performance measures of the model.
(e) Matching the output of the modelling with factors such as wind direction and location of major pollution sources.

Following data validation, only those episodes that satisfied all validation criteria were selected for modelling. Table 8.1 shows the PM2.5 concentrations of episodes that were modelled at each of the sites. Six episodes were modelled at Goodwood, and Drill Hall, five at Wynberg and four at Table View. The 16/02/96 was a clear day.

Table 8.1 PM2.5 concentrations of episodes modelled [μg/m^3]

Date Sampled	Goodwood	Drill Hall	Wynberg	Table View	Guguletu
14/07/95 am			29	19	
14/07/95 pm	51	29	25	27	
25/07/95 am		51	32		
18/08/95				13	
16/02/96	9	12			
30/04/96	23	17	18		
08/05/96	35	34	24		
27/05/96	39	25		17	
04/06/96	22				
22/08/96					75

8.1.1 Comparison of calculated and weighed masses on each filter

Table 8.2 shows calculated mass as a percent of weighed mass on the filters chosen for modelling. The calculated mass is determined by summing the masses of all chemical species measured on the filter, and also estimating the mass of elements not analysed (mostly oxygen and hydrogen). This value is used as a validation tool for the chemical analysis. The criterion is that the calculated mass should be between 75% and 135% of the weighed mass.

Table 8.2 Calculated mass as a percent of weighed mass for episodes modelled

Date Sampled	Goodwood	Drill Hall	Wynberg	Table View	Guguletu
14/07/95 am			133	121	
14/07/95 pm	105	130	134	132	
25/07/95 am		103	127		
18/08/95				104	
16/02/96	98	101			
30/04/96	89	109	80		
08/05/96	99	97	120		
27/05/96	87	102		112	
04/06/96	103				
22/08/96					80

Appendix L gives details of the concentrations of the various elements at the sampling sites. From this data it is evident that approximately 70% of the mass on the ambient filters is made up of carbon. Table 8.3 shows the average percentage contribution of total carbon to the filter mass along with the standard deviation of this value over the filter samples.

Table 8.3 Total carbon contribution to filter mass

Site	Average Carbon to Total Mass ratio [%]	Standard Deviation [%]
Goodwood	71	7
Drill Hall	73	8
Wynberg	72	9
Table View	68	10

8.1.2 Known element ratios, tracer elements, and duplicate analysis results

The ratio of lead to bromine should be relatively constant as they are mainly produced by vehicles, and vehicles emit these elements in a fixed ratio. Theoretically this ratio should be 1.3 Figure 8.1 shows a plot of lead against bromine for all ambient filters. The slope of the best fit line is 1.7, and together with the small spread of data, give confidence in the data.

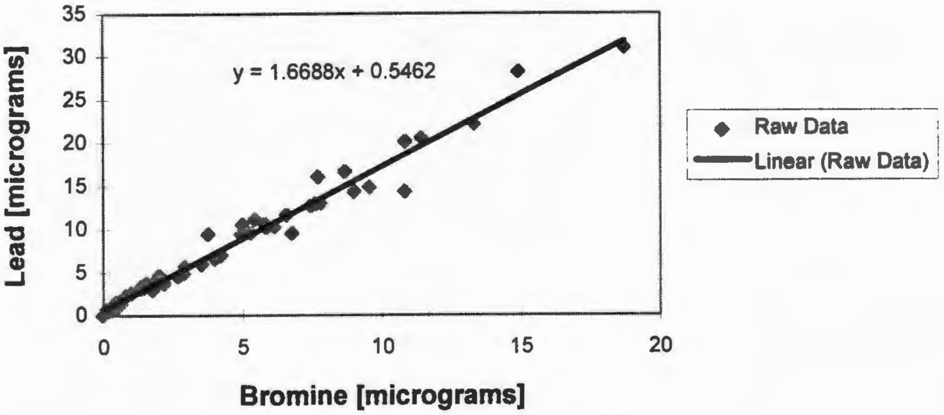


Figure 8.1 **Lead vs bromine on ambient filters**

The sulphate ion and the potassium ion concentrations showed a good correlation with the values obtained for the sulphur and potassium element by XRF analysis. The magnesium and sodium elements did not compare favourably with the sodium and magnesium ion results. This, however, was expected as the XRF analyses for these elements are considered qualitative because they are close in atomic number to the XRF detector window which is made of beryllium. The chlorine element by XRF and the chlorine ion by ion chromatography did not correlate well. No trend was found for their dissimilarity and very often they were not used as fitting species in modelling. Another problem experienced with the ions was that due to supply problems the manufacturers of the quartz filters were changed towards the end of the study. The new filters appeared to have a high background of the calcium ion and the sodium ion, which increased the uncertainties associated with the measurement of the ionic species.

The elemental results were considered very good especially in light of the fact that the Teflon filters were analysed three times for elements by XRF.

8.1.3 Statistical performance measures of the model

The Chemical Mass Balance version 7 receptor model used to apportion ambient particulates to their sources has certain statistical performance measures to assess the accuracy of the apportionment. These performance measures are described in Appendix J. Chi square is one of the most important performance measures, and should be under 4.0 for an adequate model fit. Percent mass is another useful output, which indicates the model calculated PM2.5 concentration as a percent of the measured concentration. Modelled episodes were only accepted if chi-square was less than 4.0 and the calculated mass was within 20% of the weighed mass. Chi square and percent mass are indicated in the results in Table 8.4, as well as in Appendix M.

8.2 Modelling results

8.2.1 Chemical Mass Balance Model results

Table 8.4 shows PM2.5 source apportionment results for each modelled episode at each site. Air pollution and meteorological data for the episodes modelled is given in Appendix K, detailed PM2.5 data is given in Appendix L, and details of the modelling runs can be seen in Appendix M. The apportionment was split up into the contributions of crustal material, diesel vehicles, petrol vehicles, wood burning, sea salt, boilers, sulphate, nitrate and carbon. The percent mass and chi squared are goodness of fit modelling parameters as discussed above.

The following factors must be considered when interpreting the modelling results:

(a) The crustal group represents the contributions of all geological dust sources including paved road dust.

(b) The petrol vehicle source group is represented by the contribution of well maintained and badly maintained petrol vehicles. Either a composite profile was used in modelling or the sum of the two profiles was used.

(c) The wood burning group represents the contribution of all the wood and grass burning sources.

(d) The boiler source group represents the contributions of both oil and coal fired boilers. This includes emissions from the Caltex refinery and from the Athlone power station. It was not possible to model these sources individually as they did not have unique characteristics.

(e) Emissions from Kynoch Fertiliser Factory were indicated to be insignificant.

(f) No unique chemical characteristic was given by tyre burning. Tyre burning was indicated by the model to be insignificant, but with a high degree of uncertainty.

(g) The individual sulphate and nitrate groups are secondary sulphate and nitrate which are formed by the chemical transformation of primary gaseous emissions (mostly SO_2 and NO_x).

(h) The carbon source group represents the residual organic and elemental carbon species from modelling. Also significant to the apportionment is the carbon group. Some of the carbon may be secondary in nature, but typical reaction rates of organic carbon indicate that it is unlikely that most of the carbon is secondary carbon. It is likely that a significant portion of the organic carbon derives from industrial process emissions.

Table 8.4 PM2.5 source apportionment results (%, except chi square)

Date	14/07/95	14/07/95	25/07/95	18/08/95	16/02/96	30/04/96	05/08/96	27/05/96	06/04/96	22/08/96
Tableview										
Crustal	6	5		4				6		
Diesel Vehicles	40	40		14				33		
Petrol Vehicles	6	10		3				11		
Woodburning	11	12		16				17		
Sea Salt	3	0		5				9		
Boilers	13	0		16				0		
Sulphate	4	4		32				7		
Nitrate	7	8		4				5		
Carbon	22	34		0				16		
% mass	112	113		94				104		
Chi Square	2.77	2.51		3.81				4.45		
Drill Hall										
Crustal		1	2		7	13	3	1		
Diesel Vehicles		60	43		50	13	60	50		
Petrol Vehicles		36	27		21	17	29	32		
Woodburning		10	11		12	10	16	14		
Sea Salt		0	0		2	0	0	0		
Boilers		0	1		0	0	0	0		
Sulphate		1	13		10	30	5	4		
Nitrate		2	5		2	1	6	3		
Carbon		0	18		17	33	0	0		
% mass		110	120		121	117	119	104		
Chi Square		2.51	0.67		2.76	2.42	1.65	2.29		
Goodwood										
Crustal		1			4	16	4	3	2	
Diesel Vehicles		52			16	49	63	43	52	
Petrol Vehicles		22			10	29	23	40	39	
Woodburning		14			28	19	14	16	7	
Sea Salt		0			9	0	3	0	1	
Boilers		0			0	0	5	0	0	
Sulphate		2			11	21	6	6	5	
Nitrate		4			3	3	6	2	3	
Carbon		27			0	0	0	0	0	
% mass		122			81	137	124	110	109	
Chi Square		3.26			3.04	4.77	3.17	3.23	3.43	
Wynberg										
Crustal	0	2	3			29	5			
Diesel Vehicles	47	37	41			3	43			
Petrol Vehicles	33	24	35			9	37			
Woodburning	8	19	14			26	26			
Sea Salt	0	0	3			0	0			
Boilers	4	1	0			0	0			
Sulphate	1	1	8			31	4			
Nitrate	2	0	4			1	3			
Carbon	9	5	8			17	0			
% mass	104	89	116			116	118			
Chi Square	2.05	3.12	3.76			5.5	3.89			
Guguletu										
Crustal										0
Diesel Vehicles										54
Petrol Vehicles										10
Woodburning										28
Sea Salt										5
Boilers										0
Sulphate										2.4
Nitrate										4.4
Carbon										0
% mass										104
Chi Square										3.24

8.2.2 Daily trends in the apportionment

14/07/95

Afternoon samples were modelled at all of the sites (second column of Table 8.4) while the morning samples (first column of Table 8.4) were modelled at Table View and Wynberg. There was an inversion and accompanying brown haze in the morning at this site, PM10 levels dropping off by about 12h00 at Goodwood, 14h00 at Drill Hall and 13h00 at Wynberg. The Goodwood site experienced secondary peaks during the afternoon and in particular from 17h00 thus resulting in the a high loading for the afternoon sample. The winds in the morning were from the north-east and were light ranging from 1 to 2 $m.s^{-1}$. In the afternoon the windspeed ranged from 1 to 3 $m.s^{-1}$ with the direction shifting between north-easterly and easterly.

At Table View the morning sample had a high contribution from diesel vehicles with boilers, fires and organic carbon also significant. The Wynberg sample is apportioned mainly to diesel and petrol vehicles. At these sites the afternoon/night-time samples show an increase in the contribution of wood burning, which could result from the lighting of domestic fires for cooking and warmth at night. Carbon concentrations increased from morning to afternoon at Table View and Drill Hall. This could be attributed to a number of factors. Secondary organic carbon particles could have been formed from the morning emissions, or another source of carbon could have entered the airshed during the day. This source of carbon would be associated with some sort of process industry emitting carbon that was not included in the modelling.

25/07/95

Samples were modelled at Wynberg and Drill Hall on this day. These samples were taken from 00h00 to 12h00 to coincide with a morning temperature inversion and high PM10 levels. The wind in the morning was light (1-2 $m.s^{-1}$) and from the north-east. Pollutants were dispersed by the afternoon as the wind speed steadily increased throughout the afternoon with the direction shifting to a more northerly direction.

The Drill Hall and Wynberg sites are dominated by contributions from diesel and petrol vehicles. Both sites experienced the relatively high sulphate contributions (with only the 30/04/96 having a higher sulphate contribution).

18/08/95

There was no strong inversion on this day and wind speeds were significant enough to disperse pollutants. This could then be considered a background sample at the Table View site. The predominant wind direction was between north and north-west.

The major contributor to PM2.5 at Table View was secondary sulphate followed by boilers and diesel vehicles. Sulphate is linked to the production of SO_2 which comes mainly from industry in the Cape Town Metropolitan Area. This, linked to the fact that the boiler contribution on this day is also high, shows that this day is unusual as the major contributor to pollution is industry rather than vehicles. This could be as a result of the lack of inversion conditions. The lack of inversion conditions is also shown by the fact that the PM2.5 concentration is only 13 $\mu g/m^3$ for the sampling period.

16/02/96

This sample was a summertime sample and was modelled at Drill Hall and Goodwood. There are no inversion conditions in summertime, and this sample was taken to represent a non brown haze sample.

The Drill Hall site showed contributions from emitters (particularly vehicles) that are similar to those on haze days. This is expected since vehicles are considered to be the major emitters in the central city area. The Goodwood site shows a lower contribution from vehicles compared with haze days. There is an increase in sulphates, wood fires and marine aerosol compared with haze days. An increase in sulphates is expected due to the industrial SO_2 emitters in the area. Marine aerosol is associated with sea breezes. The wood burning increase is unusual given the summer months, and may be attributed to some local wood burning during sampling.

30/04/96

This day had the highest PM10 levels of the days sampled. It was not, however, a typical brown haze episode as was discussed in an earlier chapter. It is speculated that the haze was caused by dust transported from the inland regions of the country by northerly winds. This hypothesis is supported by the fact that the PM2.5:PM10 ratio on this day was 0.27 at Goodwood and Drill Hall and 0.39 at Wynberg suggesting that the particulates were mainly crustal. This pollution episode was also characterised by low NO_x levels indicating a possible lower contribution from vehicles. The poor fit of the data relative to other days suggests that sources outside those analysed in this study were the cause of the high pollutant levels. The high crustal material contributions suggests that there is a possibility that the source is crustal. Major contribution also appears to come from sulphates suggesting that the particulates are from a sulphate source.

08/05/96

Samples were taken here from 00h00 to 24h00 during this episode in which high PM10 values persisted throughout the day at Goodwood and Drill Hall. This was as a result of an inversion in the morning and light winds throughout the day (0.5-2.5 $m.s^{-1}$) with variable direction. The Drill Hall site also showed an evening PM10 peak that reached a maximum of 100$\mu g/m^3$ compared to the morning one that reached about 160$\mu g/m^3$.

At the three sites modelled (Drill Hall, Goodwood and Wynberg) the major contributor was diesel vehicles and to a lesser extent petrol vehicles and wood burning.

27/05/96

Samples were modelled at Drill Hall, Goodwood and Table View during this brown haze episode. A temperature inversion saw high PM10 values at Drill Hall and Goodwood while another late night peak occurred at Goodwood probably due to late night shopping in the area. Windspeed ranged from 1 to 4 $m.s^{-1}$ and ranged from a north easterly to a north westerly direction.

The main contributor to the particulates at all the sites was diesel vehicles followed by petrol and wood burning. It is noticeable that the petrol vehicle contribution at the Goodwood site is similar to that of diesel. This could be caused by petrol vehicles dominating the late night peak which is associated with late night shopping at a nearby shopping complex.

04/06/96

The Goodwood site was modelled on this day. There was a strong morning inversion with an associated peak of PM10 in the morning. Winds were light and north-westerly in the morning picking up from 1 to 3.5 $m.s^{-1}$ in the afternoon as they changed to a more southerly direction.

Vehicle contribution was over 90% with other emitters being insignificant relative to this.

22/08/96

On this day sampling was performed at Guguletu on a once off basis. One of the major problems with obtaining a sample here is security. Before a sample could be taken a secure area needed to be found so as not to lose the sampling equipment. For this reason sampling only started at 12h50 and extended through the night until 10h10. There was an observed brown haze in the morning along with light and variable winds, however, there was no inversion the next morning as the wind speed had increased during the night. What was noticeable was that there appeared not to be haze conditions at the other sampling sites on this day. This suggests that the conditions here may be unique.

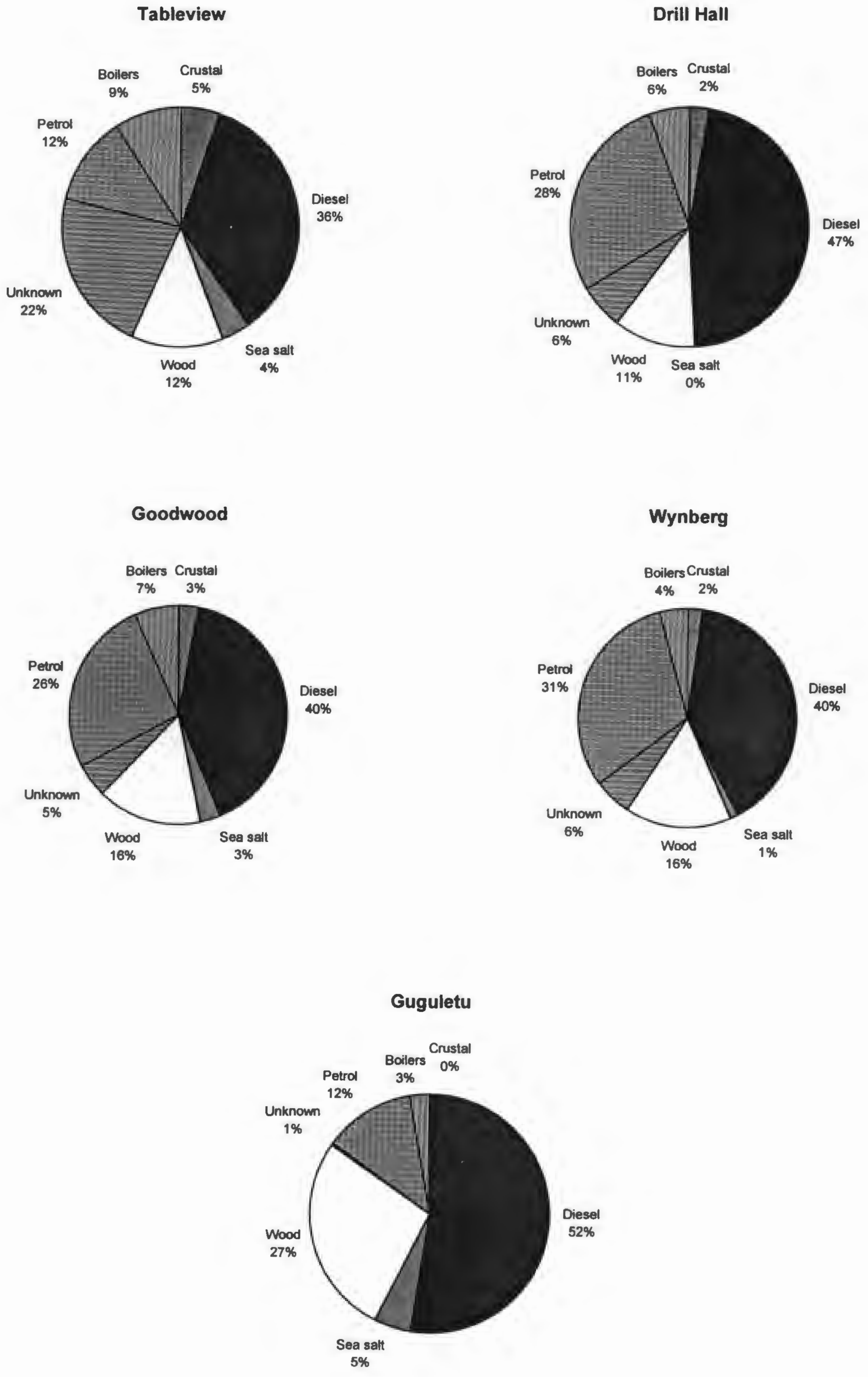
Major contributors to PM2.5 on this day were diesel vehicles and woodburning. The woodburning contribution was higher than at any of the other sites which was expected as the people living in the area rely on wood as a fuel for cooking and heating. If one considers Table 7.1 the concentration for this 10.4 hour period is 76 $\mu g/m^3$. This value was obtained from a sample that did not include the morning haze on this day. Visual observation suggested that the concentration of particulates was highest before the sample was taken. This suggests that high concentrations of particulates can be expected in this area.

8.2.3 Final PM2.5 source apportionment

Secondary sulphate and nitrate will have originated from SO_2 and NO_x respectively. Secondary sulphate and nitrate can therefore be apportioned to primary sources by estimating their contribution to SO_2 and NO_x. This has been done using the source inventory. This technique is not accurate as contribution to SO_2 and NO_x will vary depending on the height and time of emissions, as well as geographical location. Nevertheless, secondary sulphate and nitrate are not major contributors to the haze, and therefore inaccuracies in this technique will not significantly affect the source apportionment.

Figure 8.2 shows the final PM2.5 source apportionment results. It is evident that diesel vehicles are the largest single source of PM2.5. Petrol vehicles and wood burning are also significant contributors. The PM2.5 apportionment of each modelled episode is given in Appendix N.

Figure 8.2 Average PM2.5 apportionment for each site (%)



Tableview

Drill Hall

Goodwood

Wynberg

Guguletu

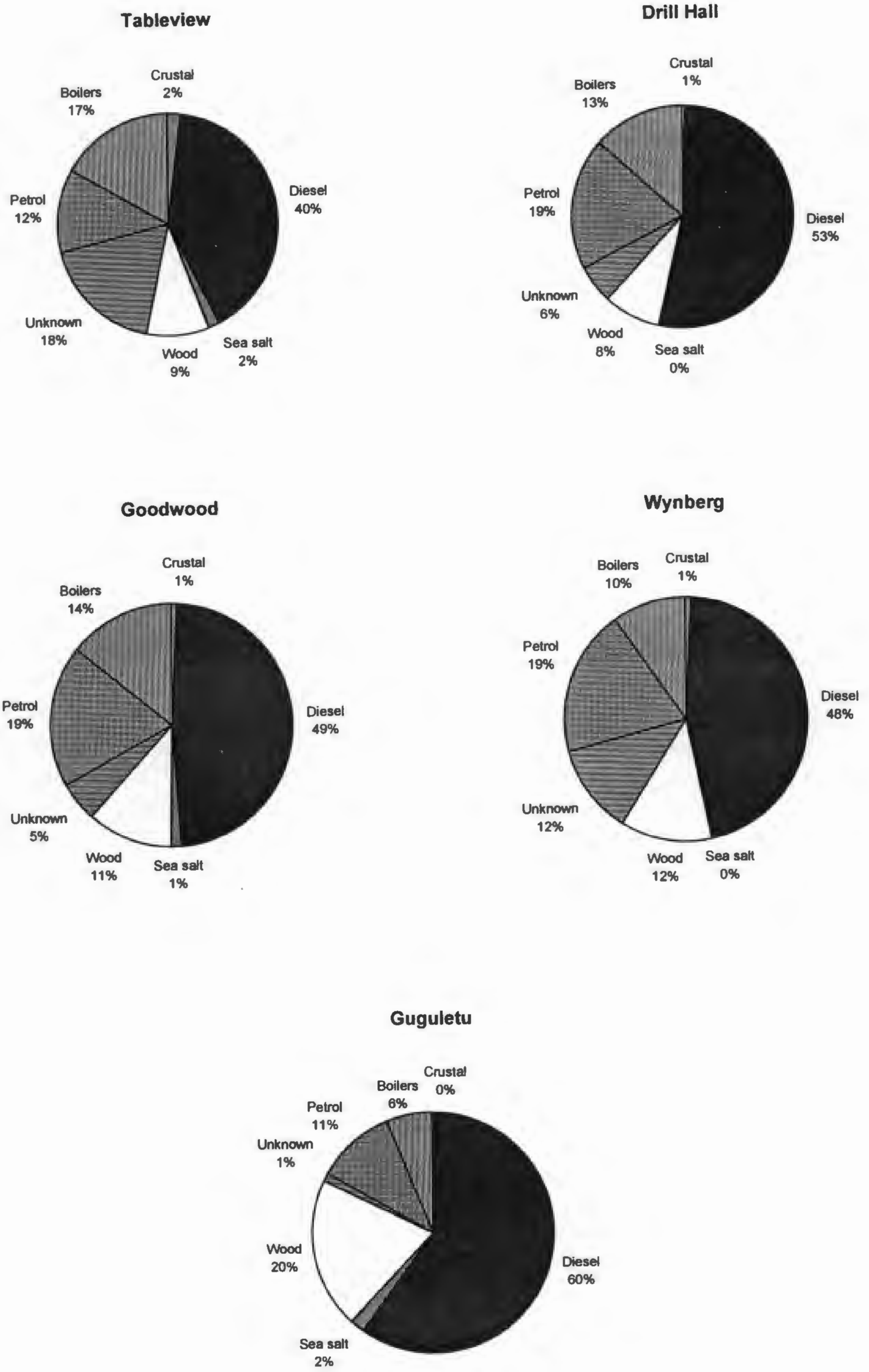
8.2.4 Visibility apportionment

Figure 8.3 shows average visibility apportionment (contribution to the brown haze) at each site. Sulphates and nitrates were apportioned to sources using the same procedure as the final PM2.5 apportionment. The PM2.5 apportionment of each modelled episode is given in Appendix N.

Important factors to be considered when interpreting the results are re-iterated below:

(a) The crustal group represents the contributions of all geological dust sources including paved road dust.
(b) The petrol vehicle source group is represented by the contribution of well maintained and badly maintained petrol vehicles. Either a composite profile was used in modelling or the sum of the two profiles was used.
(c) The wood burning group represents the contribution of all the wood and grass burning sources.
(d) No unique chemical characteristic was given by tyre burning. Tyre burning was indicated by the model to be insignificant, but with a high degree of uncertainty.
(e) Emissions from Kynoch Fertiliser Factory were indicated to be insignificant.
(f) The boiler source group represents the contributions of both oil and coal fired boilers. This includes emissions from the Caltex refinery and from the Athlone power station. It was not possible to model these sources individually as they did not have unique characteristics.
(g) The carbon source group represents the residual organic and elemental carbon species from modelling. Also significant to the apportionment is the carbon group. Some of the carbon may be secondary in nature, but typical reaction rates of organic carbon indicate that it is unlikely that most of the carbon is secondary carbon. It is likely that a significant portion of the organic carbon derives from industrial process emissions.

Figure 8.3 Average visibility apportionment for each site (%)


Tableview

Drill Hall

Goodwood

Wynberg

Guguletu

8.3 Comparison with other cities

Table 8.5 shows a comparison of the Cape Town PM2.5 apportionment data results with studies in which fine particulates were apportioned. The Cape Town data was disaggregated in the same way that the other studies presented their results. Few PM2.5 apportionment studies are available at present, and so only three cities are included in the comparison. Coarse particle apportionment would skew results to crustal samples.

Table 8.5 Average apportionment

City	Cape Town	Duarte	Denver	Tuscon
Particle Size	PM2.5	PM3.5	PM2.5	PM2.5
Crustal Material %	4	23	-	25-31
Vehicles %	60	10	26	50-62
Wood burning %	14	-	12	-
Sea Salt %	2	-	-	-
Boilers %	2	-	>20	-
Sulphate %	6	16	-	5-11
Nitrate %	4	-	-	9
Carbon %	9	12	-	-

Table 8.5 shows that the contribution of crustal material is low in Cape Town relative to the other studies. This could be attributed to the large contribution from vehicles in Cape Town. The Tuscon study shows a high vehicle contribution as well as a high contribution from crustal material. Sulphate in Cape Town is lower than Duarte and Tuscon suggesting that there is less of a contribution from industry in Cape Town than in these cities. This is supported by the higher contribution at Duarte. Cape Town's source apportionment appears to be more similar to those in UK cities where it has been found that vehicles contribute over 80% of PM2.5(70).

8.4 Discussion of modelling results

8.4.1 Accuracy of the results

A number of potential sources of error exist. These include:

(a) Filter handling errors. Filters can be contaminated, damaged, and chemical species can volatilise. Necessary precautions were taken to minimise these to acceptable limits. Some filters had to be discarded due to damage during transport.

(b) Chemical analysis errors. The analytical techniques used for chemical analysis were all done according to international standards. However some chemical species were close to detection limits, resulting in significant degrees of uncertainty. This uncertainty is entered in the chemical mass balance model, and included with the statistical performance measures.

(c) Data management errors. The chances of data management errors was reduced by duplicating a large amount of the work, starting from conversion of the raw data.

(d) Non-representative source profiles being used in the modelling. This source of error is likely to be the largest source of error. With limited resources it was impossible to fully characterise average source profiles for Cape Town. The is particularly true of carbon emissions from combustion which can vary by an order of magnitude depending on the efficiency of combustion. Diesel, which turned out to be the most significant source, is based on only one measurement of diesel emissions. To accurately characterise each source, a statistically chosen set of about 5 to 10 emissions sources should be sampled, whereas in this study usually only two samples were taken for each source.

(e) Omission of significant source profiles. This error can be detected in the statistical performance measures of the chemical mass balance model. In most cases these measures were satisfactory, except on the 30/04/96 when there was a north-easterly wind that could have brought other unaccounted sources into the Metropolitan area.

(f) Error associated with apportioning sulphates and nitrates. The use of the emission inventory to apportion sulphates and nitrates is not accurate because it does not take into account height, time and location of emissions. This error will not have a significant effect on the final results because the contribution of sulphates and nitrates is not major.

(g) Error associated with the empirical relationships between PM2.5 species and visibility reduction. This error could be significant, especially under humid conditions. This error was minimised as far as possible by selecting a set of empirical equations that were closest to the mean of three sets of equations.

Having considered all likely magnitudes of error, and the error indicated by the chemical mass balance model, it is estimated that the average standard deviation is ± 40%. For instance the 40% contribution of diesel to the brown haze at Table View could be said to be 40% ± 16%, and the 9% contribution of wood could be said to be 9% ± 3.6%.

Modelling difficulties

Some difficulties experienced were:

(a) Diesel, which turned out to be the most significant source, was only only measured once. In retrospect, this source profile should have been investigated in more detail in order to reduce the uncertainty. An sample measured at altitude could not be used due to different emissions at altitude. A sample measured in another country could not be used due to the diesel fuel characteristics being different.

(b) During the brown haze study the issue of tyre burning was raised in Cape Town. This was mainly due to the fact that the burning of tyres results in a large amount of "black smoke". An estimate was made in Chapter 5 of the contribution of tyre burning to PM10. The value obtained was not accurate as it was based on a large number of assumptions. As a result of this issue a tyre burning source profile was generated for use in modelling. During modelling of the data, however, it was found that it was difficult to use tyre burning in the apportionment. Often the model was insensitive to the source profile and the standard error of the source contribution estimate was high. Also it appeared that because of its high silicon and aluminium components, this profile could not be distinguished from crustal matter by the model. Other problems encountered were collinearity between the tyre profile and the wood burning profile. Measures to prevent these problems were unsuccessful and for this reason the tyre burning source profile was not used in the source apportionment.

(c) Vanadium, associated with fuel oil, was close to detection limits therefore giving a high degree of uncertainty for the contribution of fuel oil.

(d) Modelling showed that on some days there was a significant amount of unaccounted carbon. This excess could be because the source profiles used in modelling for combustion sources tended towards the efficient side of combustion. Another possibility is that some of the carbon contribution is due to the formation of secondary organic carbon in the atmosphere. These secondary particles would be formed from the reactions of organic carbon vapour emitted from industry. Another likely possibility is that the carbon contribution is as a result of some source that has not been included in modelling. This could be as a result of organic carbon emitted by process industries. It is possible that these process industries represent small emissions on their own but when added together are significant.

(e) The coal boiler profile used was from the Vaal Air Triangle Study which may be based on more efficient boilers than the average for Cape Town. At times boilers observed in Cape Town produce black smoke and thus could be a source of elemental carbon. There was a consistent shortage of elemental carbon contribution to the ambient levels from the sources indicating a missing source which could be coal fired boilers. The value of this concentration would be no more than 5% based on the “missing elemental carbon on the ambient filters.

(f) The source sampling showed that poorly maintained motor vehicles show high levels of organic carbon. In some cases modelling was carried out with a good and bad vehicle profile, and in other cases it was necessary to use an average vehicle profile. The assumption when using an average vehicle profile is that the contribution of good and bad vehicles to air pollution is similar. This was confirmed in London where 50-60% of the pollution is causes by 10% of vehicles(65).

(g) Zinc was poorly accounted for in the modelling. This suggested a missing zinc source. This was particularly evident at the Goodwood site. An investigation of galvanising businesses in the Cape Town Metropolitan Area show that a large number of them are situated in industrial areas within 10 km of the Goodwood sampling site. Thus galvanising plants could account for the missing Zinc source. Another potential source of zinc is the burning of refuse.

(h) Improvement to the modelling process could be the diesel profile, which was based on only one measurement. If more samples from a range of diesel vehicles had been taken then diesel profile might better represent the diesel fleet in the area. The diesel profile showed a high proportion of low temperature elemental carbon but a low proportion of high temperature elemental carbon. A sensitivity analysis was performed on the diesel high and low temperature elemental carbon, which indicated that moderate changes to these values had little effect on the apportionment results.

8.4.5 Particulate and gaseous components of the brown haze

The brown haze consists of two components; a component that originates from particulates emissions, and a component that originates from gaseous emissions. The gaseous component is largely photochemical in nature in that sunlight largely promotes the conversion of gases to brown haze constituents. Based on the visibility source apportionment it is calculated that the component that originates from gaseous emissions contributes an average of 22% towards the brown haze. Most of this is made up of sulphates derived from SO_2.

Discussion of significant findings

Average PM2.5 apportionment of the brown haze episodes modelled is shown in Figure 8.4.

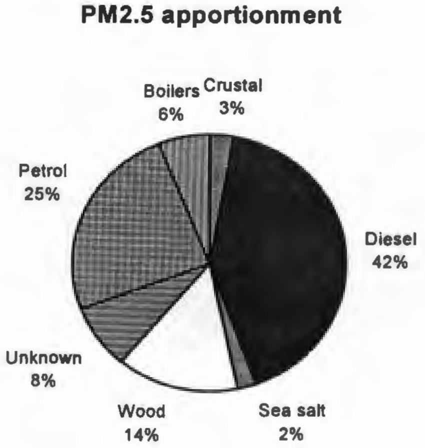


Figure 8.4 Average PM2.5 apportionment for the Cape Town Metropolitan Area

Average visibility apportionment of brown haze episodes modelled is shown in Figure 8.5.

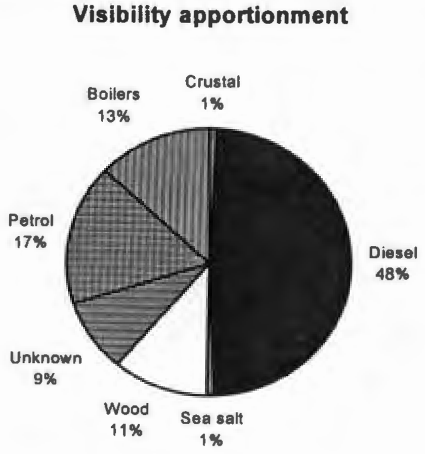


Figure 8.5 Average visibility apportionment for Cape Town for the Cape Town Metropolitan Area

Figure 8.5 shows that the major cause of the visual impact of the brown haze in Cape Town is diesel vehicles, with petrol vehicles, wood burning, and industrial boilers also being significant. A significant unknown source also exists, which comprises mostly organic carbon. It is likely that a significant portion of this organic carbon is derived from industrial process emissions. The Caltex refinery and the Athlone power station are included under boilers, together with other oil-fired and coal-fired boilers. Due to the emissions of the Caltex refinery and the Athlone power station being above the inversion layer during the worst period of the brown haze, in the early morning, they are not expected to form a significant portion of the boiler contribution.

Assuming the unknown portion is attributed to industry, contribution to the brown haze can further aggregated, as shown in Figure 8.6. The importance of vehicles in highlighted.

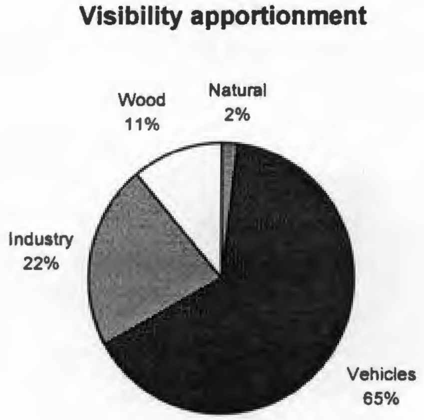


Figure 8.6 Average aggregated visibility apportionment for Cape Town for the Cape Town Metropolitan Area

The estimated uncertainty (±40%) of these results must be borne in mind. The contribution to the brown haze could be expressed as:

Vehicles	65% ± 26%	or	39% - 91%
Industry	22% ± 9%	or	13% - 31%
Wood	11% ± 4%	or	7% - 15%
Natural	2% ± 1%	or	1% - 3%

9. PROJECTED EMISSIONS FOR CAPE TOWN

9.1 Transport

9.1.1 Petrol and diesel vehicles

Table 9.1 indicates that petrol and diesel sales in the Cape Metropolitan Area have been steadily increasing over the past five years. Petrol sales are strongly linked to disposable income and the price of petrol, with the result that petrol sales in 1997 are expected to slow down with the increased petrol price. Diesel sales are strongly linked to economic growth of the region. The high growth rate of sales for 1995/1996 is unsustainable in the long term(66). It is estimated that petrol and diesel sales in the Cape Metropole will grow at an average of about 3-5% per annum over the next decade.

Table 9.1 Petrol and diesel sales in the Cape Town Metropolitan Area 1992-1996(66)

Year	Petrol		Diesel	
	Mℓ	% annual growth	Mℓ	% annual growth
1992	903		302	
1993	912	1.0	283	-6.3
1994	950	4.2	290	2.5
1995	1003	5.6	314	8.3
1996	1067	6.4	343	9.2

The average age of vehicles has been increasing steadily over the past decade in South Africa, and now stands at over 10 years. The increasing average vehicle age is likely to indicate an increasing proportion of poorly maintained vehicles. An increasing and aging vehicle population will result in:

(a) Greater quantity of emissions per vehicle.
(b) Increased total emissions from vehicles.
(c) More tyres available for burning.
(d) Greater road dust emissions.
(e) Greater fuel consumption, and therefore greater VOC emissions from the entire fuel chain including refining and tank filling.

9.1.2 Aviation, shipping and tourism

The number of ships making use of Cape Town harbour has increased at a rate of 5% per annum over the last five years. However harbour capacity is nearing saturation and after 1997 growth is expected to decrease to about 1% per annum(60). The number of people arriving through Cape Town International Airport has been increasing at about 30% per annum, with 5 million persons expected in Cape Town in 1997(67). This growth is clearly unsustainable and over the next decade a growth of 10-15% per annum in aviation activity is expected.

9.2 Industry

9.2.1 Coal and fuel oil

Economic growth in Cape town has been 4% per annum for the last two years. Much of this growth has been in the tourism and tertiary sectors rather than industry. Industrial growth is likely to be around 2% per annum and emissions from coal and oil-fired boilers and furnaces are assumed to increase at a similar rate.

9.2.2 Athlone Power Station

Uncertainty exists regarding the future of the power station. However it is likely that bag filters will be installed if the power station is to continue.

9.2.3 Caltex Refinery

There are no plans to increase the present production capacity of Caltex. In 1994 Caltex pledged to reduce all emissions, and specifically sulphur emissions, within five years. Emissions could be significantly higher than targets under abnormal operation, but with improving environmental management systems at Caltex it is likely that the incidence of abnormal operation will be reduced. In 1996 and 1997 electrostatic precipitators were fitted to the two fluidised catalytic cracking units, reducing total particulate emissions from these units by about 90%. PM2.5 emissions will also be reduced, but not to the same extent as total particulates. Caltex is also investigating means to reduce fugitive emissions(62).

9.2.4 Kynoch

Kynoch has reached maximum capacity utilisation and further capacity expansion is not planned at present. NO_x emissions are to be reduced by 80% by 2000 using 1994 as a reference, and particulate emissions from the prill tower are to be reduced to 80 tons/year from a present level of about 130 tons/year(63).

9.3 Households

Table 9.2 shows the October 1996 national census figures for the Cape Town municipal areas and Table 9.3 shows the projected population of Cape Town.

Table 9.2 1996 census data for the Cape Town Metropolitan Area(57)

Municipal area	Population
Blaauwberg	127 390
Oosternberg	240 020
Helderberg	125 410
South Peninsula	336 950
City of Tygerberg	927 060
City of Cape Town	1 050 880
Total	2 807 710

Table 9.3 Projections of the population of the Cape Metropole(58)

Year	Population	% annual growth
1995	2 833 196	
2000	3 075 873	1.7
2005	3 279 092	1.3
2010	3 586 487	1.8

The highest growth will be in the low-income economic sector, as a result of migration from rural areas and the higher birth rates of the low-income economic sector. This is supported by the projected housing backlog indicated in Table 9.4.

Table 9.4 Projected housing backlog in Cape Town(59)

Housing Backlog in 1995	134 000
Total Backlog in 2005	345 000
Total backlog in 2015	450 000

The electrification programme has electrified a large proportion of houses in Cape Town over the past three years. However continued migration from rural areas will result in a certain proportion of households not being electrified. In addition electrification alone does not result in the switching from fuels to electricity, as households are still required to purchase electrical appliances such as stoves and heaters. It has been found that most newly electrified households use electricity for lighting and television, but continue to use fuels for cooking and heating.

The effect of population growth on air pollution is:

(a) Because most population growth will take place in the low-income sector, domestic burning of wood, refuse, and tyres, will continue to be a problem.
(b) An increased vehicle population, and if the overall income level of the Cape Town population is lifted, then the number of vehicles per capita can also be expected to rise.
(c) Greater risk of uncontrolled fires.
(d) Increased construction activity.

9.4 Business as usual scenario for Cape Town

This section assumes that no measures are taken to reduce emissions. The next section examines measures that could reduce emissions. It is assumed that the meteorology remains the same in Cape Town providing the same conditions for haze formation as in the past. Over the next decade the following trends are expected in the Cape Town Metropolitan Area:

(a) A 1.5% per annum growth in population, mostly in the low-income bracket. Due to the opposing forces of electrification and population growth, domestic fuel burning levels are expected to remain the same.
(b) A 5 % per annum growth in use of transport fuels, with a similar growth in vehicle emissions. Vehicle emissions are becoming increasingly concentrated in certain congested areas such as the Waterfront.
(c) A 1% per annum growth in harbour activity, with a similar growth in harbour emissions.
(d) A 10-15 % per annum growth in airport activity.
(e) A 2% per annum growth in combustion of coal and fuel oil by industry, with a similar growth in emissions.
(f) A 4% per annum growth in economic activity, with a corresponding growth in emissions of VOCs.
(g) A significant decline in emissions from the Caltex refinery, Kynoch and Athlone power station.

Taking into account the relative contribution of the above sources to the brown haze, the following trends in emissions are likely over the next decade:

(a) PM2.5 emissions will increase with increasing diesel and petrol combustion and increased industrial activity. An increase of about 4% per annum is estimated.
(b) NO_x and VOC emissions will increase with increased petrol and diesel combustion, and increased use of industrial solvents and paints. An increase of about 4% per annum is estimated.

(c) SO_2 emissions from Caltex are not expected to increase. However SO_2 emissions from fuel use by other industries and diesel use will result in rising SO_2 emissions. A 2% per annum growth in SO_2 emissions is expected.

Primary PM2.5 emissions are the most important cause of the brown haze, and in the business as usual scenario they are estimated to increase by 48% over the next decade. It is therefore likely that the intensity of the brown haze will increase by a similar amount.

10. OPTIONS FOR REDUCING EMISSIONS

Although the business as usual scenario indicates declining air quality, a number of measures can be undertaken to ensure that the brown haze does not intensify. It is beyond the scope of this study to make specific recommendations on air pollution measures, but some of the options are highlighted. Many of these options will require significant lead times in terms of planning, implementation and effect, and a long-term planning horizon is therefore required.

10.1 Transport

A number of possible measures exist to reduce vehicle emissions, ranging from those with a considerable long-term outlook to short term emergency measures. Long-term measures include land-use planning, public transport, and the introduction of catalytic converters on new vehicles. In the absence of adequate long term planning some cities have been forced to resort to short term measures such as traffic bans (Athens, Mexico City, Bologna, Lagos, Milan, Santiago) and charges for vehicles entering a city (Salzburg, Singapore, Hong Kong, Milan, Oslo). Hopefully Cape Town will not be allowed to continue to deteriorate to a situation that warrants such drastic short-term measures.

Fuels

Presently there is debate in South Africa about the diesel/petrol demand ratio, and whether the wider use of diesel should be promoted. Diesel is more efficient, more economical, requires less crude oil imports, and requires less frequent engine replacements. However the diesel PM2.5 emission factor is approximately 10 times greater than that for leaded petrol, but NO_x and VOC emissions are less than half those of leaded petrol. Overall, for the equivalent application, diesel fuel has a significantly higher impact on the brown haze than leaded petrol.

There is general agreement that, for any particular diesel engine, there is a linear relationship between diesel fuel sulphur content and particulate emissions. The sulphur content of diesel was reduced from 0.2% to 0.05% in the UK between 1993 and 1996. It has been estimated that this reduction reduced particulate emissions by 17%(61). By contrast the sulphur content of diesel in Cape Town is 0.5%. Other diesel fuel properties affecting particulate emissions include aromatic content and fuel density.

The environmental benefits of unleaded petrol will only be realised if catalytic converters are used properly with the unleaded fuel. Without the use of catalytic converters, unleaded fuel is likely to have a marginally greater impact on the brown haze compared with leaded fuel.

One of the main attractions of reformulated petrol or diesel is that it can reduce emissions from all vehicles, and modifications can be made to minimise both summer and winter emissions. It was estimated that the 14% reduction in the summer vapour pressure of petrol in New York City between 1988 and 1990 reduced VOC emissions by 25%(61).

Alternative fuels, such as compressed natural gas or liquid petroleum gas, can virtually eliminate particulate emissions and reduce gaseous emissions considerably. Petrol or diesel engines can be modified to run on these alternative fuels. Buses and trucks are usually the first vehicles to be converted.

Maintenance and enforcement of emission standards

In London it was found that the highest emitting 10% of vehicles contributed 57% of carbon monoxide and 66% of vehicular hydrocarbons. In contrast the lowest emitting 70% of vehicles contributed 11% of carbon monoxide and 10% of vehicular hydrocarbons(61). This illustrates the potential benefits of addressing only the worst emitting vehicles.

Planned preventative maintenance and responsible driving maintains fuel economy at optimum levels and minimises emissions. These principles can be promoted through public awareness and through enforcement of legislation. Legislation exists in South Africa to control diesel emissions, but there is little enforcement, due mostly to inadequate resources. Although regular roadworthy tests are carried out for heavy diesels in Cape Town, these could be extended to all vehicles and could include rigorous emission tests. In some cities telephone numbers are available for the public to report polluting vehicles.

Table 10.1 indicates that emissions per vehicle in South Africa are considerably higher than standards in other countries.

Table 10.1 Comparison of emissions for South Africa compared with European standards (g/km).

	CO	HC + NO_x	Particulates
Petrol			
Europe standard(61)	2.20	0.50	-
South Africa - estimate(64)	16.1	3.2	1.4
Diesel			
Europe standard - indirect injection(61)	1.00	0.70	0.08
Europe standards - direct injection(61)	1.00	0.90	0.10
South Africa - estimate(64)	8.4	12.6	3.9

Vehicle emission control equipment

Particulate traps for diesel vehicles can reduce particulates by more than 50%, but they may cost up to 25% of the vehicle engine cost.

Catalytic converters are of two basic types; the oxidation catalyst and the three-way catalyst. Neither catalytic converter reduces particulate emissions. Oxidation catalysts are appropriate for diesel engines, but function better with lower fuel sulphur content. Three-way catalysts require unleaded petrol and require careful control of the air/fuel ratio. NO_x, hydrocarbon, and CO emissions are reduced by about 90%. Catalytic converters do have their problems, such as being ineffective when the engine is cold, and malfunctioning, but these problems are gradually being solved through sophisticated technology. Due to the high cost of catalytic converters, and the sophisticated control required, they are only likely to be considered for new vehicles in South Africa. Their market penetration will therefore be quite slow.

Traffic flow

It is evident that Cape Town experiences serious traffic congestion problems, resulting in poor fuel economy and therefore greater emissions per vehicle kilometre travelled. It is estimated that a vehicle travelling in a stop-start manner will have a fuel economy of 10-50% higher than a vehicle travelling at a constant speed of 80 km/hr. There is no easy solution for Cape Town's congestion problems, and widening access roads may not improve the situation due to increasing vehicle densities.

Public transport

Tables 10.2 and 10.3 show fuel consumption and emissions per passenger kilometre for different modes of transport.

Table 10.2 Litres fuel consumption per passenger km for different modes of transport(69)

Mode of transport	capacity utilisation			
	25%	**50%**	**75%**	**100%**
car	0.080	0.049	0.036	0.027
mini-bus	0.050	0.035	0.027	0.023
bus	0.027	0.019	0.015	0.012

Table 10.3 is based on the assumptions that:

- cars have on average 1.3 occupants (25% capacity utilisation),
- minibuses have on average 6 occupants (60% utilisation),
- buses use 33% of capacity on average, and
- emissions from electricity generation for rail transport do not affect Cape Town.

Table 10.3 Grams of urban emissions per passenger km for different modes of transport

Mode of transport	PM2.5	NO_x
car (petrol)	0.040	1.44
mini-bus (petrol)	0.016	0.58
bus (diesel)	0.150	0.15
rail	0	0

Important points to be derived from Tables 10.2 and 10.3 are:

- From an urban emission point of view, rail transport is preferable.
- Doubling the occupants of a car halves emissions per occupant.
- Mini-buses produce significantly less emissions per occupant than cars.
- Operating diesel buses is likely to increase PM2.5 emissions significantly. However if buses were run on liquified or compressed gas, then particulate emissions would be negligible.

If public transport is to be encouraged, it must be cheap, safe, easily accessible, reliable, and efficient. Some cities encourage public transport use on particularly bad smog days. In a 1995 London smog episode 18% of motorists responded to a call against using private vehicles on that day(61). Increasing city parking fees can also encourage use of public transport or car pooling.

Evaporative emissions

Evaporative emissions (hydrocarbons) occur when tankers deliver petrol to filling stations, when cars are being filled from petrol pumps, and from vehicle fuel systems when they are hot. The greatest public exposure to VOCs, such as carcinogenic benzene, occurs at petrol stations(e). In response some countries require that vapour collection systems be fitted to either petrol pumps or to vehicles (carbon canisters). Small carbon canisters, standard on US and European cars, absorb fuel tank vapours when the engine is hot.

Electric vehicles

Electric vehicles using batteries produce no emissions transfer emissions from the vehicle to the power stations. Presently electric vehicles are only suited to frequent stop-start applications, such as delivery vans. It is likely that within the next few decades electric vehicles, using batteries and/or fuel cells could have a significant effect on urban vehicle populations.

Car pooling

It was calculated that improving vehicle occupancy marginally from 1.25 to 1.5 per vehicle in Birmingham, would reduce the number of vehicles on the road by 17%(61).

Public awareness

The general public can be encouraged to:

- avoid leaving engines running unnecessarily,
- share vehicles,
- keep their vehicles well maintained, and
- use public transport.

Organisations can also stagger working hours to reduce emissions and congestion. Companies can also be given quotas for car pooling, and schools encouraged to promote car pooling.

10.2 Industry

Coal-fired boilers

Most industrial boilers in Cape Town use multi-cyclones. However multi-cyclones are ineffective in collecting particles below 5 microns. More effective particulate reduction equipment, such as baghouse filters or electrostatic precipitators, are too expensive for industrial scale boilers. Enforcing particle emission rates from boilers will assist in reducing PM10, but will have little effect on PM2.5. PM2.5 emissions can be reduced through:

- selection of a grade of coal which produces less particulates,
- adding sufficient moisture to the coal before combustion, and
- improving overall boiler efficiency.

High PM2.5 emissions occur during start-up and soot-blowing operations. Often these operations occur at critical times during a haze build up.

Oil-fired boilers

The properties of fuel oil being combusted has a significant effect on emissions. It should be ascertained whether current fuel standards are being adhered to, and whether the fuel standards need updating.

Athlone power station

At present Athlone power station is being operated with only cyclones for particle collection. It is likely that for such a system, the power station may be operating above particle emission standards. If Athlone power station is to be operated, bag filters should be installed.

Introduction of gas

Two possible sources of natural gas exist from Cape Town: the offshore Bredasdorp fields and the offshore Kudu fields. At present there are no definite plans for the introduction of natural gas to Cape Town, but it is expected that in the medium to long term gas could be piped to Cape Town. Once available, gas will become a competitive fuel for industry as it is easy to use, requires no storage, and produces almost no SO_2 and particulate emissions. Gas could also be used for electricity generation at Athlone power station. Market penetration will depend largely on price, but it is expected that once introduced gas will capture a significant portion of the industrial coal and fuel oil market.

10.3 Domestic fires and tyre burning

10.3.1 Domestic fires

Cooking and heating are basic requirements of a household, and therefore if emissions from domestic burning are to be reduced then alternative forms of energy should be promoted. However where non-commercial fuels are used, such as cardboard and wood, the promotion of fuel switching is difficult. Electrification will gradually result in electrified households converting to electricity, but the transition is slow. Ultimately the creation of employment and economic growth will have the largest influence on domestic burning.

10.3.2 Tyre burning

It is estimated that less than 10% of used tyres in Cape Town are disposed of in landfill (Greenhalgh, 1996). It is likely that most of the remaining tyres are being burnt for warmth and for the scrap metal. One solution would be to pay for tyres delivered to a central depot. The scrap metal in tyres is worth less than a rand per tyre, but the cost and inconvenience of transport of tyres and the added benefit of warmth provided by tyres would indicate that a larger payment is necessary. Assuming that the estimated 640 000 tyres that are burnt in Cape Town, and that R3 is paid for each tyre, R1.92 million/annum would be required. This money could either be paid by the local authority, or tyre manufacturers/distributors could be held responsible for recovering tyres resulting in the consumer ultimately paying the additional costs. The tyres could then be:

(a) recycled and used in new tyres,
(b) recycled and used in the production of other products, or
(c) made available to industry for use in high temperature furnaces.

11. RECOMMENDATIONS

If Cape Town is serious about reducing emissions, then both immediate action and longer term planning is required. Recommendations are divided into three components:

(a) Immediate action.
(b) Allocation of resources for metropolitan air quality management.
(c) Development of an air quality management system for Cape Town.

Recommendations on further research are given.

11.1 Immediate action

Immediate attention should be focused on diesel vehicles, the largest single contributor to the brown haze. Petrol vehicles and industry also require attention. Recommendations for authorities are:

- Enforce the diesel black smoke legislation.
- Introduce measures to reduce the number of smoking petrol vehicles.
- Enforce the industrial black smoke legislation.
- Initiate discussions with the oil industry about the potential benefits from fuel reformulation.
- Initiate the upgrading of air pollution capacity in the Cape Town Metropolitan Council.
- Initiate the development of an air quality management system for Cape Town.
- Existing national air pollution legislation should be re-assessed as much of the legislation is outdated.

11.2 Allocation of resources for air quality management

Responsibility for managing Cape Town's air quality lies primarily with the Health Department of the Cape Town Metropolitan Council. Presently this Department does not have the manpower, resources, or influence to adequately enforce current legislation, to adequately examine air quality data, or to ensure that air quality is optimally integrated within metropolitan planning. It is therefore recommended that:

- Manpower of the Air Pollution Division be increased.
- Adequately qualified and experienced manpower be taken on.
- The necessary budget for facilities to test and monitor emissions be allocated.
- The Air Pollution Division be given sufficient power to be able to enforce standards and have a say in metropolitan planning.

11.3 Air quality management system

It is recommended that the Cape Town Metropolitan Council introduce an integrated air quality management system in Cape Town. Components of an air quality management system are shown in Figure 11.1.

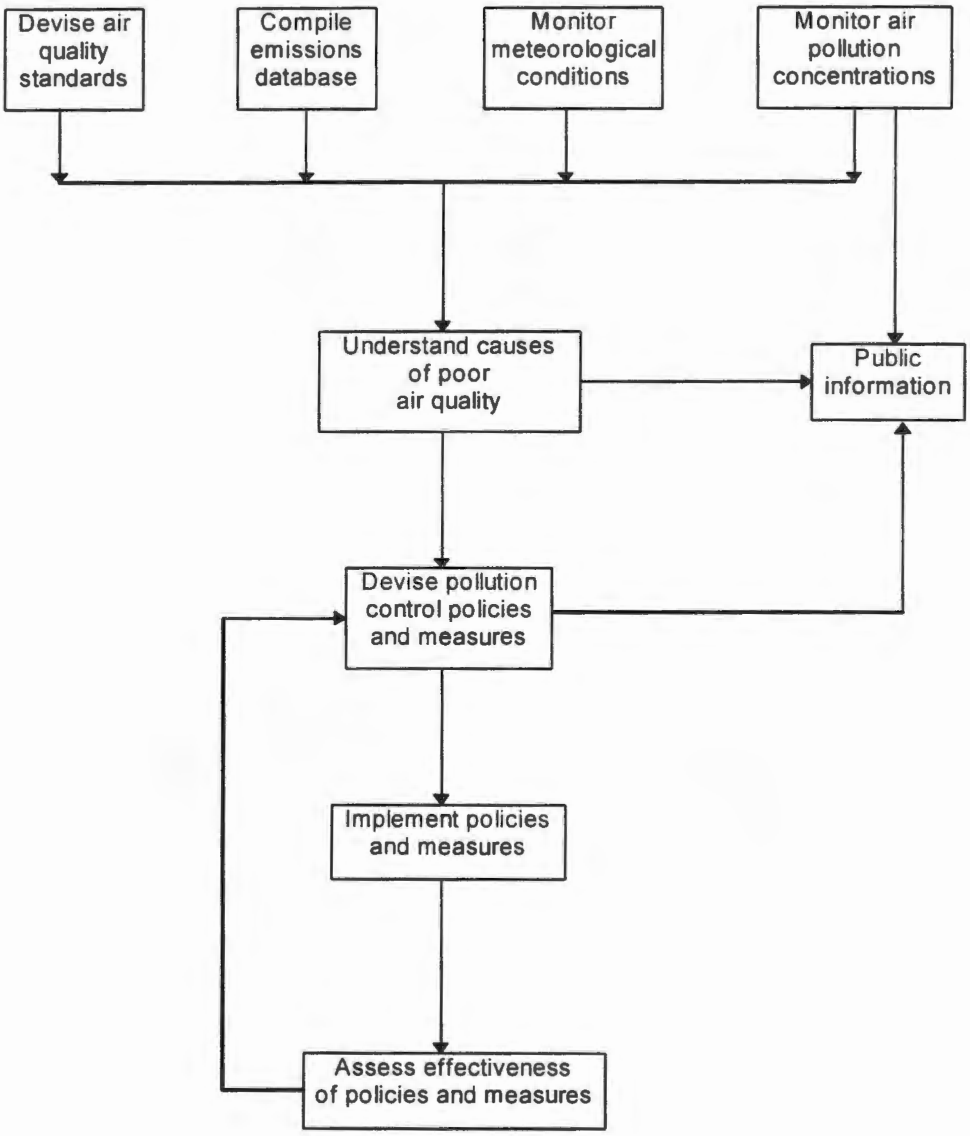


Figure 11.1 Air quality management system

Each component of the air quality management system is discussed separately, but it must be remembered that they form an integrated system.

11.3.1 Air quality standards

If necessary air quality standards, more stringent than national standards, can be adopted. For instance in the light of new PM2.5 standards, and their potential impact on visibility and health, it is recommended that Cape Town adopt the EPA PM2.5 standard. The setting of standards should be accompanied by legislation to ensure that when standards are exceeded the necessary resources can be allocated to improving air quality.

11.3.2 Emissions database

This study provides a rough emissions inventory, and the city council has a database of combustion in Cape Town. A motor vehicle emissions project is currently determining emission factors for South African vehicles and fuels. These resources should be integrated into an accurate and integrated emissions database. The database could be divided into point sources (such as industrial stacks), area sources (such as domestic fires), and line sources (such as major roads). Procedures for regularly updating the database should be developed.

11.3.3 Monitoring

Cape Town presently has a sophisticated and well managed air pollution monitoring network, although some modification is recommended. The most urgent monitoring action required is the establishment of a monitoring station in or near an informal area on the Cape Flats. The Wynberg monitoring caravan has been in operation for two years, and has indicated low pollution levels in that area. This caravan would be better utilised in a township area which is likely to experience significantly higher pollution levels than Wynberg. The PM10 monitoring equipment should be converted to PM2.5 monitoring, as PM2.5 accounts for most of the health and visibility effects of PM10. The ACCU's installed at the four ambient sites should be used to collect PM2.5 filter samples either over a period of a week or on every sixth day. The filters should be chemical analysed and the data used to monitor changes in ambient particle compositions. Receptor modelling could also be carried out on an ongoing or periodic basis. With motor vehicles being an important source of the brown haze, monitoring of vehicle-related pollution (NO_x, NO_2, CO, NMHCs, ozone) should continue, and be upgraded where necessary. Based on the Milnerton Air Quality Study(23), it is likely that benzene exceeds accepted health guidelines in some areas in Cape Town, and therefore benzene monitoring should also be included. Due to varying meteorological conditions in Cape Town, meteorological monitoring should be upgraded at some of the sites. Trafrfic flow in Cape Town should also be monitored on a periodic basis. This study has not considered specific localised hazardous air pollutants which may also exist.

11.3.4 Understanding the causes of poor air quality

This study provides an assessment of the current causes of the brown haze and presents rough estimates for the future. The study should be integrated into a wider understanding of air quality in Cape Town, including important components affecting health. Information should be periodically updated and improved. Receptor and dispersion modelling could assist in the understanding of the causes of air pollution. If air quality should further deteriorate in Cape Town, then it may be necessary to predict air quality over the short term so that warnings can be issued. Presently local authorities in Cape Town do not have the resources to carry out short term air quality forecasts.

11.3.5 Devising, implementing and assessing pollution control policies and measures

The involves an ongoing process of planning, implementing and assessment. Realistic hourly, daily and yearly targets should be set for those air pollutants of particular concern (PM2.5, NMHCs, NO_2 and NO_x). Targets should be attainable and set over the short, medium and long term. The targets must be supported by implementable mitigation measures, which consider the resource constraints of local government. The plan will require consultation with a number of representative bodies. The existing Cape Metropolitan Air Pollution Committee should steer the development of policies and measures. National policies of relevance should also be considered.

11.3.6 Public information

The purpose of air quality management is to protect the public from potential health, odour, and aesthetic effects of air pollution. The Cape Metropolitan Council therefore has a duty to inform the public about :

(a) The levels of important air pollutants relative to internationally accepted standards.
(b) Exceedences of standards when they occur, and smog alert or health advisory warnings.
(c) Where Cape Town is heading with respect to air quality.
(d) Proposed policies and measures to be introduced to improve air quality.
(e) Effectiveness of the implementation of policies and measures.

Public information can be provided through the newspapers, radio, libraries, environmental organisations, public bodies, and public meetings. Provision of public information is already carried out to some degree by local authorities in Cape Town.

Awareness can also extend to other local government departments, schools and companies.

11.4 Further research

The following recommendations are made regarding further research:

(a) Improve the diesel profile and re-run the model. This will greatly reduce the uncertainty of the modelling.

(b) Develop local analytical capacity for carbon. This species has been shown to be the most significant component of the brown haze in Cape Town.

(c) Investigate non-methane hydrocarbons more closely. A great deal of uncertainty exists regarding the sources of different types of non-methane hydrocarbons.

(d) Measure traffic flow volumes in Cape Town and develop a traffic flow model.

(e) Develop scanning electron microscopy at the University of Cape Town. The university recently acquired new microscopy equipment. Software could be developed to automate particle scanning, thus enabling sources to be identified directly.

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APPENDICES

APPENDIX A: EMISSION INVENTORY

SUMMARY OF FUEL USE AND EMISSION FACTORS

The following two tables indicate uncertainty which is classified as low (-20% to +20%), medium (-50% to +50%), and high (-70% to +200%). Generally SO_2 and NO_x will have more accurate emission factors than PM10 and VOCs.

SOURCE	UNCERTAINTY	EMISSION FACTORS					
		Units	SO_2	NO_x	VOCs	PM10	PM2.5
Residential							
Coal	Medium	g/kg	19	1.5	5	4.1	1.64
Paraffin	Low	g/l	8.5	1.5	0.09	0.2	0.2
LPG	Low	g/kg	0.01	1.4	0.5	0.07	0.07
Wood	Medium	g/kg	0.75	5	22	17.3	12.1
Transport							
Petrol vehicles	Medium	g/l	1.7	18	36	0.60	0.50
Diesel vehicles	Medium	g/l	9.3	6.1	5	6.6	6.1
Brake and tyre wear	Medium	g/km				0.0021	0
Paved roads	High	g/km				0.23	0.023
Unpaved roads	High	g/km				75	7.5
Ship diesel	Medium	g/l	9.3	100	4.2	7.1	6.4
Ship bunker oil	Medium	g/l	63	32	6	3.7	3.3
Industry & commerce							
Coal	Low	g/kg	19	7.5	0.025	3.9	1.6
HFO	Low	g/l	63	5.7	0.034	3.7	3.3
FFS fuels	Low	g/l	5.4	5.7	0.034	3.7	3.3
Diesel	Low	g/l	9.3	100	4.2	7.1	6.4
Power paraffin	Low	g/l	8.5	1.5	0.024	0.12	0.12
Athlone power station	Low	g/kg	19	7.5	0.025	3.9	1.6
Other							
Tyre burning	High	g/kg	36	2	16	50	25
Medical incineration	High	g/kg	1.09	1.78	0.15	2.33	2.33
Wildfires	High	g/kg	0.75	2	12.1	8.6	6.0

SOURCE	UNCERTAINTY		USAGE
		Units	**Quantity**
Residential			
Coal	Medium	ton	9 732
Paraffin	Medium	kl	40 428
LPG	Medium	ton	21 816
Wood	High	ton	108 492
Transport			
Petrol vehicles	Low	kl	936 000
Diesel vehicles	Low	kl	292 000
Brake and tyre wear	Medium	km	9.28×10^9
Paved roads	Low	km	9.26×10^9
Unpaved roads	High	km	1.86×10^7
Ship diesel	High	kl	7 385
Ship bunker oil	High	kl	18 181
Industry and commerce			
Coal	Low	ton	250 000
HFO	Low	kl	122 000
FFS fuels	Low	kl	27 000
Diesel	Low	kl	9 000
Power paraffin	Low	kl	4 600
Athlone power station	Low	ton	119 000
Other			
Tyre burning	High	ton	6 695
Medical incineration	High	ton	1 308
Wildfires	High	ton	82 775

RESIDENTIAL

Average monthly energy usage of different types of low-income households in the Western Cape Region is contained in the EDRC low-income housing database (Afrane-Okese, 1995):

Dwelling	**Elec. (kWh)**	**Wood (kg)**	**Paraf. (l)**	**Gas (kg)**	**Coal (kg)**
Formal electrified	480	38	11	2	0
Formal non-electrified	0	83	11	3	13
Planned shacks	0	4	31	24	0
Unplanned shacks	0	3	37	18	9
Formal partial electrified	308	8	14	15	0
Backyard shacks	195	25	15	32	0
Mixed housing	351	3	7	20	0

Middle and high income households use mostly electricity, and their only other significant fuel usage is wood for braais and fireplaces. It is estimated that the average middle to high income household uses 3 kg wood/month.

The number of households in each of the above dwelling types is estimated from the National Electrification Forum housing data for the Western Cape (Boshoff, 1995). The following data is for the magisterial districts within the greater Cape Town area.

Magisterial district	**Houses**	**Electrified**	**Not electrified**
Bellville	76 407	70 489	5 918
Cape Town	64 051	60 869	3 182
Goodwood	61 355	58 306	3 049
Kuils River	35 240	30 362	4 878
Mitchells Plain	57 289	6 733	50 556
Simons Town	18 006	15 846	2 160
Somerset West	16 529	13 072	3 457
Wynberg	228 610	202 753	25 857
Total	557 487	458 430	99 057

In addition the following information is also supplied for the Western Cape Development Region in urban areas (Boshoff, 1995):

Housing type	Total	Electrified	Not electrified
Formal houses	638 693	567 504	71 189
Formal institutions	43 777	39 642	4 135
Informal backyard	7 722	4 091	3 631
Informal planned	66 986	24 339	42 647
Informal unplanned	25 983	2 769	23 214
Total	783 161	638 345	144 816

The proportion of unelectrified houses in the greater Cape Town area and the Western Cape urban areas is both 18%. It would therefore be expected that the proportion of different housing types in the greater Cape Town area is similar to the Western Cape urban areas. It is estimated that the ratio of low-income formal electrified houses to middle to high-income electrified houses is 1:4. The following presents the number of different housing types in the greater Cape Town area based on the National Electrification Forum database and the above estimate, and has a breakdown of monthly and annual fuel consumption.

Housing type	Number	Wood (ton)	Paraf. (kl)	Gas (ton)	Coal (ton)
Middle to high income formal electrified	348 819	1046	0	0	0
Low-income formal electrified	87 205	3313	959	262	0
Formal non-electrified	51 523	4276	567	155	668
Planned shacks	29 171	117	904	700	0
Unplanned shacks	15 879	48	588	286	143
Formal partial electrified	22 406	179	314	336	0
Backyard shacks	2 484	62	37	79	0
Total monthly	557 487	9 041	3 369	1 818	811
Total annual	557 487	108 492	40 428	21 816	9 732

Emission factors for PM10 obtained from van Nierop (1995), for SO_2 and NO_x from Dracoulides (1994), and for VOC's from EPA (1995). It is estimated that for wood burning 70% of PM10 is in the Pm2.5 range. Anthracite is also used in the high-income households in Cape Town. Total anthracite usage by the household sector in South Africa is about 25 000 tons per annum (Department of Mineral and Energy Affairs, 1995). Sales in the Cape Town region are unknown, but Cape Town accounts for about 1% of national domestic coal usage (Cooper, 1993). If it is estimated that about 1% of national domestic anthracite is used in Cape Town, then 250 tons/annum is used. This is less than 3% of coal usage, and is therefore not considered.

	unit	SO_2	NO_x	PM10	VOC
coal	g/kg	19	1.5	4.1	5.0
paraffin	g/l	8.5	1.5	0.2	0.09
LGP	g/l	0.01	1.4	0.07	0.5
wood	g/kg	0.75	5	17.3	22

TRANSPORT

liquid fuels

Total liquid fuel sales in the Greater Cape Town areas for 1995 is as follows (Peens, 1996):

Petrol	936 Ml
Diesel	301 Ml
Paraffin	46 Ml
Fuel Oil	122 Ml
LPG	64 Ml

Peens (1996) estimates that 90% of the paraffin is for domestic use and 10% industrial and 3% of diesel is for industrial use. Also a significant amount of the LPG is used outside the greater Cape Town area.

Petrol and diesel vehicles

The average age of a car in 1992 was 9.6 years and that of predominantly diesel type vehicles 8.0 to 10.7 years depending on the type (CSS, 1992). The level of vehicle maintenance in South Africa is known to be lower than in first-world countries. In addition catalytic converters were only technically possible in South Africa since February 1996 when unleaded petrol became available. All of these factors make the use of emission factors from first-world countries complicated.

Emission factors for SO_2 can be calculated from the average sulphur content of petrol (0.12%) and diesel (0.53%) in the Western Cape. The EPA (1995) indicates that 64% of particulates from leaded gasoline vehicles are in the PM10 range, and 100% of diesel particulates are in the PM10 range.

The following table presents petrol and diesel vehicle emission factors from a number of sources. The AA gives the average fuel economy of vehicles under 1300 cc to be 8.6 km/l, and van Nierop calculates the average fuel economy of diesel vehicles in the Vaal Triangle to be 4.2 km/l. Using these fuel economy values the following emissions factors are derived from a number of sources (no exhaust control in all cases).

Emission factors for petrol and diesel vehicles (g/l).

	Dracoulides	van Nierop	Sumersell	IEA	UK DoE	Dutkiewicz[a]
Petrol						
NO_x	19		23	29-43		18
VOCs			17	29-43		54
PM10	9	0.16	0.1	<0.4	0.6	
Diesel						
NO_x	37		2.9	14-29		6.1
VOCs			0.7	2.9-7.1		3.5
PM10	33	6.6	1.1	4.3	1.2 - 9.0	

[a] Assuming South African vehicles emit 75% of the European legal limit. Diesel is for light duty trucks.

The above table indicates the range of emission factors that have been used. The origins of emission factors for Dracoulides and Sumersell are uncertain and their data is therefore excluded. The UK value for non-catalytic leaded petrol vehicles was used for PM10 (0.6 g/l). The midpoint of IEA values are used for VOCs as these include evaporative emissions. The values for NO_x were taken from Dutkiewicz whose values appear to reflect the average of the range indicated.

The following summarises emission factors used in this study.

	unit	SO_2	NO_x	PM10	VOC
petrol	g/l	1.7	18	0.16	36
diesel	g/l	9.3	6.1	6.6	5.0

The UK Department of Energy estimates that for petrol vehicles 84% of PM10 is PM2.5, and for diesel vehicles 92% of PM10 is PM2.5.

Paved roads

Using the average fuel economy rates in the previous the section 9,276 million vehicle kilometres were travelled in 1995. The quantity of dust emissions from vehicle traffic on a paved road may be estimated using the following empirical expression (EPA, 1995):

$$E = k\,(sL/2)^{0.65}\,(W/3)^{1.5}$$

E = particulate emission factor (g/km)
k = particle size multiplier (4.6 for PM10)
sL = loading of material less than 75 mm (g/m^2)
W = mean vehicle weight (tons)

Silt loading can vary from 0.01-400 g/m2. In the absence of site specific data the EPA recommends using conservatively high emission estimates for silt loading of 0.4 g/m2 for high vehicle density roads and 2.5 g/m2 for low vehicle density roads. It was estimated that for the United Kindom, with significantly higher rainfall, a a maximum silt loading would be 0.02 g/m2. This value was used for Cape Town. A mean vehicle weight of 3 ton is assumed. The PM10 emission factor is calculated to be 0.23 g/km. It is estimated that only about 10% of this is in the PM2.5 range.

Unpaved roads

The quantity of dust emissions from vehicle traffic on a paved road may be estimated using the following empirical expression (EPA, 1995):

$$E = 1.7\ k\ (s/12)\ (S/48)\ (W/2.7)^{0.7}\ (w/4)^{0.5}\ ((365-p)/365)$$

E = emission factor (kg/km)
k = particle size multiplier (0.36 for PM10)
s = weight % of road surface material less than 75mm
S = mean vehicle speed (km/hr)
W = mean vehicle weight (tons)
w = mean number of wheels
p = number of days per year with at least 0.254 mm precipitation

The EPA gives the range of unpaved road silt content to typically be 4-20%. It is assumed that in Cape Town the silt content of unpaved roads is low and is conservatively estimated at 2%. Values selected for the remaining parameters are mean vehicle speed of 40 km/hr, mean vehicle weight of 3 ton, mean number of wheels of 4, and 70 days per year with at least 0.254 mm precipitation. The PM10 emission factor is calculated to be 75 g/km. It is estimated that only 10% of this is in the PM2.5 range.

This subject of paved and unpaved roads was examined by van Nierop (1995) in some detail for the Vaal Triangle and he calculated a PM10 emission factor of 660 g/km for unpaved roads and 3.69 g/km for paved roads. These values are similar to those found in a tracer study of paved and unpaved roads in the Washington area (Claiborn, 1995). The values determined for Cape Town are about an order of magnitude less than those calculated for the Vaal Triangle.

van Nierop (1995) assumed for the Vaal Triangle that 0.365% of kilometres travelled is on unpaved roads. A lower value of 0.2% is selected for the greater Cape Town area.

Brake and tyre wear

The EPA (1995) estimates brake wear PM10 emissions to be 0.008 g/km and tyre wear 0.0013 g/km. Most of this will be greater than PM2.5.

Aviation

Approximately 1600 landings and take-offs of scheduled aircraft occur monthly at D.F. Malan airport (D.F. Malan Air Traffic Control, 1996). Excluded are light aircraft. A jumbo or medium range jet takes about 33 min for a landing/takeoff cycle (idle, taxi, takeoff, climbout, approach, taxi, idle). Emissions are given per landing cycle. Typically for a boeing total emissions for a landing/takeoff cycle are (EPA, 1995):

	kg/aircraft	tons/year
NO_x	30	576
SO_2	2.4	46
VOCs	24.5	470
PM10	1.7	33

It is assumed that 100% of particulates are in the PM10 range.

Shipping

The following number of ships made use of Cape Town harbour in 1995 (Portnet):

Type of Ship	Year total
Ocean going	1 938
Coasters	165
SA Trawlers	430
Foreign fishing	822
Others	314
Total	3 669

Fuel is used by ships in the harbour area is estimated (McCarthy, SAF Marine). He estimates that at any one time there are three tugs operating each of which consumes 10 ton/day of bunker fuel. He also estimates that for container vessels 4 tons of fuel are used in entering and leaving the harbour, and for smaller vessels about 1 ton of fuel. He also estimates that about 30 containers enter the harbour each month. Ships either burn marine gas oil, which is the same as diesel (0.55% sulphur), or bunker fuel oil, which is the same as heavy fuel oil (3.5% sulphur). It is estimated that the 90% of the fuel used for the ship's engines is bunker oil and 30% of the fuel used for the ship's generators is bunker oil, with the remainder being diesel. The following summarises the fuel consumption estimates.

Ship type	Number per year	tons/day fuel	hours in harbour	tons fuel per entry	tons diesel per year	tons bunker oil per year
Containers	365	6	24	4	1 656	1 944
Other ocean going	1 738	1.5	48	1	3 824	3 128
SA Trawlers	430	0.3	24	1	133	426
Foreign fishing	822	0.5	120	1	1 521	1 356
Others	314	1.0	24	1	251	377
Portnet ships						10 950
Total	3 669				7 385	18 181

The same emission factors as for industrial diesel engines were used for diesel. The EPA gives the NO_x emission factor for coastal ships to be 32 g/l and VOCs to be 6g/l, and these are used for bunker oil. In the absence of further data industrial HFO emission factors are used for bunker oil.

INDUSTRY AND COMMERCE

Emissions from the following large industries were determined independently:

Athlone Power Station
Caltex
Kynoch

For the remainder total fuel consumption in the Cape Town Metropolitan area is used to estimate emissions.

Athlone power station

The following coal consumption figures were provided by Roggen (1996).

Month	tons coal
May 1995 (estimated)	9 000
June	9 800
July	13 000
August	13 300
September	13 900
October	15 900
November	17 200
December	7 300
January 1996	1 800
February	2 200
March	6 400
April	9 200
Total	119 000

During this period only two-stage cyclones were used to control particulates so the same emission factors are used as with industrial coal combustion in boilers.

Kynoch

Kynoch provided the following data for 1995.

Month	**No$_x$ (tons)**	**Particles (tons)**
January	100	10.25
February	0	1.19
March	33	6.13
April	83	11.04
May	87	9.82
June	80	15.99
July	74	11.82
August	98	14.80
September	87	12.62
October	80	12.30
November	92	10.51
December	74	11.55
Total	888	128.02

The particulate emissions for 1995 were re-calculated by Kynoch at a later date, and found to be be 135 tons compared with the 128 given above. Particles are limestone ammonium nitrate (LAN). In the absence of information on the size distribution of the particles it is assumed that all are in the PM10 size range and 90% is in the PM2.5 range.

Caltex

Caltex has provided the following emission data for 1995 (Parker, 1996):

SO_2	10 880	tons
NO_x	1 643	tons
Particulates - furnace	226	tons
Particulates - FCCU[1]	268	tons

It is assumed that particulates from the furnaces are all in the PM10 range, and it is given that 77% of the FCCU particulates are in the PM10 range. It is assumed that 70% of PM10 is PM2.5.

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[1] Fluidised Catalytic Cracker Unit

The EPA (1995) gives the following VOC emissions from an uncontrolled oil refinery (330 000 bbl/day):

Valves	9.4 g/bbl
Flanges	0.9 g/bbl
Pump seals	1.8 g/bbl
Compressor seals	1.5 g/bbl
Relief valves	0.6 g/bbl
Drains	1.4 g/bbl
Cooling towers	2.2 g/bbl
Oil/water separators	44.2 g/bbl
Total	62.1 g/bbl

Caltex produces about 75 000 bbl per day (3259 Ml/year).

Coal

Coal consumption in the greater Cape Town region is 240 000-260 000 ton/year (van Wyk, 1996), excluding Athlone power station. The PM10 emission factor for coal combustion is given by van Nierop (1994) to be 3.08 g/kg but he assumed that the collection efficiency for PM10 was the same as that for TSP which is unacceptably inaccurate as shown in the following Table (stoker fired boiler using a high efficiency cyclone).

Particle size (µm)	% at cyclone inlet	cyclone efficiency	overall % collection	emission (g/kg)
0 - 2.5	2	33.5	0.7	1.3
2.5 - 5	2.5	64.5	1.6	0.9
5 - 10	5	80.2	4.0	1.0
10 - 20	11.5	90.7	10.4	1.1
20 - 40	16	95.2	15.2	0.8
40+	63	98.5	62.1	0.9

The EPA gives 3.9 g/kg for a coal-fired spreader stoker boiler with multiple cyclones. This agrees well with the above table and is therefore used. Pm2.5 will be about 40% of PM10 based on the above table.

The latter value is used in this study. Dracoulides (1994) gives SO_2 to be 19 g/kg and NO_x 7.5 g/kg. The EPA gives a VOC emission factor of 0.025 g/kg for a coal-fired spreader stoker boiler.

Heavy Fuel Oil

Fuel oil consumption in the greater Cape Town area was 122 Ml kl in 1995 (Peens, 1996). It is assumed that all fuel oil is used in boilers. van Nierop (1995) gives the PM10 emission factor for HFO to be 1.03 g/l, but this depends on sulphur content and the inland HFO has negligible sulphur compared to the HFO in Cape Town. The EPA (1995) gives the PM10 emission factor for residual fuel oil in an uncontrolled boiler to be 3.7 g/l. The latter value is used. About 90% of PM10 will be in the PM2.5 range. Dracoulides (1994) gives the SO_2 emission factor to be 63 g/l and the NO_x to be 5.72 g/l. The EPA gives the VOC emission factor for residual oil industrial boilers to be 0.034 g/l.

Power paraffin

It is estimated that 4.6 Ml of power paraffin was used in the greater Cape Town Region in 1995 (Peens, 1996). The PM10 emission factor for distillate oil of 0.12 g/l and the VOC emission factor of 0.024 g/l (EPA, 1995) is used. Dracoulides (1994) gives the SO_2 emission factor to be 8.5 g/l and the NO_x to be 1.5 g/l.

Diesel

It is estimated that 9.0 Ml of diesel was used in the greater Cape Town Region in 1995 by industry and commerce (Peens, 1996). It is assumed that all diesel is used in uncontrolled industrial engines. The EPA (1995) gives the PM10 emission factor to be 7.1 g/l, NO_x to be 100 g/l and the total organics to be 8.2 g/l. It is assumed that 50% of total organics are VOCs. Based on the sulphur content of diesel, the SO_2 emission factor is 9.3 g/l.

Fuel Firing Systems Refiners

Fuel Firing Systems Refiners have a small refinery plant in Vissershoek. Waxy fuel oil is obtained mainly from SASOL and Mossgas and some from waste lub oil. It is partially refined and sold with a specified sulphur content of less than 0.5% although it is claimed that the sulphur content is about 0.01%. Average monthly sales are 22 000 kl/year (mostly used by Consol Glass). Blended fuel is recycled from industrial waste oil, diesel and HFO from ships. Estimated sulphur content is 1.0 -1.5%. (1.5% is assumed). About 5 000 kl/year is sold (mostly used by Cape Marine Oil) (Sands, 1996). Emission factors for both fuels are assumed to be the same as for HFO except for SO_2 which will be 5.4 g/l based on an average sulphur content of 0.3% for both fuels.

OTHER

Medical incinerators

It has been estimated (Tolosana, 1994) that medical waste incineration is about 1308 tons/year. The EPA (1995) gives emission factors for the uncontrolled burning of medical waste to be 1.09 g/kg for SO_2, 1.78 g/kg for NO_x, 2.33 g/kg for PM10, and 0.15 g/kg for VOCs.

Wildfires

Fuel consumed and emission factors of wildfires is estimated to be the same as that given for California by the EPA (1995) which is 40 tons of vegetation burnt per hectare (10 000 m2), and emission factors of 8.6 g/kg for PM10, 2.0 g/kg for NO_x, and 12.1 g/kg for VOCs. The SO_2 emission factor of 0.75 g/kg for wood is used (Dracoulides, 1994). It is estimated that 70% of PM10 is in the PM2.5 range.

Statistics for Cape Town (Cape Town Fire and Rescue Service, 1995) indicate the following uncontrolled fires for December 1995.

Term	Size (m2)	Average (m2)	Number	Total area (m2)
Small	100-500	300	185	55 000
Large	500-10000	5 000	116	580 000
Extensive	10000+	50 000	25	1250 000
Total				1 885 000

For June 1995.

Term	Size (m2)	Average (m2)	Number	Total area (m2)
Small	100-500	300	25	8 000
Large	500-10000	5 000	2	10 000
Extensive	10000+	50 000	1	50 000
Total				68 000

This gives 7 540 tons of vegetation burnt in December 1995 and 272 tons burnt in June 1995. The wildfire statistics were provided on printouts with December requiring 10.5 pages and June 0.5 pages. This indicated about 650 tons of vegetation burnt per page of recorded fires. The amount of vegetation burnt in the remaining months is estimated using this factor.

Month	pages	tons vegetation burnt
January	10	6 500
February	6	3 900
March	4	2 600
April	4	2 600
May	1	650
June	0.5	325
July	1	650
August	1	650
September	2.5	1 625
October	3	1 950
November	10	6 500
December	10.5	6 825
Total	53.5	34 775

It has been estimated by the Fire and Rescue Service that there are at least five fires larger than 1 square kilometre. Assuming that in 1995 10 km^2 was burnt, about 40 000 tons of vegetation was burnt in these fires.

In addition to uncontrolled fires, some controlled fire burning takes place in Cape Town. It has been estimated by the Cape Town (Mr Prince) and Regional Services Council (Mr Herold) that about 2 000 000 m^2 (200 hectares) of scrub was burnt under controlled conditions. About 8 000 tons of vegetation was burnt.

Total vegetation burnt by wildfires in 1995 is therefore 82 775 tons.

Tyre burning

It is estimated that approximately 1.7 million tyres are discarded each year in the Western Cape (Meyer, 1996), and it is estimated that 75% of these tyres are discarded in the greater Cape Town area. The average weight of the rubber of one tyre is about 7 kg (Swart, 1996). It is estimated that only 10% of tyres are used for land-fill with the fate of the remaining discarded tyres unknown (Greenhalge, 1996). It is therefore assumed that 50% of all tyres are burnt. The above estimates give 4463 tons of rubber tyre burnt per annum.

Emissions from tyres depend on the burn rate, with greater emissions occurring at lower burn rates (EPA, 1995). The EPA (1995) gives particulate emission factor of 50 g/kg, but this includes tyres and upholstery of vehicles. For the burning of tyres alone only certain elemental particulate emission factors are given, but these in total are in excess of 120 g/kg. The particle size distribution is unknown. Observation of the low temperature burning of tyres confirms that PM10 emission rates are far in excess of those of wood (17 g/kg). A value of 50 g/kg is assumed and it is assumed that 50% of this is in the PM2.5 range. The

NO_x emission factor is 2 g/kg and the VOC emission factor is 16 g/kg (EPA, 1995). The sulphur content of tyres is about 1.8% (Meyer, 1996) and it is assumed that all sulphur is given off as SO_2. The SO_2 emission factor will therefore be 36 g/kg.

Evaporative VOCs

The EPA (1995) gives the following emission factors for various sources of evaporative VOCs. Included are the estimated consumption figures in 1995 from which total VOC emissions are calculated. Consumption of paints, varnishes, etc was estimated to be 10% of national production which is available for 1988 (1988 Census of Manufacturing).

VOC source	Emission factor	Annual consumption	Annual VOC emissions (tons)
Paint	560 g/kg	4027 kl	3383
Varnish	500 g/kg	2278 kl	1708
Lacquer	770 g/kg	381 kl	440
Enamel	420 g/kg	1821 kl	1147
Primer	660 g/kg	840 kl	832
Solvent degreasing	1000 g/kg	3834 kl	3834
Crude oil ballasting	0.129 g/l	3259 Ml	420
Petroleum loading at marine terminals	0.215 g/l	895 Ml	192
Petroleum loading at rail terminals	0.59 - 1.43 g/l	895 Ml	904
Gas stations - underground filling	0.04 - 1.38 g/l	1237 Ml	878
Gas stations - tank emptying	0.12 g/l	1237 Ml	148
Vehicle refuelling displacement loss	1.32 g/l	1237 Ml	1633
Vehicle refuelling spillage	0.08 g/l	1237 Ml	99

Sources that are too complex for this study are:

(a) Dry cleaning involves the use of non-aqueous organic solvents which can either be petroleum solvents or synthetic solvents. Depending on the type of solvents dry cleaning processes used, varying amounts of VOCs are produced.

(b) Many industries generate waste water that contains organic compounds. During collection, containment, and transfer the waste water is often open to the atmosphere when VOCs are emitted.

(c) Polyester resin plastic products include baths, sinks, coatings, and boats. During their fabrication process VOCs are produced from the fresh resin surfaces. Solvents used for cleaning tools and equipment also give rise to VOCs.

(d) Waste solvent reclamation gives rise to VOCs. Typical industries practising waste solvent reclamation are solvent refining, polymerisation processes, vegetable oil extraction, metallurgical operations, pharmaceutical manufacture, surface coating, and cleaning operations.

(e) Cleaning of rail tank cars, tank trucks, and drums gives rise to VOCs from residual substances in these vessels. Sometime solvents are also used to clean these vessels.
(f) Inks and solvents used in various types of printing processes give rise to VOCs.
(g) Various commercial products release VOCs including aerosols, toiletries, detergents, polishes, waxes and various other household products.
(h) Textile fabric printing produces VOCs from mineral spirit solvents in print pastes or inks. Emission factors depend on the type of printing process which can be roller, flat screen, or rotary screen.
(i) Aspalt cutback used in road construction also produces VOCs.

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APPENDIX B: SOURCE SAMPLING

EQUIPMENT

Mintek sampler unit

The Mintek unit samples on to four filters simultaneously and provides the option of either using a PM10 or PM2.5 sampling head. The sampler is of stainless steel giving it resistance against corrosion and heat. The sampler can be used in two configurations depending on the source to be sampled.

Configuration 1

This configuration is used for sampling from industrial stacks and fires. A diagram of this configuration is shown in Figure 1. The probe is placed in the emission stream and bolted on with a flange. From the probe the sample passes through a flow orifice tube and a heating element. The orifice pressure drop indicates whether sampling is done iso-kinetically. The heating element keeps the sample above its dew point, before dilution with ambient air, so as to prevent condensation of water in the system. After the heating element, the sample is diluted and cooled by filtered ambient air from the intake blower. Thorough mixing of the diluted sample is carried out in the mixing tube that is trombone shaped and contains baffles this simulates atmospheric ageing of stack emissions. The sample then enters a resuspension chamber where it is sampled through either PM2.5 or PM10 heads onto four filters. Flow control in the entire unit is facilitated by the outlet blower.

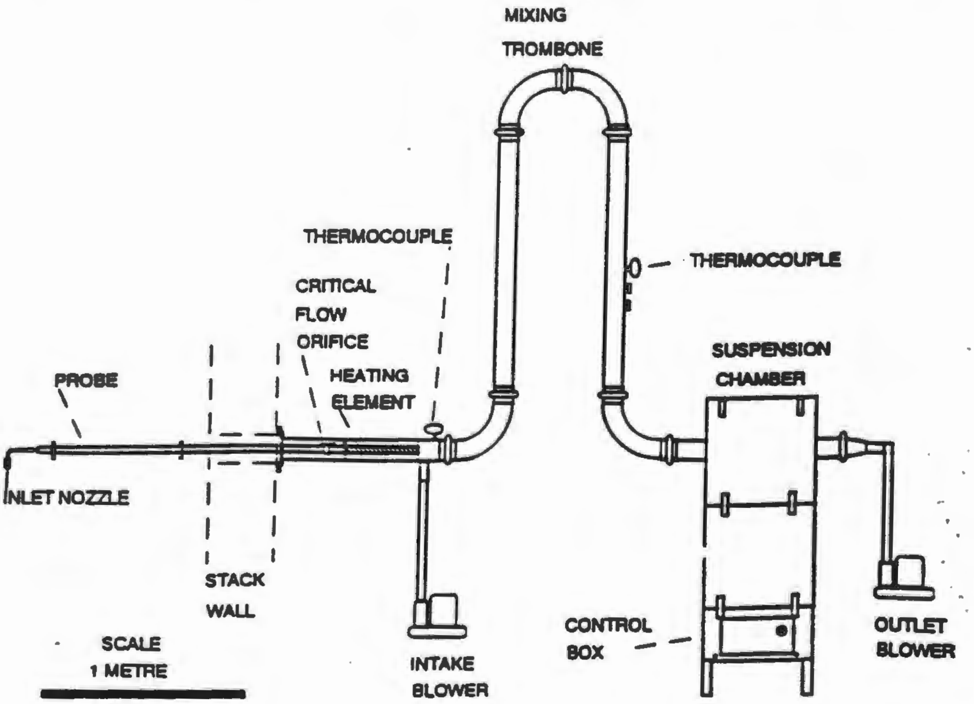


Figure 1. Mintek Sampler Unit in Configuration 1.

Configuration 2

The second configuration (Figure 2.) is used for resuspending grab samples. Here only the sampler and the resuspension chamber are used from the first configuration. In this mode the one opening of the resuspension chamber is connected to a Buchner flask which has compressed air blown through it. The other opening of the chamber is fitted with a filter to let in makeup air. A smooth rubber tube connected the flask to the sampler.

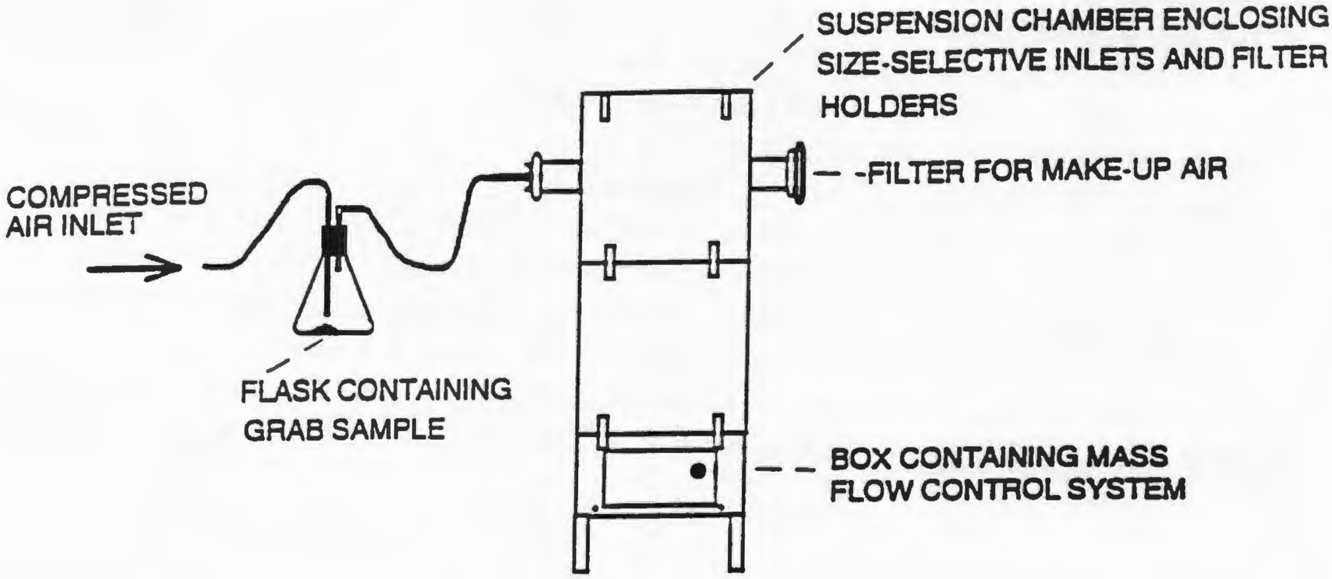
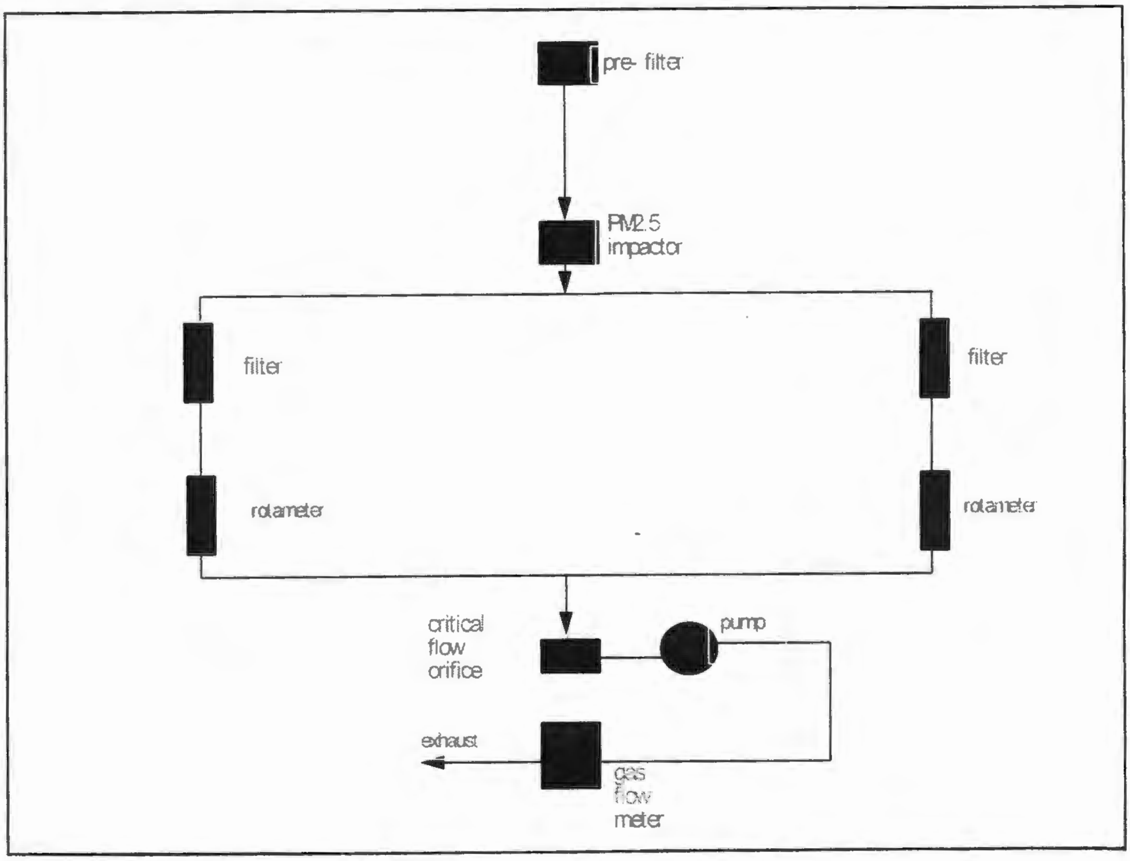


Figure 2. Mintek Sampler Unit in Configuration 2.

Energy Research Institute sampler unit

A second sampler, designed at the Energy Research Institute, is also used to carry out source sampling. It is predominately used for the sampling of resuspended soil, fires and motor vehicles. The sampler collects onto two filters at a time. It has a PM2.5 impactor before the filters to classify the particulates. As with the Mintek sampler it has different configurations for geological sources and combustion sources.



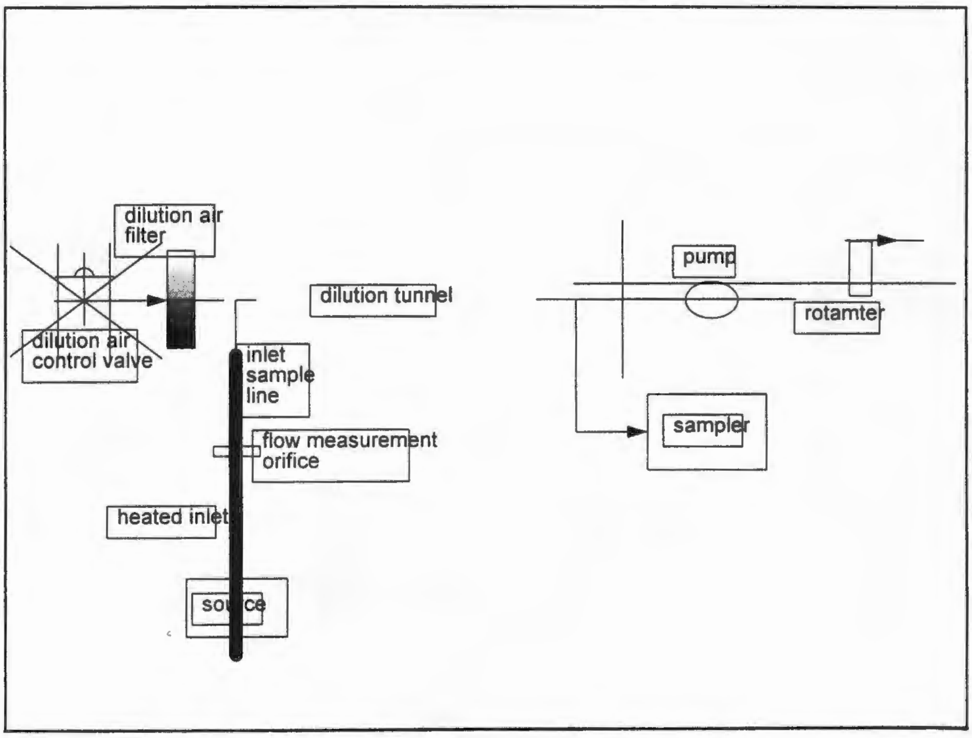
Schematic of Energy Research Institute Sampler Unit.

Configuration 1

This configuration is used for the resuspension of geological material. It is similar to configuration 2 for the Mintek sampler. Here a cellulose chamber is placed over the sampler. The chamber has two openings. The one is covered with a filter so as to provide makeup air to the chamber. The other is connected to a Buchner flask. The Buchner flask holds the geological sample which is 'puffed' into the chamber from a dry compressed air source. The dust is resuspended in the chamber and from there the PM2.5 size fraction is sampled onto filters.

Configuration 2

This configuration is used for combustion sources such as fires and motor vehicle sampling. Due to the fact that there is a considerable amount of moisture associated with these sources a dilution chamber conditions the source stream before filter samples are taken. The dilution chamber is shown in Figure .. It has a heated sample line to the source to be sampled. This line is kept above 100ºC to prevent any moisture form condensing out of the sample. Make up air is sucked through a filter and mixed with the sample to dilute it. Mixing of the dilution air and the sample then takes place in a dilution chamber. A side stream to the PM2.5 sampler unit allows for filter samples to be taken.



Energy Research Institute Sampler Unit in Configuration 2.

METHODOLOGY FOR CHARACTERISING SOURCES

Resuspended soil

This source category includes the following specific sources: road dust, beach sand, wind blown raw materials (coal and cement), and wind blown soil. All of the sampling sites may be affected by wind blown soil and samples are taken at each of these sites. A beach sand sample will be taken near Tableview. A road dust sample will be taken from the CBD and from a suburban site.

Sampling will be as follows for wind blown soil:

- Three kilograms of soil will be collected from different points around the ambient sampling site.
- Samples are then sieved to 38 microns using a shaker unit.
- Sample is dried to 40/C in a low moisture environment
- Sample is then aspirated in a resuspension chamber.
- Resuspension chamber is then sampled with a PM10 and PM2.5 sampler onto filters.

Motor vehicles

Characterisation of the emissions of motor vehicles is difficult due to the number of variables involved. Emissions are largely dependent on the following:

- driving conditions
- vehicle age and maintenance level
- vehicle engine capacity
- fuel type

Vehicles on the road experience different driving conditions such as acceleration, deceleration, idle and different loads. These conditions will be represented by running vehicles on a rolling road dynamometer and taking them through the ECE type 1 test driving cycle(12). This driving cycle involves the vehicle running at different driving conditions. It represents an average of the conditions that a vehicle will experience in driving in an urban area.

Vehicle age and maintenance also play a part in the amount and type of emissions. The combustion state at which the engine is running will effect such things as the elemental to organic carbon ratio in a sample. For this reason cars with good maintenance records and ones with poor records will be tested. This will give a range of profiles to input into modelling.

Vehicles also run on either diesel or gasoline. Both types of vehicles will be tested in the study. Further vehicles have a range of engine capacities. For the purposes of the study these will be split between heavy and light vehicles. Petrol vehicles are typically in the light category.

Thus a number of source profiles for the characterisation of motor vehicle sources will be generated. Four petrol and four diesel vehicles will be tested based on the combination of the variables, heavy or light, and well or poorly maintained. Each of these are driven over an ECE driving cycle during which time filter samples are collected.

The procedure for collecting filter samples from a vehicle are as follows:

- Place vehicle on the rolling road dynomometer at ERI.
- Connect up ERI sampler unit in configuration 2 to the tailpipe of the vehicle.
- Adjust flow through the dilution tunnel so that sampling from the tailpipe is isokinetic, by measuring flow in the tailpipe and in the sample inlet with the use of orifice plates.
- Simultaneously start the ECE driving cycle and sampling onto filters.
- Run through ECE driving cycle.

Residential fuel burning

This category involves the emissions from the burning of wood, coal, and household gas. Profiles for the burning of coal and household gas are available from other studies(10,13). Emissions from wood, which is the main source of domestic heating in the Greater Cape Town area, are sampled in the study. This is done by connecting up the ERI sampler unit in configuration 2 to a hood arrangement. The hood arrangement consists of a brazier (to burn the wood in), a hood (to direct the smoke up a flue), a connection to a flue, and a sampling port that can be connected to the ERI sampler unit in configuration 2.

There are two main types of wood burnt in the Greater Cape Town area. These are Port Jackson and Rooikrantz wood. The procedure for sampling the emissions from a wood fire is:

- Place some wood in the brazier.
- Ingnite wood .
- Place brazier under the hood which is connected to the dilution tunnel.
- Start blower for dilution tunnel with dilution ratio set at approximately 1:10.
- Start sampler for collecting onto filter media.
- After approximately 1000µg of sample has been collected on each filter, turn off the sampling system.
- Remove filters from filter holders.

Grass fires

Grass fires are mainly a summertime occurrence but are studied because frequently haze episodes start occurring from the month of March which is still dry and fires are frequently observed. Freshly cut grass was collected for burning. The ERI sampler was set up in configuration 2 and connected to the sampling hood mentioned in section 4.3.3. Instead of a brazier a flat tray is used to burn the grass in. This provides better combustion conditions for the grass. The procedure for sampling from grass fires is similar to that wood burning.

Information about the occurrence of fires will be obtained from the Cape Town Fire and Rescue Service.

Tyre burning

An estimate of the overall yearly emissions for tyre burning shows that it is not a significant source of emissions (section 3.4). It has, however, significant and very visible localised impact. Tyres are burnt for the wire that is found in the rubber, the burning of a tyre is characterised by billowing black smoke. The emissions from tyres is studied here using a setup similar to that for the burning of wood.

Industrial emissions

Industrial emissions include emissions from boilers which are usually oil, coal or gas fired. Commercial boilers, such as for hospitals, are also included in this category. Further industrial emissions also include specific factory emissions. In the Cape Town area the following industrial emissions will be characterised:

- Coal fired boiler
- Oil fired boiler
- Caltex oil fired boiler
- Caltex gas fired boiler
- Caltex furnace
- Caltex fluidised catalytic cracker unit (FCCU)
- Kynoch Ammonium Nitrate emissions

The coal fired boiler profile will be obtained from MINTEK source profiles determined for the Vaal Traingle(10). The coal used in Cape Town is derived from the same region as that used in the Vaal Triangle. The source profile for a chain grate stoker fired boiler with multiple cyclones will be used. This source profile will also cover the Athlone Power Station which uses the same technology. An combustion expert confirmed that the characteristics of particulates from the power station should be no different from those of industrial boilers(17).

Industrial emissions present problems for sampling. These are primarily due the fact that most of these emissions come from reasonably tall chimney stacks. Emissions react to some extent up the length of the stack and therefore sampling should be carried out near the top of the stack. This causes logistical problems in so far as it is difficult to get sampling equipment to the source and in most instances no sampling ports are located near the top of the stack. For this study sampling will be carried out near the base of stacks.

Stack sampling must be done isokinetically. MINTEK have developed an isokinetic sampler for this sort of application [MINTEK sampler in configuration 1]. This sampler will allow for both PM10 and PM2.5 samples to be collected.

Kynoch emissions are mainly of ammonium nitrate. The source profile for Kynoch will be based on a bulk chemical analysis of the product. It will be assumed that the chemical constituents are homogeneous through all size fractions.

The procedure for sampling from stacks is as follows:

- Open port in the side of the stack.
- Manoeuvre an S- type pitot tube in to the middle of the stack. Make sure that the opening is perpendicular to the flow.
- Record the pressure difference for use in calculation of the sampling rate.
- Calculate the sampling rate. This is done using the following steps outlined by MINTEK:

- Calculate the flue gas density by $Y_s=Y_o.(T_o.P_o)/(T_s.P_s)$ ....(1)

  Y_s=density of stack gas (kg/m^3)
  Y_o=gas density at STP (kg/m^3)
  T_o=273K
  T_s=stack temperature (K)
  P_o=101.325 kPa
- Calculate the stack flue gas velocity by v_s=k.Ö(.-P/Y_s) ....(2)

  v_s=point velocity of flue-gas at pitot tube inlet position (m/s)
  k=pitot tube characteristic constant
  -P=pressure drop measured across pitot tube
- Calculate the volumetric flow rate at which to sample by

  $Q_o=v_s.A_n$..(3)
  Q_o=volumetric sampling rate (m^3/s)
  A_n=sample nozzle opening (m^2)
- Calculate the required pressure drop across the orifice on the sample inlet line by

  $LH=K[Q_o.P_i/T_i]^2$ ....(4)
  LH=orifice differential pressure (Pa)
  K=orifice constant = 1.4412×10^9

- By adjusting the air flow of the two blowers set the differential pressure across the orifice [calculated above] for isokinetic sampling.
- Sample onto cellulose nitrate filters for approximately 30 min. These are then weighed to determine the sampling time necessary to obtain filter samples that have an approximate loading in the range 500 to 2000 μg
- Sample onto quartz, nuclepore and teflon filters for the time calculated.

Sea salt

Source characterisation for sea salt will be carried out at Cape Point which is located 50 kilometres south of the CBD on the tip of the Cape Peninsular. The ERI sampler unit in configuration 1 with the cellulose hood removed was used to obtain these samples. The sampler was set up at the CSIR Atmospheric Trace Gas Research Station. Sampling was carried out on days when there was an onshore air flow predicted by the Weather Bureau. Three sets of samples were taken on suitable days and the sampling times were approximately 30 hours long.

Background checks

Although background sources can be significant, it is unlikely that there is any contribution from background sources in Cape Town as there is not much heavy industry within a few hundred kilometres of the study area. Nevertheless the contribution of background sources will be checked. This will be done using a mobile sampler. The samples be taken at areas outside the study area on the prevailing wind side.

APPENDIX C: AMBIENT SAMPLING

EQUIPMENT

The system used for sampling was the TEOM series 1400a Ambient Particulate (PM10) Monitor connected to the Ruprecht and Patashnick Automatic Cartridge Collection Unit (ACCU). A diagram of this is shown in the Figure below. A further modification to this system was the addition of a PM2.5 impactor, which is rated at 13.7 l/min and is supplied by Ruprecht and Patashnic, in the line to the ACCU. The ACCU system has eight channels for collecting filter samples and one bypass channel. Flow passes through one of these channels at a time and the TEOM can be programmed to do such tasks as episodic sampling, multiplexing and sampling at specific times.

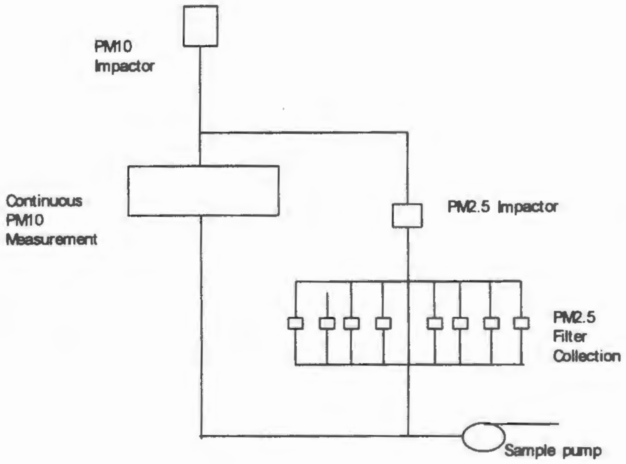


Diagram of the ambient particulate sampling equipment.

Four of these units were used in the study. Once-off ambient PM2.5 samples were also collected at two further sites; Cape Point and Khayelitsha. These sites are too inaccessible for ongoing sampling, but samples from these sites was important for a better understanding of the brown haze. A sampler built at the Energy Research Institute was used.

The results from the four samplers was be total PM10 concentration through the TEOM oscillating mass balance, and total PM2.5 concentration from the weighing of the filters loaded in the ACCU. PM10 concentrations were continuously measured whilst PM2.5 concentrations were measured on selected days and data represented average values for the sampling period (12 or 24 hours). Chemical analysis of the PM2.5 filters provided detailed chemical information.

Filter holders

The ACCU is loaded with filter packs. The filter packs consist of a filter holder (Gelman 47mm inline filter holder Cat. no. 1119) loaded with a filter. The details of the components of the filter holders are shown in the Figure below. The filter holders are made up of a support disk for the filter, an o-ring for sealing and a casing in which the above are housed and to which piping can be connected.

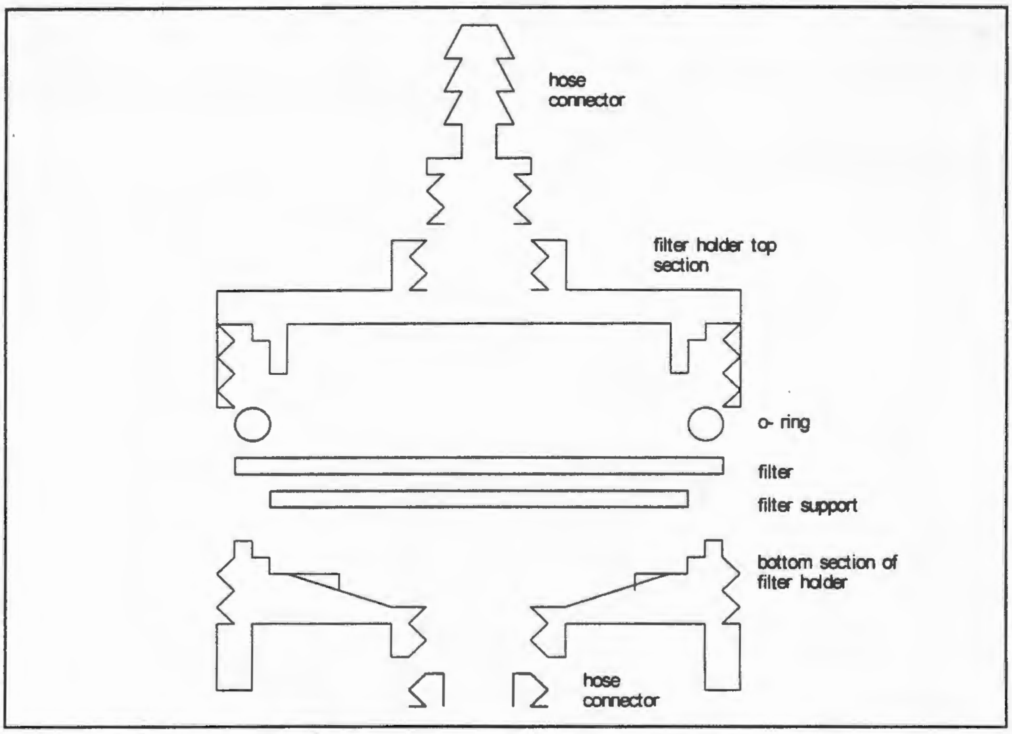


Diagram of filter holder

These filter holders are connected to 6mm piping and when sampling takes place the sample air is expanded from 6mm to 47mm onto the filter. This is over a short distance and there was some concern that this would cause uneven deposition on the filters. This could result in an uneven particle size distribution on the filter and could skew analysis results. In order to check this, filter samples were obtained simultaneously using a normal 2filter holder and a filter holder with a diffusion tube. No statistical difference could be found in the number, size and shape of particles at six points along the radius of the filters.

SAMPLING PROCEDURE

Once it was decided that there would be meterological conditions conducive to haze formation a sampling procedure was initiated at the four sites. A communications programme designed to communicate with the TEOM analysers was developed by the Cape Town City Council Scientific Services Branch. This programme enables sampling to be triggered remotely at all sites using a modem.

The following procedures were carried out when it was decided that there would be an episode the following day:

- Run Ericom3 [communications programme].
- Dial one of the sampling sites by way of modem.
- Download the ACCU timetable. This gives the TEOM system data on what time to start sampling, what channel to sample on, and the time of finishing sampling.
- Edit the ACCU timetable so that the sampling times are correct for the following day.
- Send the edited ACCU timetable to the site.
- Activate the ACCU timetable.
- Repeat procedure fore nect site.
- On completion, recheck that all sites have been activated.

APPENDIX D: FILTER HANDLING

Filters are used in this study as the surfaces onto which particulates are collected. Due to the analysis that is needed in the study various filter media are used. They are Teflon, Quartz Fibre and Polycarbonate media. Filter handling procedures are based on those of the Desert Research Institute (Chow et al, 1990)(14).

All filters are handled using stainless steel tweezers.

Pre-Weighing Operations

Teflon Filters:
After Teflon filters are received they are stored in the filter handling area for one to two weeks until they are to be weighed. This is because it is suggested(1) that Teflon filters are unstable just after manufacture and that they need a period of a few weeks to stabilise in mass.

Quartz Fibre Filters:
Quartz Fibre filters absorb organic gases from both the ambient air, and during manufacture. Therefore a process of pre-firing is necessary to reduce artifacts to negligible levels. The filters are fired at 900°C. Since filters are analysed over a temperature range from 25°C to 800°C. The pre-firing removes all possible interferences to analysis.

Filters are fired in batches of 25 or 50 in a 5kW electric kiln at 900°C for approximately 5 hours. The kiln then takes approximately 24 hours to cool down to 100°C so that the filters can be removed. The filters are then placed back into the plastic box in which they arrived. From there they are placed in a desiccator in a fridge until they are to be used.

Polycarbonate Filters:
Polycarbonate filters are kept in the manufacturer's packaging until ready to be used.

Filter labelling

Teflon filters:

XXXXTZZZZ

X= Date of weighing of blank filter

T= Denotes a Teflon filter

Z= Number from 1 onwards which is unique to the filter.

Teflon Filters are labelled in the following fashion:
The labels used are Chevron self adhesive labels. They are of paper and are stuck onto the petri-slides. The filter number can then be written onto this area.

Quartz fibre filters:
Quartz Fibre filters have labels that are in the following configuration:

XQY

Where X is the date on which the filter was pre-fired. Q indicates that the filter is a Quartz filter, and Y is the number of filter that has been used. Values of Y start at 1, which is the first filter that is used.

Polycarbonate filters :
The form of label on these filters are different depending on whether the filter is used for source or ambient sampling. For source sample the label is of the form:

XY#Z

Where X is a set of letters describing the source. Y is a number that is equal to either 10 or 2.5. This number represents wether the sample is PM10 or PM2.5. Z is a number starting from 1. Sources sampled have the following values for X:

OB - HFO fired boiler.
CALOL - HFO fired boiler at Caltex.
CALF - Caltex HFO and gas fired furnace.
WSOL - Geological dust from near the Wynberg ambient sampling site.
TSOL - Geological dust from near the Tableview ambient sampling site.
RW - Woodburning of Rooikrantz wood.

Ambient samples are labelled in the following manner:

XY#ZN

Where X are letters that distinguish the site at which the filter was sampled. From Y one can tell if the sample is PM10 or PM2.5 as it will have either a value of 10 or 2.5. Z is the date on which the filter was sampled, and N denotes a nuclepore polycarbonate filter.

Values for X here are:
DH - Samples taken at the CBD site.
TV - Samples taken at the Tableview site.
WB - Samples taken at the Wynberg site.
GW - Samples taken at the Goodwood site.
KH - Samples taken at the Khayelitsha site.

Weighing operations for teflon filters

Teflon filters are used for gravimetric analysis and therefore need to be weighed before and after loading. The weighing takes place at the National Accelerator Centre at Faure. The apparatus used is a Mettler M3 balance that is accurate to 1μg. Batches of 25 to 50 filters are weighed at time.

Minimisation of Measurement Interferences:
Humidity and temperature can affect the weight of the filter, so it is important to monitor these. Chow et al$^{(1)}$ suggest that the filters be stored in the weighing environment before weighing. Due to the distance of the balance (about 50 kilometres from the filter storage area) this is not possible. The filters weighing is therefore treated more carefully. On arriving at the balance the filters are immediately placed out on a bench to equilibrate as much as possible to the environment, which is temperature and humidity controlled. The first filters are allowed to equilibrate on the balance. Weights are taken when the filter does not change in mass for about 5 minutes. This method means that the first few filters take a large amount of time to weigh while those that were equilibrating on the bench take far less time as they are in equilibrium with the surroundings by the time they are to be weighed.

Microbalances are also sensitive to static electricity. Static buildup is particularly evident on filters that have been exposed. A radioactive source is located inside the balance chamber to dissipate any potential static charge.

Weighing Procedure:

(i) Filters are transported to the weighing room in the original manufacturers containers.
(ii) The container is placed open on a bench next to the balance.
(iii) About ten filters at a time are placed in labelled petri-slides and lined up next to the balance.
(iv) Each filter is removed from its petri-slide and held up to a fluorescent light. If no pinholes or discoloration are observed the filter is placed on the weighing pan.
(v) The filter is then left on the pan until it has reached a stable weight as defined above.
(vi) The filter is removed from the pan and placed in a labelled petri-slide.
(vii) Weight, label and date of weighing are recorded.
(viii) Weighed Teflon filters are stored under ambient conditions in a dust-free room.

Filter Weight Reproducibility:

Every second filter is reweighed by the procedure used above. The criterion for the acceptance of the weight of the filter is if the weights are within 10 μg of each other. If this is not achieved then the filter is weighed again until this criterion is achieved.

Some batches of filters that have already been weighed are also reweighed by a different operator and the same criterion as above is implemented. This is to guard against operator error.

Weighing operations for polycarbonate filters

These filters are used for Scanning Electron Microscope analysis. They are weighed primarily to assess whether the loading of the filter is sufficient for analysis. The filters need to be loaded to between 200 μg and 500 μg and so accuracy is not required. The filters are weighed in a temperature controlled environment at the Energy Research Institute on a Mettler AE200 balance that is accurate to 100 μg.

Weighing Procedure:
(i) Place filter in labelled petri-slide.
(ii) Allow filter to stand in the weighing environment overnight to acclimatize to the weighing environment.
(iii) Check calibration of the balance by following the calibration procedure in the manual for the balance.
(iv) Place o-ring on the pan and zero the balance.
(v) Check filter for pinholes or discoloration by holding it up to a light source.
(vi) Place filter on the o-ring and record mass.
(vii) Remove filter from the balance.
(viii) Re-zero if necessary.
(ix) Re-weigh the filter. If the weights are the same, replace the filter in the petri-slide for use in sampling.
(x) Weighed Polycarbonate filters are stored under ambient conditions in a dust free room.

Filter holder loading operations

The filter holders are Gelman Polycarbonate Inline Filter Holders. They are designed to be installed in the ACCU.

Teflon filters:
Due to the nature of the filter holders and the thinness of the Teflon filters it was found that the particulates deposit on the filter in a grid formation that is the same as the backing grid for the filter holder. To overcome this drain disks are placed in the filter holder before the Teflon filters. This results in a more uniform deposit on the filter.

The procedure for loading teflon filters is:
(i) Unscrew filter holder.
(ii) Label filter holder with the same label as on the petri-slide of the filter to be used.
(iii) Place drain disk in the filter holder.
(iv) Place filter on the drain disk.
(v) Place o-ring on the filter.
(vi) Screw filter holder back together.
(vii) Place filter holder into container.
(viii) Place container and filter holder into waterproof bag for transportation.

Quartz fibre filters:

Due to the thickness of these filters there is no need for a drain disk. The procedure for loading quartz filters is:

(i) Remove filter box from desiccator.
(ii) Label filter holder with number consecutive to last Quartz filter used. Record this number.
(iii) Unscrew filter holder.
(iv) Place filter in the filter holder.
(v) Place o-ring on the filter.
(vi) Screw filter holder back together.
(vii) Place filter holder into container.
(viii) Place container and filter holder into waterproof bag for transportation.
(ix) Put filter box back into the desiccator.

Polycarbonate filters:

These filters are also of the membrane type as with Teflon filters and so their loading procedure is the same.

ACCU loading/unloading operations

The ACCU system is loaded with the Quartz and Teflon filters. There is no distinction between the two types of filters as far as loading/unloading operations are concerned. These operations occur when six of the eight current channels have been sampled on at a particular site.

Some checks are done during these operations. These consist of recording the total sampling time and volume flowrate through each of the 8 channels of the ACCU. This is done to check whether there were any power failures during the sampling period that were not logged. Before loading filter holders it is checked that the ACCU is not sampling through any of the 8 channels.

Unloading filters

The following procedures are followed for unloading of filters:

(i) Remove used filter holder from channel.
(ii) Record filter label and date of filter removal.
(iii) Replace used filter holder with unused one in the channel.
(iv) Record label and date of installing the filter holder.
(v) Record time and volume flowrate for the channel from the TEOM output display.
(vi) Transport used filter holders to the filter handling area for unloading of filters.

Loading filters

Loaded filters are transported from the sampling sites in their filter holders. It is important that the loaded filters are kept in a dry, cold environment before weighing. The filters are placed in a desiccator in a fridge before weighing. The temperature in the fridge is 0°C.

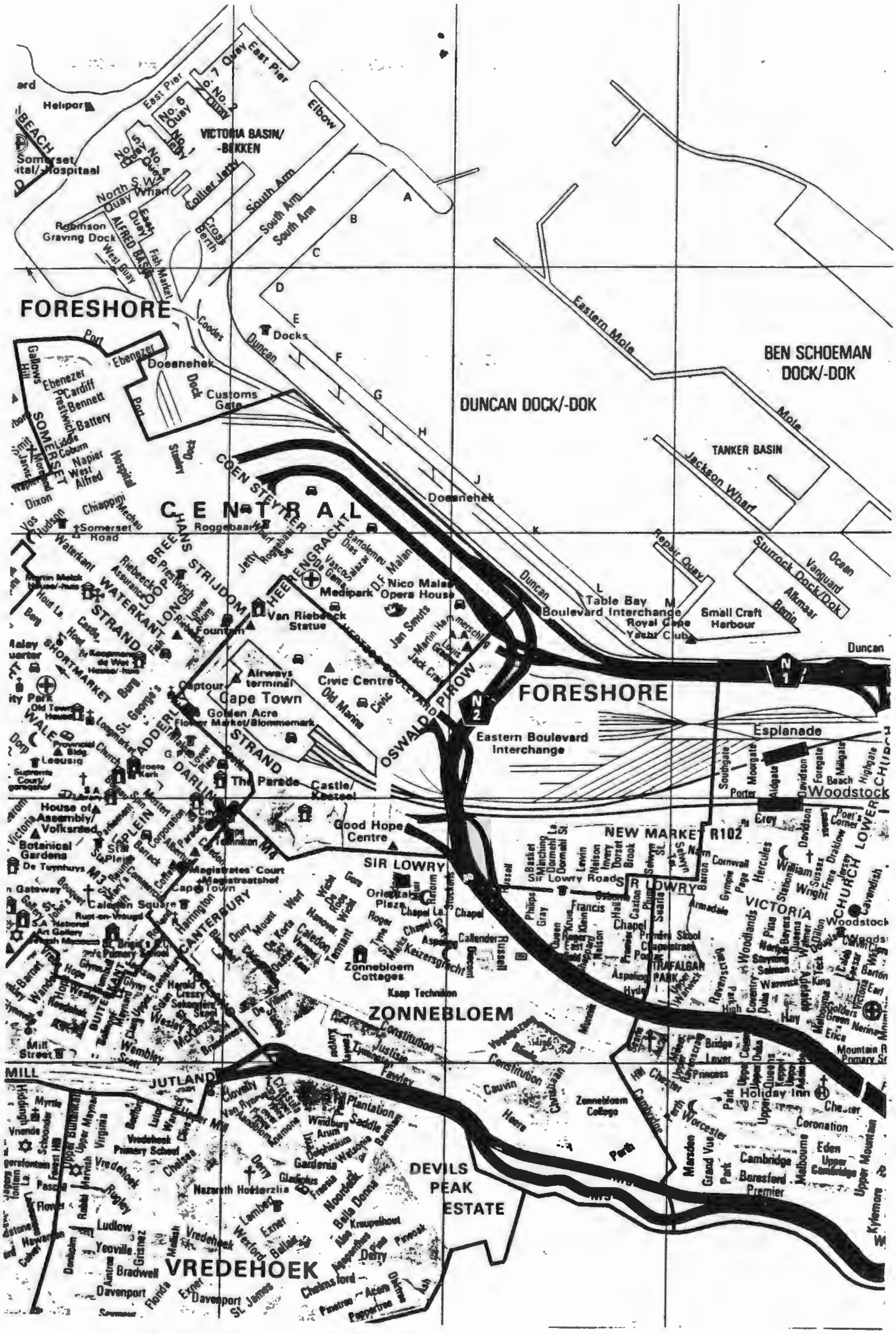
The filter holders, once they have been unloaded, need to be cleaned so that they can be loaded with new filters for sampling. Cleaning is done with warm water and lint free towels.

Loading of the ACCU is carried out as follows:

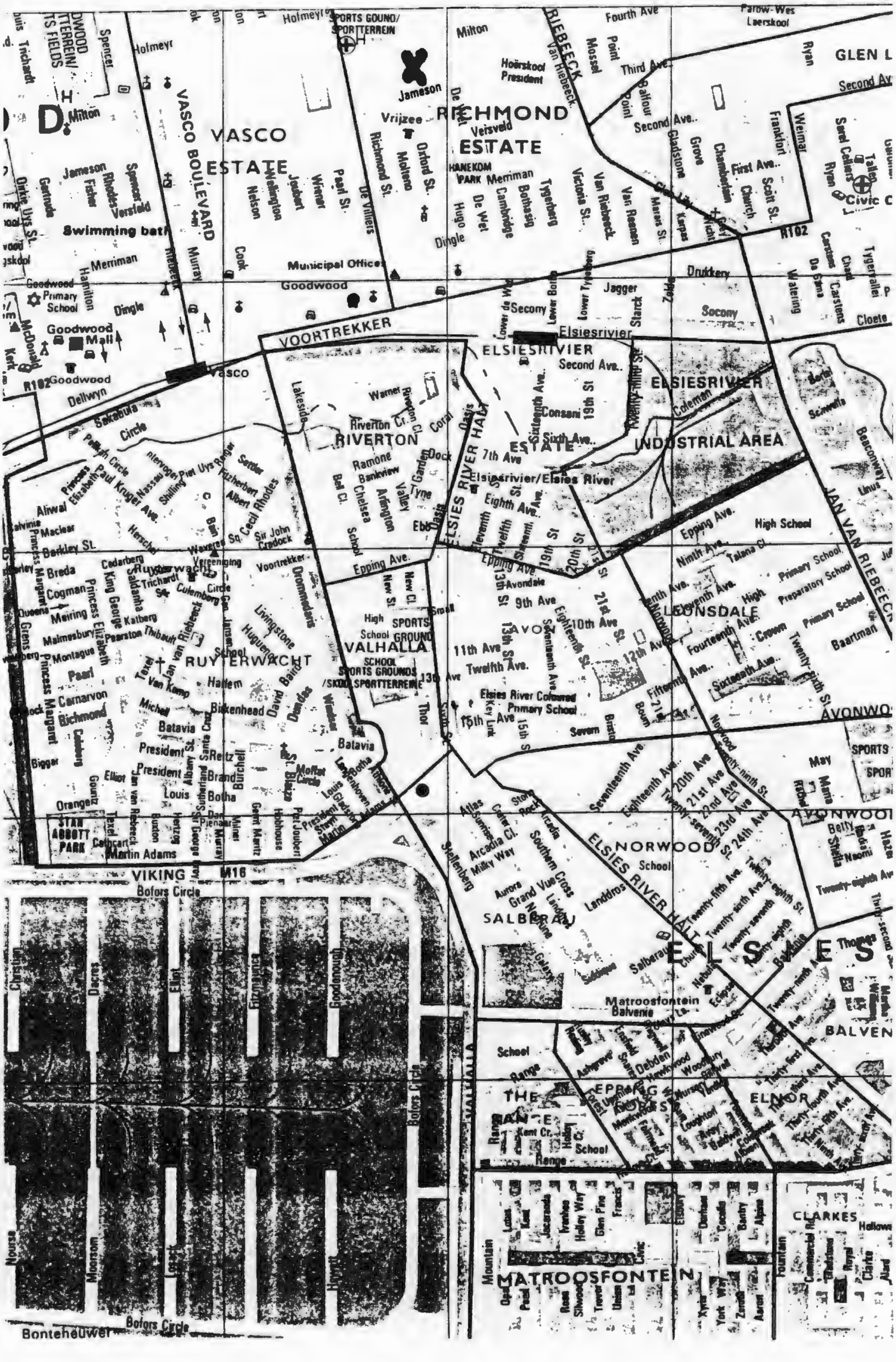
(i) Place filter holders on bench in the filter handling area.
(ii) Retrieve empty petri-slide whose label matches that on the filter holder.
(iii) Unscrew filter holder.
(iv) Remove the o-ring.
(v) Remove the filter from the filter holder.
(vi) Place the filter into the petri-slide.
(vii) Place the petri-slide in the desiccator.

APPENDIX E: DETAILED MAPS OF EACH SAMPLING SITE

Central City



Goodwood


VASCO ESTATE
RICHMOND ESTATE
VOORTREKKER
RIVERTON
ELSIESRIVIER ESTATE
ELSIESRIVIER INDUSTRIAL AREA
RUYTERWACHT
VALHALLA
LEONSDALE
NORWOOD
SALBERAU
ELSIES
THE RANGE
ELNOR
MATROOSFONTEIN
CLARKES
Goodwood Mall
VIKING
M16
R102
JAN VAN RIEBEECK
ELSIES RIVER HALT

Tableview

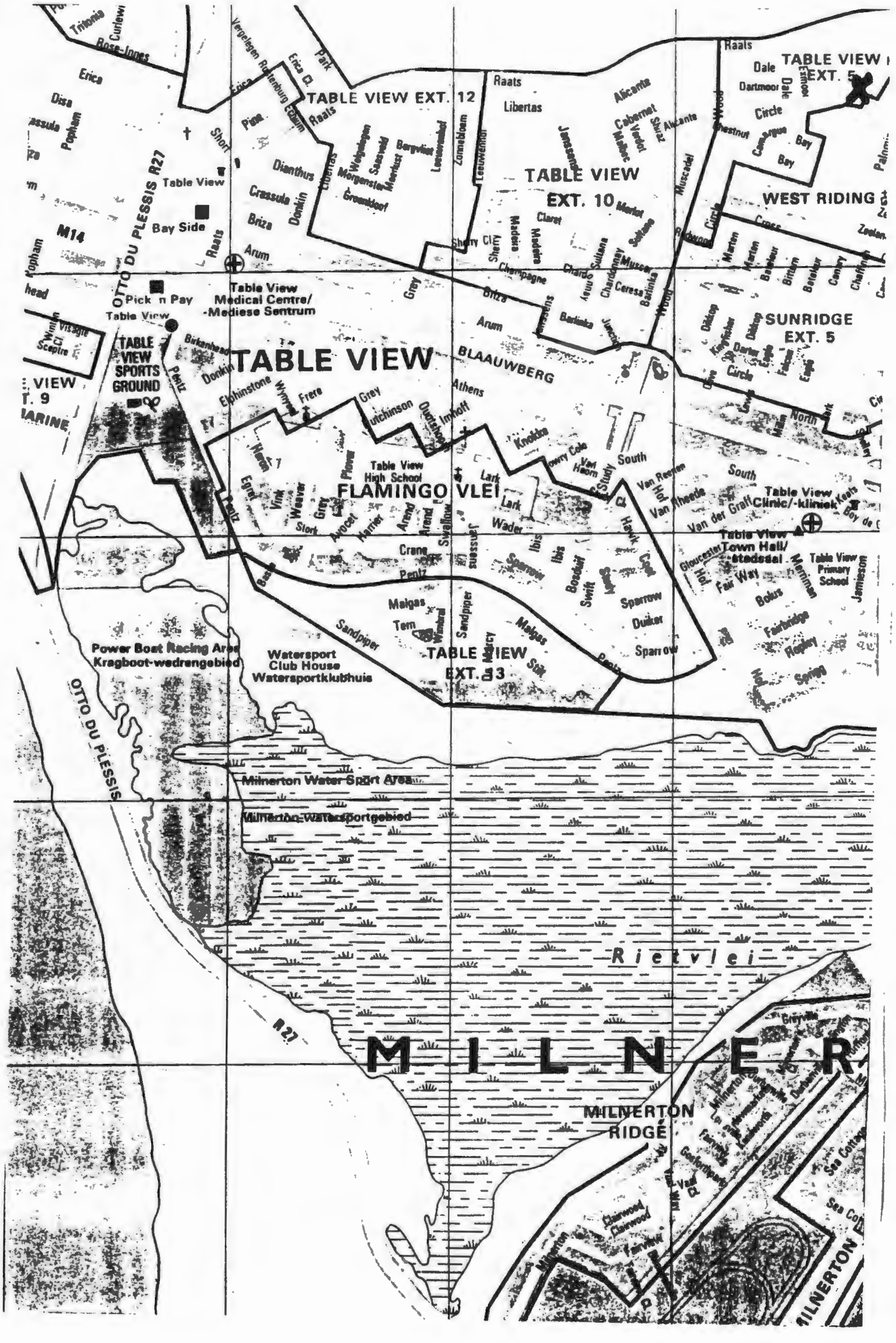


TABLE VIEW
TABLE VIEW EXT. 12
TABLE VIEW EXT. 10
TABLE VIEW EXT. 5
WEST RIDING
SUNRIDGE EXT. 5
FLAMINGO VLEI
TABLE VIEW EXT. 13
TABLE VIEW SPORTS GROUND
OTTO DU PLESSIS R27
BLAAUWBERG
M14
Table View
Bay Side
Pick n Pay Table View
Table View Medical Centre/ Mediese Sentrum
Table View High School
Table View Clinic/-kliniek
Table View Town Hall/ -stadsaal
Table View Primary School
Power Boat Racing Area Kragboot-wedrengebied
Watersport Club House Watersportklubhuis
Milnerton Water Sport Area
Milnerton watersportgebied
Rietvlei
R27
MILNER
MILNERTON RIDGE
MILNERTON

Wynberg


NEWLANDS
HERSCHEL RD
Claremont Civic Centre/ burgersentrum
CLAREMONT PUBLIC GARDENS
SPORTSFIELD/ SPORTTERREIN
Harfield Road
ROSMEAD
Kenilworth
KENILWORTH
TENNANT
WYNBERG PARK
Military Hospital/ Militêre Hospitaal
Wynberg Boys High School
C.E.D. Museum
CEMETERY
MAYNARD
Wynberg Station
Maynardville Open Air Theatre/ Opelugteater
Withinshaw Centre
WYNBERG
Victoria Hospital
ALPHEN HILL
MAIN CONSTANTIA
PRINCE GEORGE
Alphen
Alphen Interchange
CONSTANTIA SPORTS GROUND
GABRIEL RD
Sanlam Centre
MAIN
PLUMSTEAD
VICTORIA
WILLIAM HERBERT SPORTS GROUND
EDINBURGH
TROVATO LINK
WATERLOO
M4
M3

Guguletu


MANENBERG
SHERWOOD PARK
GUGULETU
NYANGA
NEW CROSSROADS
DUINEFONTEIN
LANSDOWNE
Nyanga
School
School
School
Thames
Red River
Rio Grande
Tugela St.
York
George
King
Zak
Vistula
Magalies
Wye
Zwartkops
Manenberg
Ny 3
Ny 21
Ny 50
Ny 54
Ny 60
Ny 61
Ny 71
Ny 72
Ny 75
Clyde
Aspden
Sharon
Boston
Colorado
Denver
Fourth
Third
Second
First

APPENDIX F: ANALYTICAL METHODS

Analysis of filter samples is important link in the source apportionment study as the data from analysis allows for modelling of Brown Haze episodes to take place. Important in analysis is to ensure the quality of data obtained and so it is important that rigorous procedures be followed to make sure that all filter samples are treated in a standard way thus minimising errors due to measurement effects. The procedures for analysis in this study are based primarily on those proposed by Chow and Richards (1990)(14). These are very detailed and comply with EPA requirements.

Weighing

For weighing operations the following guidelines are proposed by Chow and Richards:

- Important that the balance room is dust free.
- Accuracy of the balance must reflect detection limits of analytical apparatus.
- Temperature control. For gravimetric analysis EPA requirement is 20 ± 5/C.
- Humidity control. EPA requirement is 30 ± 5%.
- Balance is sensitive to static electricity so care must be taken to ground them before weighing on anti-static mats.
- Calibration of balances should be done regularly.
- All filters should be documented along with the tests done on them.
- A standard operating procedure should be drawn up incorporating the above points to increase accuracy of analysis.

Weighing is carried out at the National Accelerator Centre. The balance that is used is a Mettler M3 which reads to 1 μg. The balance room fits in with all the requirements above. Documentation is described in section 7 and the standard operating procedure is shown in section 4.1.2.

XRF

This analysis was performed at the Desert Research Institute in the United States. Procedures conformed to EPA standards.

Ion Chromatography

Ion Chromatography is the analytical method used to measure the concentration of ions on the filter samples. The analysis is performed at the Geological Sciences Department at the University of Cape Town following the procedures outline by Chow and Richards (1990). Ionic species to be measured are chloride, nitrite, nitrate, sulphate and ammonium. Before the samples can be analysed the ionic species need to be extracted from the filters into solution. Methodology for extraction of the ions from the filters prior to analysis is as follows:

- Remove filters from the petri-slides and place them into polystyrene extraction tubes. For analysis half of a Quartz fibre filter is used. The extraction tubes are housed in an extraction rack.
- Add 15.0 ml of deionised-distilled water (DDW) to the extraction tube containing the filter.
- Add 15.0 ml DDW to one empty extraction tube and mark it as a blank.
- Cap the tubes making sure that the exposed area on the filter is completely and continually submerged.
- Place the extraction rack in an ultrasonic bath that has been filled to approximately 80% with distilled water. Make sure that the water level in the ultrasonic bath is higher than the extraction solution level. Also measure the temperature in the bath and make sure that it is approximately 25°C.
- Sonicate for 60min checking the temperature of the bath at 30 min intervals. If the temperature exceeds 27°C, add ice to the bath to bring the temperature down.
- Remove the extraction rack and place it on the test tube shaker. Shake for 60 min at 60 cycles per minute.
- Store the extracted samples in a refrigerator prior to chemical analyses.

The next step is the analysis itself. This is undertaken on a Dionex ion chromatograph.

Thermal optical reflectance

The analysis for organic and elemental carbon cannot be performed in this country. This analysis will be done at the Desert Research Institute in Nevada USA and so quartz filters will be sent to this institute for analysis. The procedure for this analysis can be found in detail San Joaquim Air Quality Study standard operating procedure report by Chow and Richards. An outline of this analysis method will follow.

Thermal optical reflectance is based on the principle that organic and elemental carbon can be oxidised at different temperatures. More specifically organic carbon can be volatised from the sample at low temperatures in a helium atmosphere while elemental carbon is not removed. The analyser operates by:

- Exposing the sample to different temperature and oxidation conditions thereby liberating different carbon compounds. This involves staged heating to 550°C and then further heating to 700 and 800°C respectively.
- Oxidising these compounds to carbon dioxide by passing them through heated manganese dioxide.
- Reducing the carbon dioxide to methane by passing it over a hydrogen enriched nickel catalyst.
- Measuring the methane formed in a flame ionisation detector.

A further feature of the analyser is its optical (laser reflectance) component which is used to correct for the pyrolysis of organic carbon compounds to elemental carbon. This prevents the organic fraction of the carbon being underestimated. The pyrolysis correction is made by continuously noting the filter reflectance throughout the analysis. Reflectance is measured by a helium-neon laser and a photodetector.

Microscopic analysis

Microscope analysis is a technique that is often used in source apportionment studies. It has the advantages of enabling the detailed study of size, shape and chemical composition of individual particles. To do this an automated procedure for the analysis is individual particles on a filter sample needs to be developed. For this extensive software development is needed and large analysis times are required. Furthermore, for the microscope to be able to discern one particle from another the particles need to be at least a diameter apart on the filter paper. To achieve this filter samples must be taken for short time periods, typically for one hour. Thus if a full episode of 12 hours were to be sampled 12 filter samples would be needed as opposed to the one that is required by this study.

Thus SEM analysis has large costs both in analysis times and in filter papers required. Furthermore the Leica s440 Sigma digital microscope that is available to this study through the Electron Microscope Unit at UCT does not allow for automated particle by particle analysis. So a quantitative study would not be possible here. Instead a semi-quantitative technique will be used. This will mainly act as a check on receptor modelling results and give an indication of any sampling contamination. Imaging will be used to analyse particle shapes and sizes and X-ray mapping will give an indication of what elements are in each particle. From these three types of data and from comparing source and ambient filters qualitative source apportionment can be undertaken by matching particles 'seen on source and ambient filters.

APPENDIX G: THE CHEMICAL MASS BALANCE MODEL

The Chemical Mass Balance Model

The specific model to be used is the Chemical Mass Balance Model. The model consists of the following sets of equations:(15)

$$C_i = F_{i1}S_1 + F_{i2}S_2 + \ldots + F_{ij}S_j + \ldots + F_{iJ}S_J \quad i = 1..I,\ j = 1..J \ldots\ldots(1)$$

where: C_i = Concentration of species i measured at a receptor site
F_{ij} = Fraction of species i in emissions from source j
S_j = Estimate of the contribution of source j
I = Number of chemical species
J = Number of source types

Inputs to the model are C_i and F_{ij} and the outputs are S_j. The accuracy of the outputs depends on the accuracy of the inputs and for this reason values of the inputs are inputted along with estimates of the errors associated with these values.

Before going ahead in using this model it is recommended in the EPA '*Protocol For Applying and Validating the CMB Model*'(6) that checks be made to see whether the model is appropriate or not for the data to be obtained.

A general summary of the recommended steps for the validation of the model is:

- Determine the general applicability of the CMB model to the application at hand.
- Set up the model by identifying and assembling the source types, source profiles, and receptor concentrations needed for model input. Make a preliminary application of the model to these data.
- Make any model input changes which can be justified to resolve the identified problems. Rerun the model.
- Assess the stability of the model results and their consistency with the preliminary analyses.
- Evaluate the model results by comparing them with other receptor or dispersion model results and reconcile any differences.
- Examine the model's statistics and diagnostics to identify potential deviations from the model assumptions. These are:
  - (i) Compositions of source emissions are constant over the period of ambient and source sampling.
  - (ii) Chemical species do not react with one another, i.e., they add linearly.
  - (iii) All sources with a potential for significantly contributing to the receptor have been identified and have had their emissions characterised.
  - (iv) The number of sources or source categories is less than the number of species.
  - (v) The source compositions are linearly independent of each other.
  - (vi) Measurement uncertainties are random, uncorrelated, and normally distributed.

Applicability of the CMB Model

In the recommendations for validation of the model mention was made of the determination of whether the model is applicable to the apportionment task at hand. The applicability of this particular model is determined along the following lines:

- A sufficient number of samples have been taken in accordance with the guidelines of the study (eg. every sixth day for 24 hours).
- Minimal concentration analyses on samples are: Al, Si, S, Cl, K, Ca, Ti, V, Mn, Fe, Ni, Cu, Zn, Br and Pb. The inclusion of Cr, As, and Se; elements; cations; anions; and elements and organic carbon are desirable too. The analyses must be such that the concentrations of the majority of the species should be greater than the detection limit and the variability of the filter blank. The uncertainties of the measured concentrations should be known or estimated.
- The potential sources can be identified and grouped into categories that are unique with respect to their chemical makeups. These groups should be sufficiently different so as to be discernable by the model.
- The compositions of the source profiles are representative of how the source is perceived at the receptor. This implies that changes in the source composition between source and receptor are accommodated to make the model physically meaningful.
- The number of types of sources must be less than the number of chemical species measured.

Model setup

When setting up the model it will be necessary to choose the fitting species and source profiles. The choice of these may vary from sample to sample depending on specific emissions and on meterological conditions. For example a factory could be running a different fuel in their boilers. Meterological conditions could effect the choice of sources for a fit an example of this would be when the prevailing wind makes it impossible for a certain source to be 'seen' at the receptor site. There are EPA documents that give guidelines on data quality(6,15).

An important aspect of the accuracy of the model is the accuracy of the inputs to the data. Here it is recommended that strict quality assurance methods be applied. The accuracy of data uncertainties in particular will have a large influence on the model as the model is weighted towards those values that have a small uncertainty.

For ambient samples the uncertainty is mainly represented by the uncertainty in the analytical measurements and the uncertainties represented by the sampling flowrate. There are guidelines on how to input data and their uncertainties in the '*EPA Protocol for Applying and Validating the CMB Model*'(6,15). It is important that uncertainties be assigned otherwise the model could give undue weight to a particular measurement.

When running the model the choice of fitting sources must be done carefully. Based on the ambient conditions a source may or may not affect the receptor. An example of this could be if the source is downwind of the receptor. It is also suggested in the validation protocol that sources can be eliminated if it is found that; based on emission rates, stack height, microscopy, distance from receptor etc.; the source contributes <5% say, then it should be left out of the fit. Also to be eliminated are those sources that are not emitting at the time of sampling. Once again it is important that the uncertainties of the source profile measurements be estimated as accurately as possible. A useful guide for these uncertainties is that the lower limit of the uncertainty is the analytical uncertainty while an upper limit can be obtained when it is seen that the sum of all fractions of elements in a source profile can not exceed 1.

APPENDIX H: VISIBILITY APPORTIONMENT

The Brown Haze Study focused on the visibility degradation effects of the haze. Visibility(V) or visual range of an observer is linked to the transmission of light through the atmosphere by an extinction coefficient (b_{ext}). This relationship is given by the Koschmieder equation as(27):

$$V = -\ln(C_{min})/b_{ext} \quad \text{(2)}$$

where C_{min} is the minimum perceptible contrast between two objects, such as a mountain and the horizon. This is usually taken as 2%(25) making (2):

$$V = 3.912/b_{ext} \quad \text{(2a)}$$

Light extinction (represented by b_{ext}) is made up of the following independent components:(35)

- Scattering by gases (Rayleigh Scattering) which is a constant value for a given temperature and pressure. Atmospheric gas molecules divert light from a sight path.
- Gases absorb light and transform it into molecular energy. Nitrogen dioxide concentration is associated with light absorption by gases because absorption by other gas molecules is negligible.
- Absorption of light by particles occurs when black or coloured particles transform light into heat. Absorption is linked to the concentration of elemental carbon in the atmosphere.
- Particles scatter light in a similar way to gases. Scattering is a function of the wavelength of light, particle size and the index of refraction for the particles. Particles of 0.5μm in diameter are the most efficient at scattering light.

Therefore a basic model for the extinction coefficient is as follows:

$$b_{ext} = b_{sg} + b_{ag} + b_{sp} + b_{ap} \quad \text{(3)}$$

where s and a refer to scattering and absorption respectively, and g and p indicate contributions of gases or particles. A number of studies(25,26,27) have shown that different chemical species have differing effects on visibility degradation. These visibility effects are split amongst six main groups which are:

- fine ammonium sulphate (S)
- fine ammonium nitrate (N)
- fine organic carbon (C_{ao})
- elemental carbon (C_{ae})
- remainder of fine particles (R)
- gaseous NO_2

Groblicki et al (1981)$^{(27)}$ incorporated the effects of these visibility affecting groups into the basic model for the extinction coefficient (3) using multiple linear regression. This yielded the following equation:

$$\begin{aligned} b_{ext}(Mm^{-1}) = {} & [6.6S + 2.8N + 4.4 \times 1.2 \times C_{ao} + 3.2C_{aef} + 1.7R - 17] \\ & + (1.73S)/(1-\mu) + (1.47N)/(1-\mu) + 12.5C_{aef} + 3.8C_{aec} \\ & + 0.33\ NO_2 \ldots\ldots (4) \end{aligned}$$

where: μ= relative humidity(RH) /100
the term in [...] represents b_{sp} in (3)
the subscripts c and f represent the coarse and fine fractions.
S, N, C_{ao}, C_{ae} and R are in units of $\mu g/m^3$
NO_2 has units of ppbv
$Mm^{-1} = 10^{-6}$ m

Equation (4) is used to determine the contributions of the six main visibility affecting species to light extinction. The equations are:

$$f_S = [\ S(0.066 + 0.0173\ (1-\mu)^{-1} - 0.011\ b_{sp}^{-1})\ ] / b_{ext} \ldots\ldots (5)$$

$$f_N = [\ N(0.028 + 0.0147\ (1-\mu)^{-1} - 5 \times 10^{-3}\ b_{sp}^{-1})\ ] / b_{ext} \ldots\ldots (6)$$

$$f_{Cao} = [\ 1.2C_{ao}(0.044 - 7 \times 10^{-3}\ b_{sp}^{-1})\ ] / b_{ext} \ldots\ldots (7)$$

$$f_{Cae} = [\ C_{aef}\ (0.157 - 5 \times 10^{-3} b_{sp}^{-1}) + 0.037\ C_{ae}\ ] / b_{ext} \ldots\ldots (8)$$

$$f_R = [\ R\ (0.017 - 2.9 \times 10^{-3}\ b_{sp}^{-1})\ ] / b_{ext} \ldots\ldots (9)$$

$$f_{NO2} = [\ 3.3\ NO_2\ ] / b_{ext} \ldots\ldots (10)$$

where f is the fractional extinction due to a certain species.

Studies by Watson et al$^{(43)}$ and Richards et al$^{(44)}$ also proposed models for b_{ext} as a function of the six visibility reducing species and relative humidity. They are:

$$b_{ext}= [1.0+[1.0/(1-\mu)]]S + [1.8+[1.3/(1-\mu)]]N + R + [3.4+[0.6/(1-\mu)]]C_{ao} + 13.1C_{ae} + 0.21NO_2 + 13 \ldots\ldots (11)$$

$$b_{ext}= [0.384+0.792RH]S + [0.32+0.66RH]N + R + 9.1C_{ae} + [0.32+0.66RH]C_{ao} + 0.17NO_2^{*} + 9.9 \ldots\ldots (12)$$

Note: NO_2^{*} is in units of $\mu g/m^3$

The models mentioned above are Multiple Linear Regression Extinction Models and for the calculation of b_{sp} have the general form:

$$b_{sp} = \sum_{j=1}^{n} E_j C_j \ldots\ldots (13)$$

where E_j is the scattering efficiency of species j, n is the number of components and C_j is the measured concentration of the jth chemical component. The Ej's are "estimated using multiple linear regression when a time series of corresponding b_{sp} and C_j have been measured, with b_{sp} as the dependent variable and the C_j as independent variables$^{(28)}$."

Equation (4) for example represents a model derived from measurements of b_{sp} made in Denver. So the applicability of the model is assessed relative to the Denver airshed. Lowenthal et al(28) stated that this type of model has physical significance under restrictive conditions which are:

- all components contributing to scattering are included as independent variables
- the components are externally mixed
- sufficient samples have been taken to provide stable solutions
- scattering efficiency for each component is constant
- chemical concentrations are uncorrelated in time

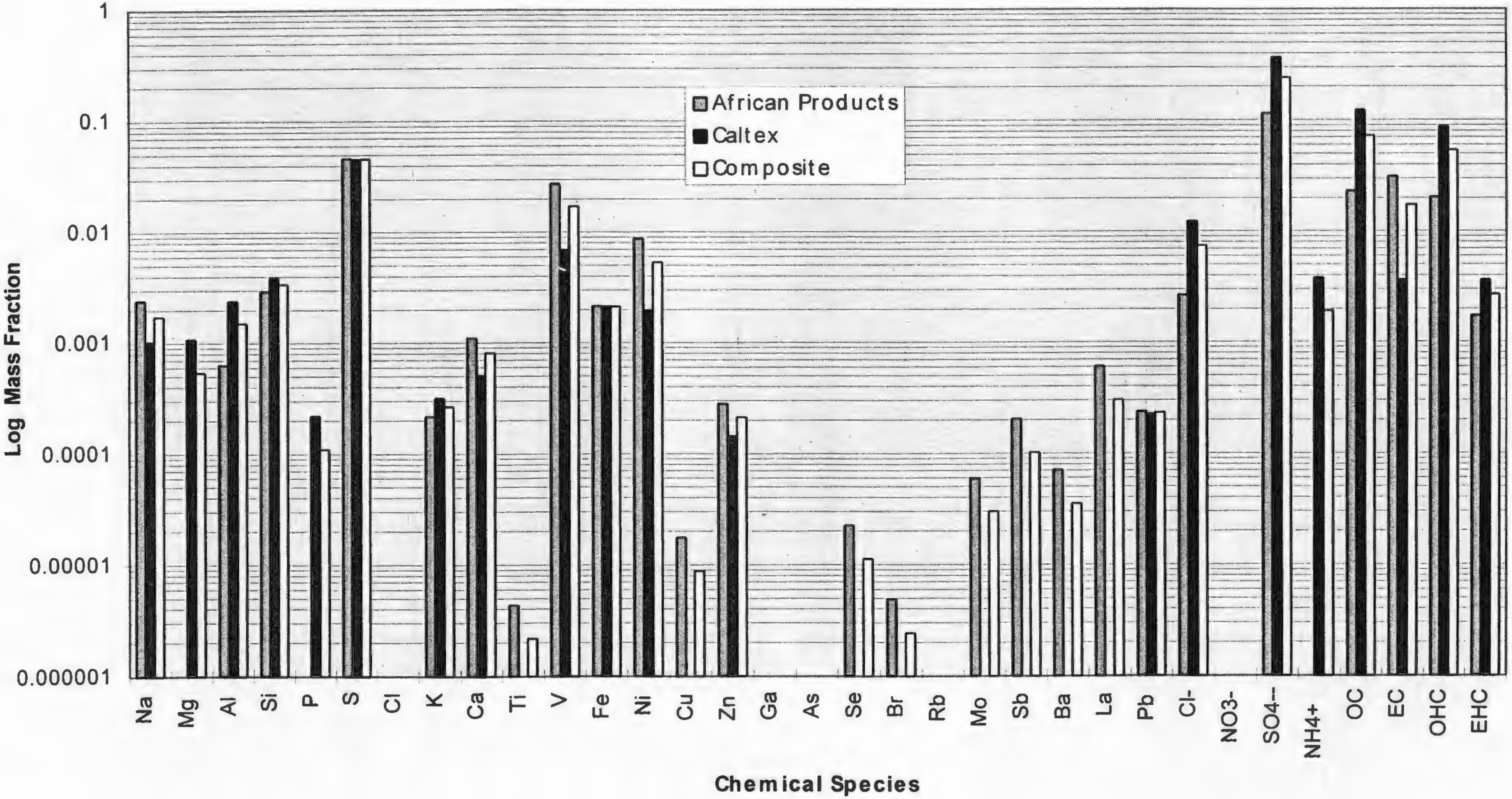
He went on to say that few studies have examined the effects of deviations from model assumptions on the calculated E_j's. The paper showed that the results from this model were similar to those obtained from a more complex model called the Elastic Light Scattering Interactive Efficiencies Model which gave results that deviated by 11-26% from measured values. However, the report did show that the E_j's calculated at different sites varied by up to a factor of 4.

APPENDIX I: SOURCE PROFILES

Source profile codes for modelling

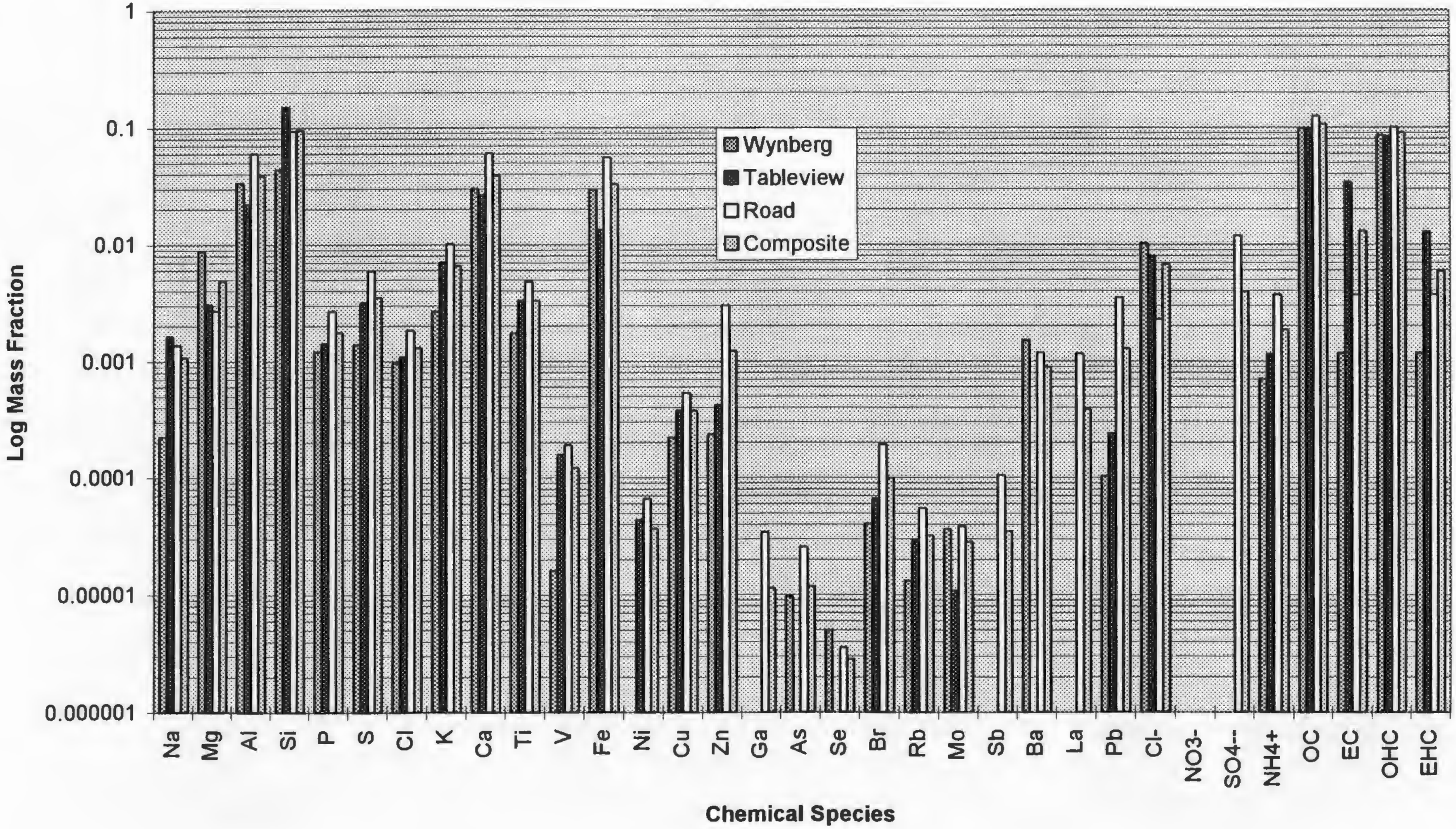
Modelling Code	Description	Profile Type
APOBL	African Products oil fired boiler	Primary
CALOB	Caltex oil fired boiler	Primary
WBDST	Crustal material from the Wynberg sampling site	Primary
TVDST	Crustal material from the Table View sampling site	Primary
RDUST	Crustal material from paved roads	Primary
CALCT	Catalyst material from Caltex	Primary
RKBRN	Burning of Rooikrantz wood	Primary
PJBRN	Burning of Port Jackson wood	Primary
TYBRN	Burning of Tyres	Primary
GRBRN	Grass Burning	Primary
DIVEH	Diesel vehicles	Primary
SO4	Sulphate	Secondary
NO3	Nitrate	Secondary
MARI1	Sea Salt	Primary
KYLAN	Ammonium Nitrate	Primary
SASFA	Fly Ash from coal burning	Primary
PCEMT	Portland Cement	Primary
CRUST	Crustal Material	Combined
WBURN	Wood Burning	Combined
CRUSTC	Crustal Material and Fly Ash	Combined
OHC	Organic High Temperature Carbon	Secondary
OLC	Organic Low Temperature Carbon	Secondary
EHC	Elemental high temperature carbon	Primary
VEH1	Leaded petrol vehicle (well maintained)	Primary
PETVH	Leaded petrol vehicle (poorly maintained)	Primary
VEH2	Leaded petrol vehicle (average)	Combined
DIES2	Diesel vehicle	Primary
COMPB	Oil fired boiler	Combined

Graph Source Profiles for African Products Oil Fired Boiler, Caltex Oil Fired Boiler and Composite Oil Fired Boiler Profile

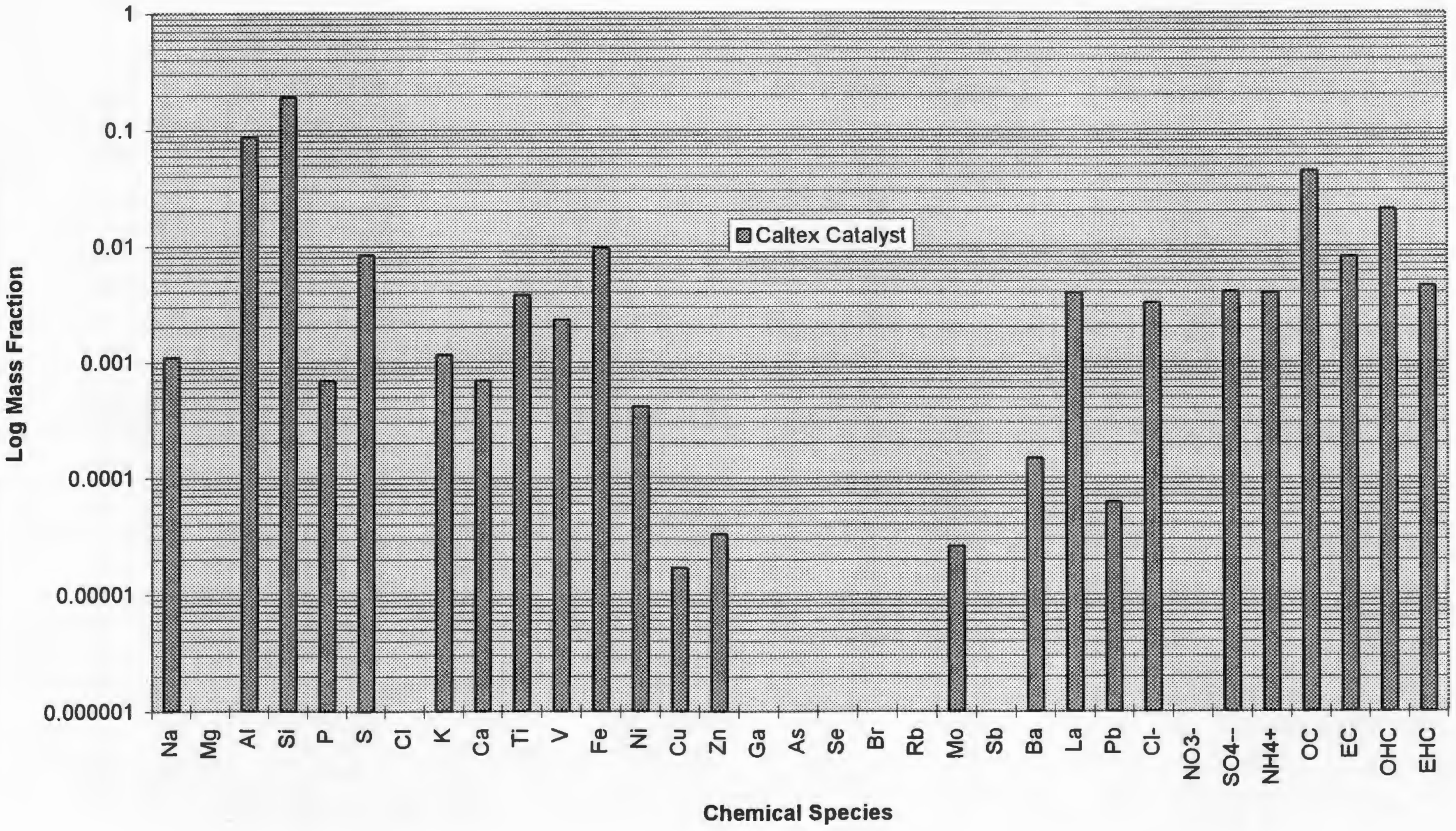


NAME	APOBL [%]	uncertainty [%]	CALOB [%]	uncertainty [%]	COMPB [%]	uncertainty [%]
Na	0.002425902	0.000515602	0.001031293	0.004235374	0.001728597	0.002133321
Mg	0	0.00059887	0.001079365	0.001702041	0.000539683	0.000902162
Al	0.000636419	0.000132464	0.002380499	0.000359184	0.001508459	0.000191416
Si	0.002919687	0.000112212	0.003858503	0.000304308	0.003389095	0.000162169
S	0.046532551	0.000159322	0.045350113	0.000377778	0.045941332	0.000205
Cl	0	0.000757584	0	0.000856236	0	0.000571636
K	0.000217036	2.77271E-05	0.00031746	0.000386395	0.000267248	0.000193694
Ca	0.00111256	4.19817E-05	0.000504762	0.00050839	0.000808661	0.00025506
V	0.027492568	0.000129335	0.006888435	0.000275283	0.017190502	0.000152076
Fe	0.002145763	2.42503E-05	0.002128798	6.48526E-05	0.00213728	3.46191E-05
Ni	0.008727771	3.71143E-05	0.001951474	4.94331E-05	0.005339622	3.09075E-05
Cu	1.75576E-05	4.39809E-05	0	9.20635E-05	8.77879E-06	5.10147E-05
Zn	0.000281356	8.17036E-06	0.000142857	3.35601E-05	0.000212107	1.72702E-05
Br	4.86745E-06	1.94698E-05	0	8.43537E-05	2.43372E-06	4.32858E-05
Pb	0.000238157	1.79922E-05	0.00022449	0.000268934	0.000231324	0.000134768
Cl^-	0.002659713	0.000265971	0.012244898	0.00122449	0.007452306	0.000626521
NO_3^-	0	0	0	0	0	0
SO_4^{2-}	0.114576271	0.011457627	0.364897959	0.036489796	0.239737115	0.019123169
Low Temp. Organic Carbon	0.002868318	0.002043977	0.035827664	0.012551794	0.019347991	0.006358564
Low Temp. Elemental Carbon	0.029378531	0.005514375	0	0.003393794	0.014689266	0.003237521
High Temp. Organic Carbon	0.020338983	0.003215993	0.08707483	0.015419501	0.053706906	0.007875653
High Temp. Elemental Carbon	0.001738375	0.000434594	0.003628118	0.001814059	0.002683246	0.000932695

Graph of Crustal Material Source Profiles



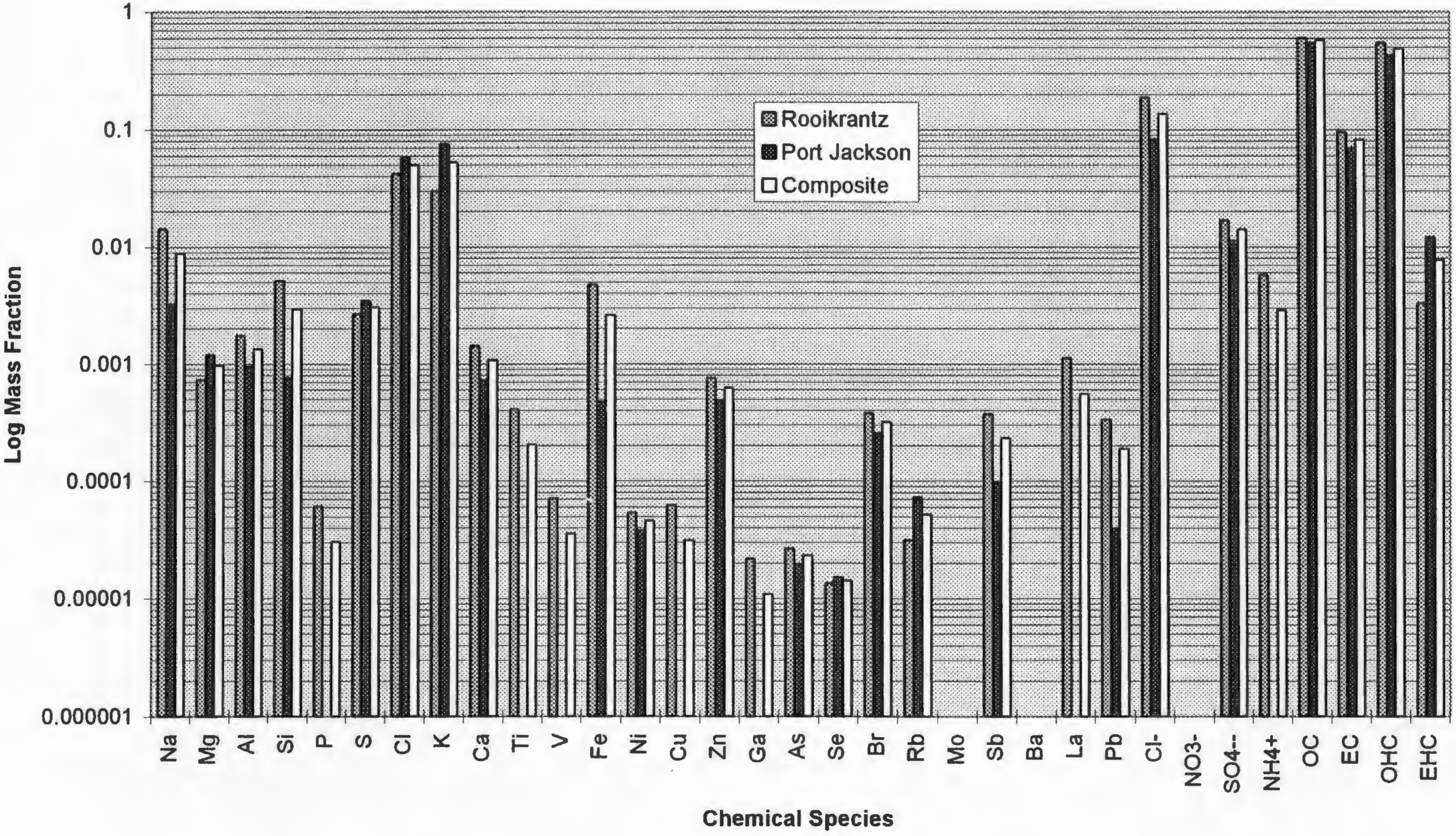
NAME	WBDST [%]	uncertainty [%]	TVDST [%]	uncertainty [%]	RDUST [%]	uncertainty [%]	CRUST [%]	uncertainty [%]
Na	0.000223324	0.00303207	0.001625552	0.003852366	0.001355626	0.002652592	0.001068167	0.001858028
Mg	0.008717201	0.000727697	0.003060568	0.000676972	0.002676865	0.000481669	0.004818211	0.000368154
Al	0.033594169	0.000630612	0.022159306	0.000633438	0.059743489	0.000539697	0.038498988	0.00034804
Si	0.043538192	0.000444606	0.148925237	0.000824921	0.092811252	0.000426549	0.09509156	0.000343206
S	0.001374344	8.86297E-05	0.003162461	0.000121136	0.005932238	0.000138432	0.003489681	6.80625E-05
Cl	0.000958601	0.00013586	0.001085489	0.000150158	0.001832364	0.000145133	0.001292151	8.30454E-05
K	0.00265277	0.000143149	0.007013249	0.000188013	0.01009823	0.000182174	0.006588083	9.94584E-05
Ca	0.029927988	0.000278134	0.026473502	0.000279495	0.060213906	0.000251327	0.038871799	0.000155864
V	1.6035E-05	0.000468513	0.000157729	0.000516088	0.000190265	0.000388116	0.000121343	0.000265934
Fe	0.029436443	0.000154227	0.013426183	0.000110095	0.055383186	0.000137927	0.032748604	7.81243E-05
Ni	0	5.59767E-05	4.35331E-05	6.11987E-05	6.61188E-05	1.09987E-05	3.65507E-05	2.7888E-05
Cu	0.000219242	2.12828E-05	0.000376025	2.42902E-05	0.000531479	1.30215E-05	0.000375582	1.16071E-05
Zn	0.000233528	2.21574E-05	0.000415457	2.52366E-05	0.002998609	2.40202E-05	0.001215865	1.37631E-05
Br	4.05248E-05	5.36443E-05	6.62461E-05	2.01893E-05	0.000191656	1.45386E-05	9.94757E-05	1.97109E-05
Pb	0.00010379	0.000162391	0.000239432	6.15142E-05	0.003490139	4.94311E-05	0.001277787	6.01832E-05
Cl^-	0.010145773	0.001014577	0.007949527	0.000794953	0.002275601	0.00022756	0.0067903	0.000436285
NO_3^-	0	0	0	0	0	0	0	0
SO_4^{2-}	0	0	0	0	0.011795196	0.00117952	0.003931732	0.000393173
Low Temp. Organic Carbon	0.011953353	0.005288151	0.013880126	0.006676975	0.024652339	0.003031499	0.016828606	0.002653228
Low Temp. Elemental Carbon	0	0.002181724	0.021451104	0.006197755	0	0.00099545	0.007150368	0.002215175
High Temp. Organic Carbon	0.085714286	0.012536443	0.083911672	0.012618297	0.100126422	0.012010114	0.08991746	0.007154071
High Temp. Elemental Carbon	0.001166181	0.001166181	0.012618297	0.002523659	0.003666245	0.000758534	0.005816908	0.000960567



Graph of Caltex Catalyst Dust Source Profile

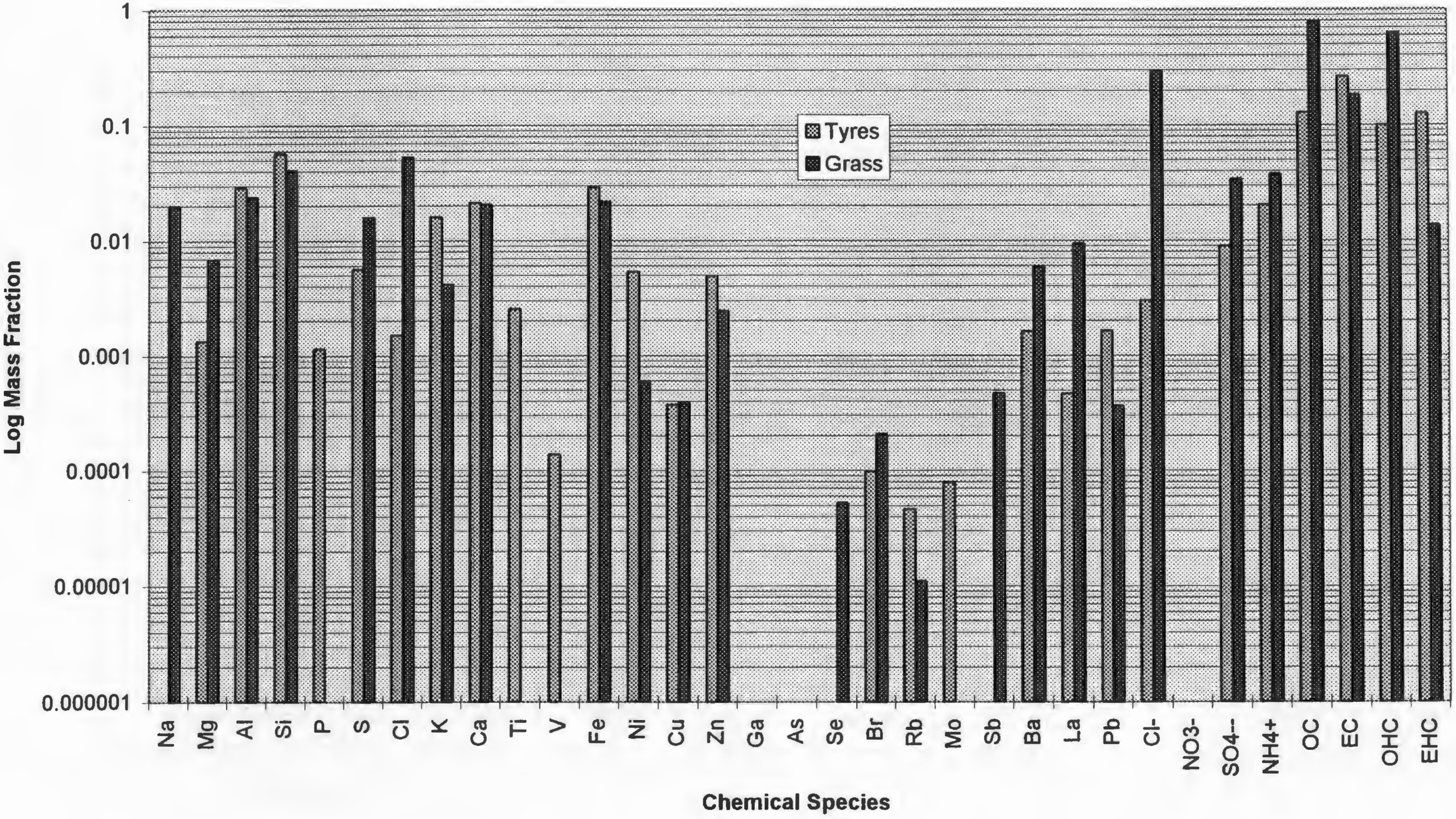
NAME	CALCT [%]	uncertainty [%]
Na	0.001088967	0.001733315
Mg	0	0.000959383
Al	0.087414278	0.000427961
Si	0.19046874	0.000383991
S	0.008367496	5.86263E-05
Cl	0	0.000160195
K	0.001148675	3.0503E-05
Ca	0.000689129	2.86101E-05
V	0.002301839	9.31855E-05
Fe	0.009508437	3.7642E-05
Ni	0.000412006	7.35533E-06
Cu	1.69281E-05	4.00216E-06
Zn	3.32071E-05	4.16441E-06
Br	5.40833E-07	1.1033E-05
Pb	6.19794E-05	1.18442E-05
Cl^-	0.003228772	0.000322877
NO_3^-	0	0
SO_4^{2-}	0.004023797	0.00040238
Low Temp. Organic Carbon	0.023309897	0.00327684
Low Temp. Elemental Carbon	0.003515414	0.001296872
High Temp. Organic Carbon	0.02055165	0.002758248
High Temp. Elemental Carbon	0.004488913	0.000811249

Graph of Wood Burning Source Profiles



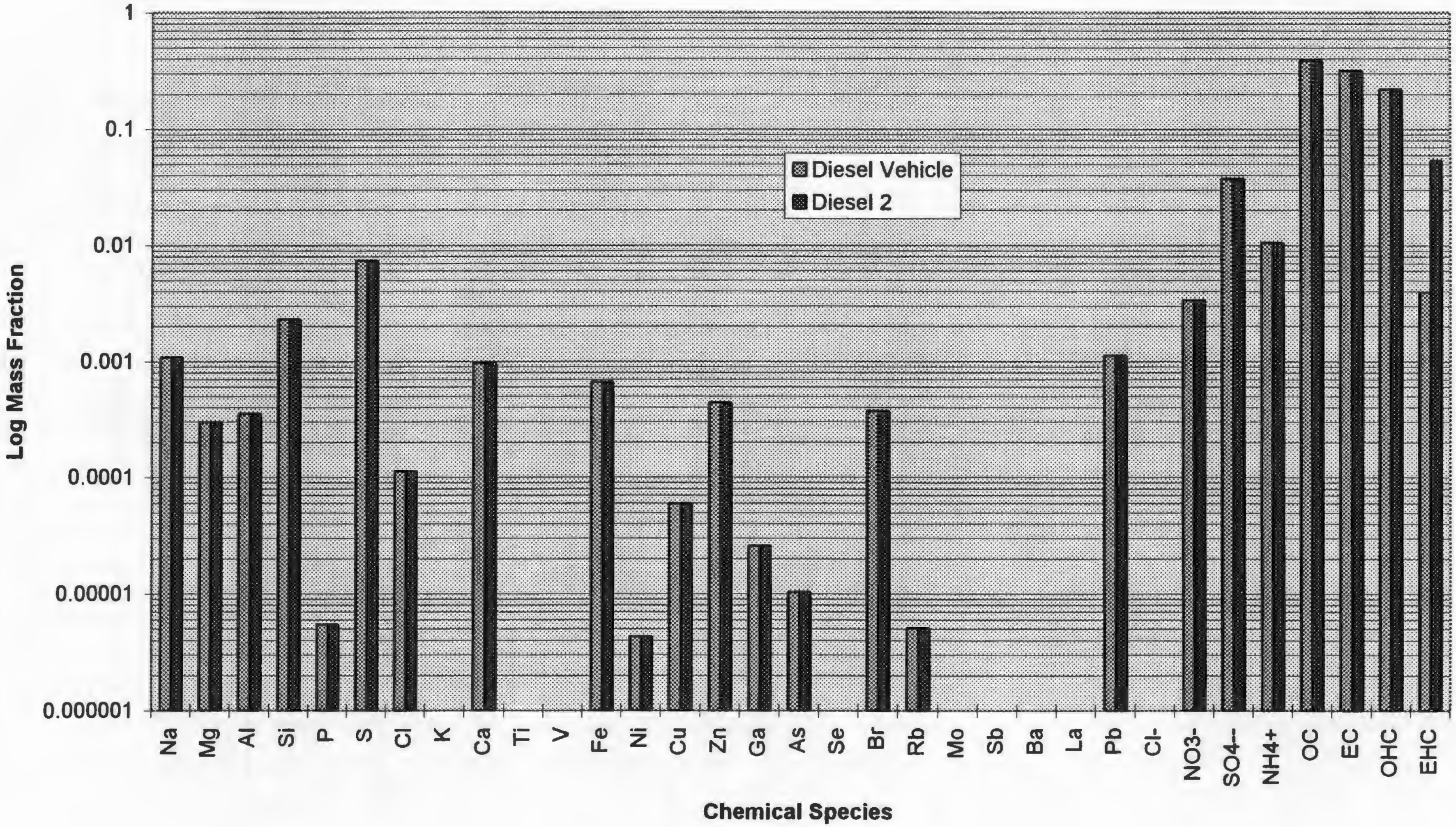
NAME	**RKBRN [%]**	**uncertainty [%]**	**PJBRN [%]**	**uncertainty [%]**	**WBURN [%]**	**uncertainty [%]**
Na	0.014286269	0.001351343	0.003234522	0.004239024	0.008760395	0.002224604
Mg	0.000728657	0.00131791	0.001190619	0.00162364	0.000959638	0.001045597
Al	0.001738209	0.000268358	0.000939212	0.000301313	0.00133871	0.000201746
Si	0.005109851	0.000214328	0.000757598	0.000215385	0.002933725	0.000151927
S	0.002662687	0.000153731	0.00346454	0.000193246	0.003063613	0.000123468
Cl	0.041805373	0.000507164	0.058426642	0.000701689	0.050116007	0.000432892
K	0.02992597	0.000312537	0.075604503	0.000547467	0.052765236	0.000315198
Ca	0.001414627	0.0002	0.0007197	0.001239775	0.001067163	0.000627902
V	7.13433E-05	0.000453134	0	0.000570356	3.56716E-05	0.000364224
Fe	0.004727463	6.65672E-05	0.000474672	3.60225E-05	0.002601067	3.78444E-05
Ni	5.34328E-05	5.61194E-05	3.78987E-05	6.5666E-05	4.56658E-05	4.31897E-05
Cu	6.20896E-05	1.9403E-05	0	6.60413E-05	3.10448E-05	3.44163E-05
Zn	0.000753134	2.62687E-05	0.000488931	2.81426E-05	0.000621032	1.92487E-05
Br	0.000381194	2.1791E-05	0.000253659	2.47655E-05	0.000317426	1.64938E-05
Pb	0.000335224	5.64179E-05	3.93996E-05	0.0002	0.000187312	0.000103903
Cl^-	0.18680597	0.018680597	0.083076923	0.008307692	0.134941447	0.01022231
NO_3^-	0	0	0	0	0	0
SO_4^{2-}	0.016835821	0.001683582	0.011257036	0.001125704	0.014046428	0.001012627
Low Temp. Organic Carbon	0.056119403	0.035469671	0.120450281	0.010351305	0.088284842	0.018474625
Low Temp. Elemental Carbon	0.091641791	0.016843864	0.057410882	0.01246208	0.074526336	0.010476392
High Temp. Organic Carbon	0.545373134	0.06358209	0.424765478	0.049906191	0.485069306	0.040414447
High Temp. Elemental Carbon	0.003283582	0.00119403	0.012007505	0.002626642	0.007645543	0.00144265

Graph of Tyre and Grass Burning Profiles



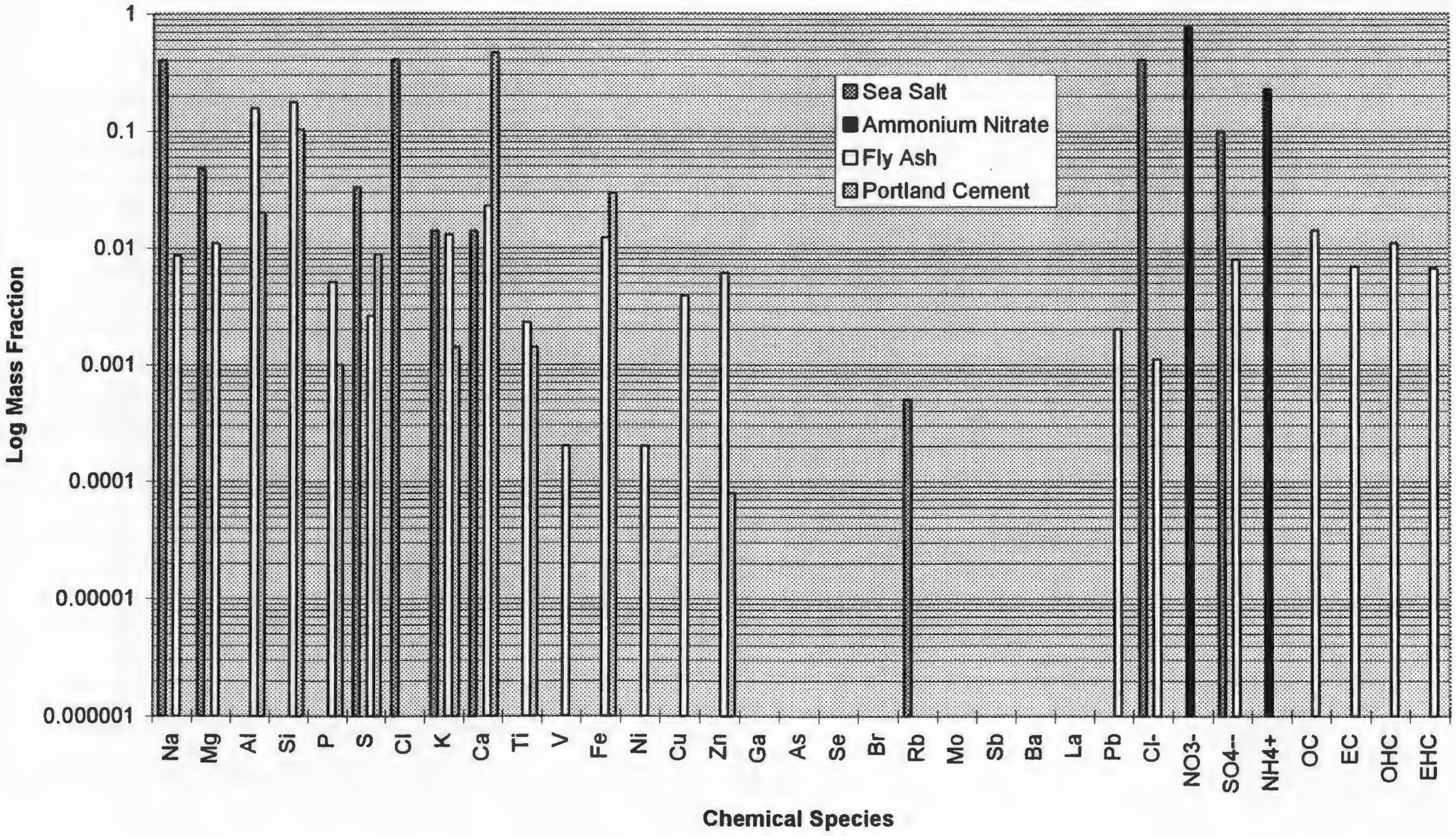
NAME	TYBRN [%]	uncertainty [%]	GRBRN [%]	uncertainty [%]
Na	0	0.002243899	0.019890678	0.003567797
Mg	0.001327188	0.000351592	0.006826271	0.001394915
Al	0.028718568	0.000394695	0.023782203	0.001024576
Si	0.056408886	0.000338329	0.040363559	0.000825424
S	0.005609682	0.000101724	0.01584322	0.000437288
Cl	0.001498806	0.000111008	0.05269661	0.000973729
K	0.015917241	0.00016008	0.004116102	0.000320339
Ca	0.021211008	0.000175597	0.020577119	0.000483051
V	0.000137931	0.000240716	0	0.00234322
Fe	0.029108488	0.000102785	0.021723729	0.000233898
Ni	0.005289655	3.64721E-05	0.000595763	6.10169E-05
Cu	0.000372016	1.49867E-05	0.000389831	5.9322E-05
Zn	0.004896419	3.06366E-05	0.002414407	7.79661E-05
Br	9.7878E-05	1.00796E-05	0.00020678	5.67797E-05
Pb	0.001630371	3.88594E-05	0.000363559	0.000507627
Cl^-	0.002984085	0.000298408	0.294152542	0.029415254
NO_3^-	0	0	0	0
SO_4^{2-}	0.008912467	0.000891247	0.033813559	0.003381356
Low Temp. Organic Carbon	0.028912467	0.001251191	0.156779661	0.012935879
Low Temp. Elemental Carbon	0.134880637	0.040758927	0.168644068	0.033289016
High Temp. Organic Carbon	0.099602122	0.012068966	0.621186441	0.075423729
High Temp. Elemental Carbon	0.126127321	0.022413793	0.013559322	0.004237288

Graph of Diesel Vehicle Source Profile



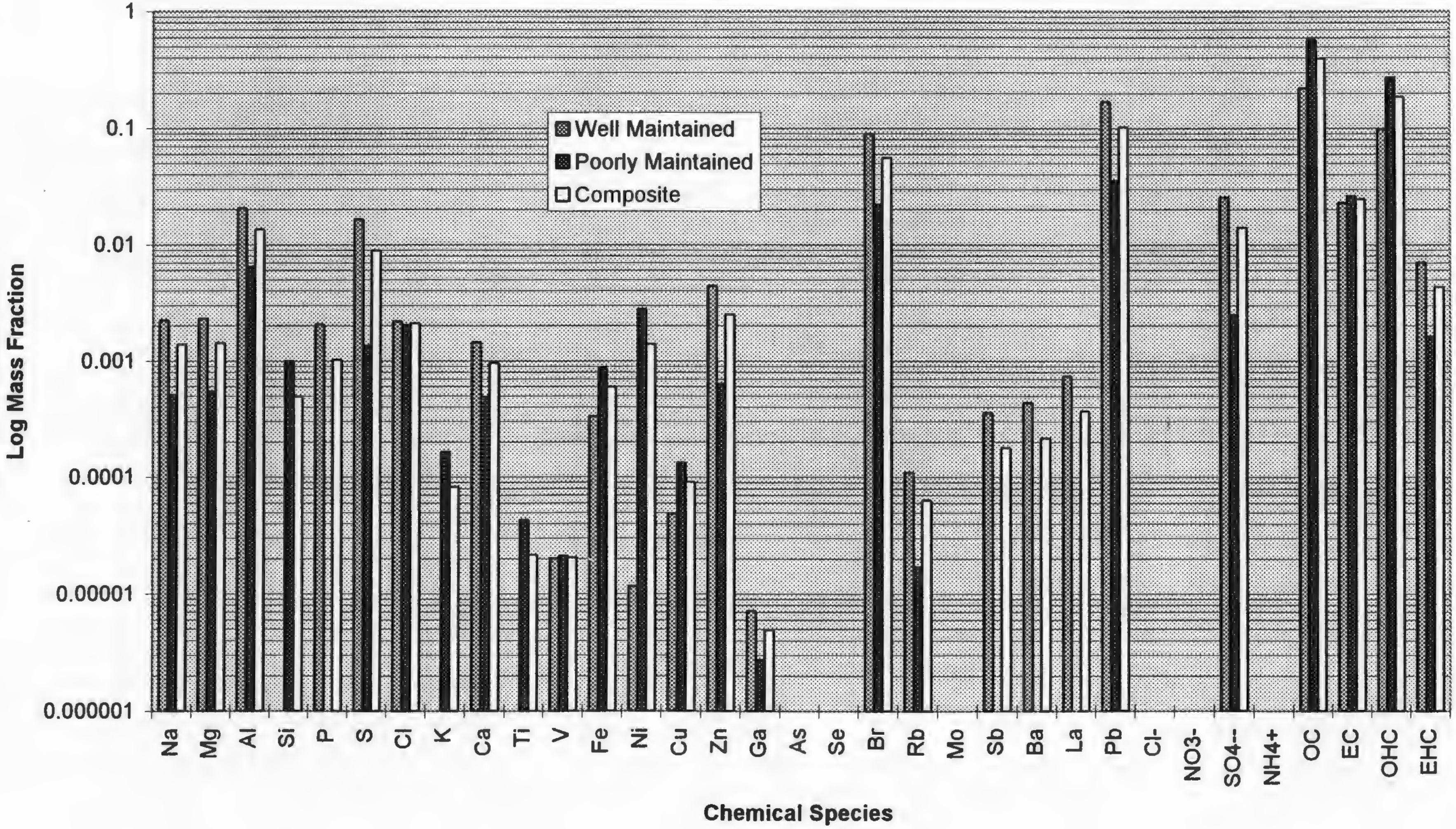
NAME	DIVEH [%]	uncertainty [%]	DIES2 [%]	uncertainty [%]
Na	0.001078516	0.001335742	0.001078516	0.001335742
Mg	0.000298047	0.000699023	0.000298047	0.000699023
Al	0.000353906	0.000399023	0.000353906	0.000399023
Si	0.002292383	0.000119922	0.002292383	0.000119922
S	0.007339453	0.000116406	0.007339453	0.000116406
Cl	0.0001125	0.000226758	0.0001125	0.000226758
K	0	0.000156055	0	0.000156055
Ca	0.000961328	7.89062E-05	0.000961328	7.89062E-05
V	0	0.000317969	0	0.000317969
Fe	0.000658594	2.46094E-05	0.000658594	2.46094E-05
Ni	4.29687E-06	3.59375E-05	4.29687E-06	3.59375E-05
Cu	5.95703E-05	1.30859E-05	5.95703E-05	1.30859E-05
Zn	0.000441211	1.67969E-05	0.000441211	1.67969E-05
Br	0.00037207	1.875E-05	0.00037207	1.875E-05
Pb	0.00112207	4.6875E-05	0.00112207	4.6875E-05
Cl^-	0	0	0	0
NO_3^-	0.003359375	0.000335937	0.003359375	0.000335937
SO_4^{2-}	0.037363281	0.003736328	0.037363281	0.003736328
Low Temp. Organic Carbon	0.16640625	0.025584447	0.16640625	0.025584447
Low Temp. Elemental Carbon	0.311523437	0.030076223	0.261523437	0.030076223
High Temp. Organic Carbon	0.219140625	0.025976562	0.219140625	0.025976562
High Temp. Elemental Carbon	0.00390625	0.001367187	0.05390625	0.001367187

Graph of Ammonium Nitrate, Portland Cement, Sea Salt and Fly Ash Source Profiles



NAME	MARI1 [%]	uncertainty [%]	KYLAN [%]	uncertainty [%]	SASFA [%]	uncertainty [%]	PCEMT [%]	uncertainty [%]
Na	0.4	0.04	0	0	0.0086	0.0002	0	0
Mg	0.048	0.009	0	0	0.0109	0.0002	0	0
Al	0	0	0	0	0.1563	0.0046	0.02	0
Si	0	0	0	0	0.1764	0.0021	0.102	0
S	0.033	0.013	0	0	0.0026	0.00016	0.0088	0
Cl	0.4	0.1	0	0	0	0.000160195	0	0
K	0.014	0.002	0	0	0.0129	0.0008	0.0014	0
Ca	0.014	0.002	0	0	0.0227	0.0021	0.461	0
V	0	0	0	0	0.0002	0.0001	0	0
Fe	0	0	0	0	0.0122	0.00013	0.0294	0
Ni	0	0	0	0	0.0002	0.00001	0	0
Cu	0	0	0	0	0.0039	0.00029	0	0
Zn	0	0	0	0	0.0061	0.00024	0.00008	0
Br	0	0.002	0	0	0	8.43537E-05	0	0
Pb	0	0	0	0	0.002	0.0009	0	0
Cl^-	0.4	0.1	0	0	0.0011	0.0002	0	0
NO_3^-	0	0	0.775	0	0	0	0	0
SO_4^{2-}	0.1	0.04	0	0	0.0079	0.0055	0	0
Low Temp. Organic Carbon	0	0	0	0	0.0031	0.001473092	0	0
Low Temp. Elemental Carbon	0	0	0	0	0.0003	0.001256981	0	0
High Temp. Organic Carbon	0	0	0	0	0.011	0.0005	0	0
High Temp. Elemental Carbon	0	0	0	0	0.0066	0.0002	0	0

Graph of petrol Vehicle Profiles



NAME	VEH1 [%]	uncertainty [%]	PETVH [%]	uncertainty [%]	VEH2 [%]	uncertainty [%]
Na	0.002239838	0.004645591	0.000510035	0.000961573	0.001374937	0.002372032
Mg	0.002306156	0.021777514	0.00054468	0.004560867	0.001425418	0.01112499
Al	0.020596149	0.00285334	0.006403631	0.000708775	0.01349989	0.001470026
Si	0	0.002135726	0.000989713	0.000162733	0.000494856	0.001070958
S	0.016441645	0.004810078	0.001350429	0.003018053	0.008896037	0.002839256
Cl	0.002171856	0.000714999	0.002025214	0.000153707	0.002098535	0.000365667
K	0	0.000234847	0.0001647	1.78517E-05	8.235E-05	0.000117762
Ca	0.001434039	0.000113145	0.000475946	2.34997E-05	0.000954992	5.77797E-05
V	1.99667E-05	0.000425244	2.09783E-05	8.17448E-05	2.04725E-05	0.000216515
Fe	0.000332303	2.70977E-05	0.000857791	1.17499E-05	0.000595047	1.47677E-05
Ni	1.16473E-05	5.15807E-05	0.002762632	1.60363E-05	0.00138714	2.7008E-05
Cu	4.8966E-05	5.46708E-05	0.000132879	6.40444E-06	9.09227E-05	2.75223E-05
Zn	0.004388163	4.15973E-05	0.000636006	7.41301E-06	0.002512084	2.11264E-05
Br	0.088554077	0.000447112	0.022060817	9.61674E-05	0.055307447	0.000228669
Pb	0.169173758	0.000435465	0.035386233	9.21836E-05	0.102279996	0.000222557
Cl^-	0	0	0	0	0	0
NO_3^-	0	0	0	0	0	0
SO_4^{2-}	0.025362491	0.002536249	0.002476046	0.000247605	0.013919269	0.001274153
Low Temp. Organic Carbon	0.1209	0.00425	0.294099849	0.042062235	0.207499924	0.020990305
Low Temp. Elemental Carbon	0.0159	0.0001	0.024609178	0.002526973	0.020254589	0.001251059
High Temp. Organic Carbon	0.0982	0.0056	0.27100353	0.031517902	0.184601765	0.016005766
High Temp. Elemental Carbon	0.007	0.0005	0.001613717	0.000453858	0.004306858	0.000337634

APPENDIX J: CHEMICAL MASS BALANCE MODEL PERFORMANCE MEASURES

Source Contribution Estimate

The source contribution estimate (SCE) shows the contribution in µg/m^3 of each source modelled to the mass on the ambient filter. Negative values of the SCE are not meaningful. Values of the SCE that are less than its standard error show that that calculating a source contribution is beyond the sensitivity of the model. The T-statistic value is the ratio of the SCE to the standard error and a value below 2 also shows that the calculation of a source contribution is outside the sensitivity of the model.

Chi Square

This value is calculated from the weighted sum of squares of the differences between the calculated and measured fitting species. The weighting is inversely proportional to the squares of the precisions in the source profiles and ambient data for each species. A value less than 1 indicates a very good fit while values greater than 4 indicate that one or more species concentrations are not well explained by the source contribution estimates.

R Square

This value is the fraction of the variance in the measured concentration data which is explained by the variance in the calculated species concentrations. It is determined by linear regression of measured versus model-calculated values for the fitting species acceptable values for this diagnostic are between 0.8 and 1. Values below 0.8 suggest that the SCE do not explain the ambient data well.

Percent Mass

The percent mass is the ratio of the sum of the model-calculated SCE to the measured mass concentration on the ambient sample. This value should be 100⌖20 %.

Similarity/Uncertainty Cluster Display

Similarity/uncertainty clusters are groups of sources that the model cannot separate either because their chemical profiles are too similar or their uncertainties are high. The sum of the sources that are collinear is displayed along with their uncertainty. The following steps are recommended if two or more source profiles are collinear:

- improve source profiles by measuring additional species,
- reduce the uncertainties in the source profiles of the cluster sources to values that are realistically achievable,

- use an estimate of the sum of the source categories that are collinear as a source profile,
- combine the profiles of the cluster sources into a single composite profile. This will then represent the combined impact of the sources, and
- delete species that are causing similarity in the source profiles from the fit.

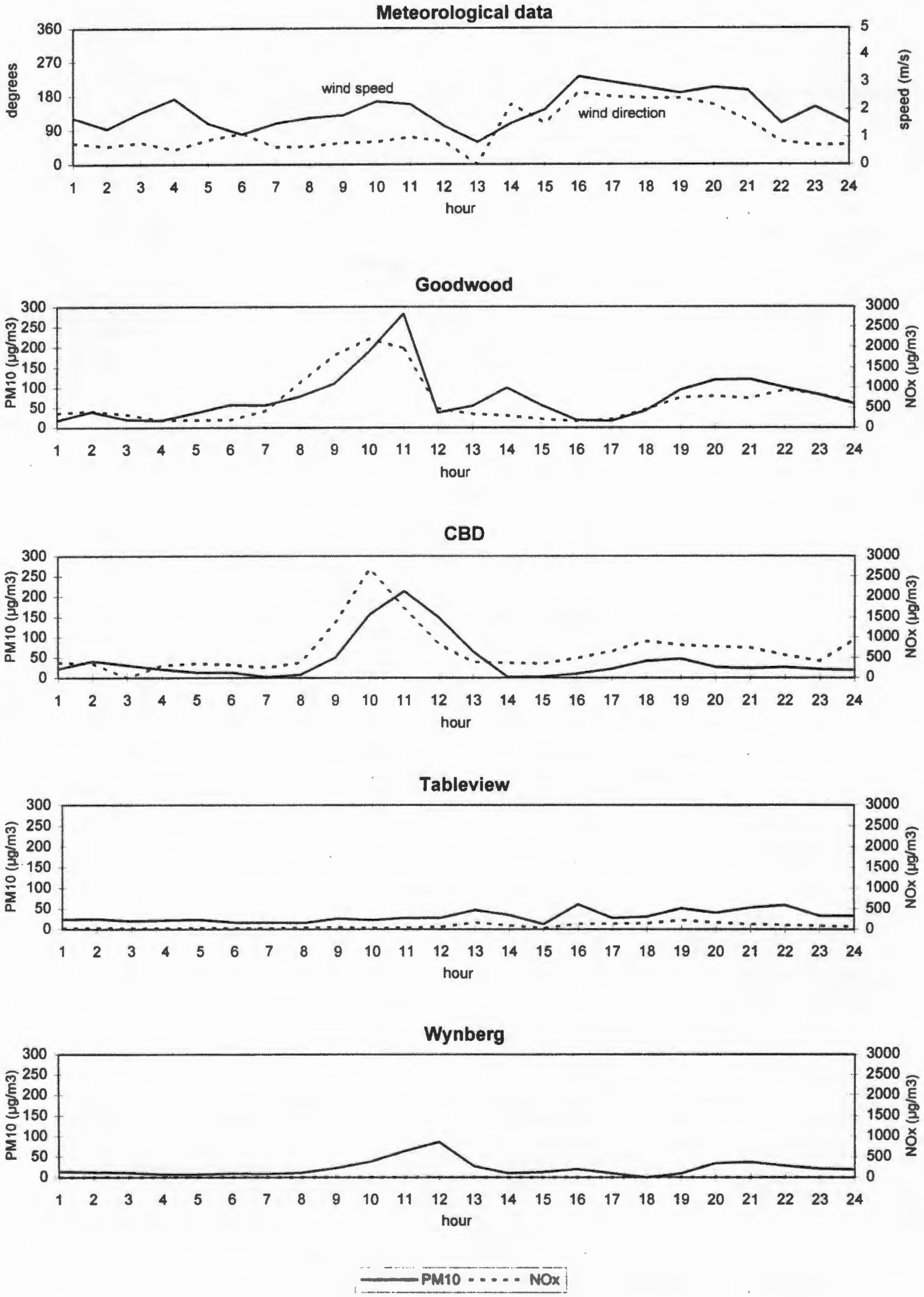
R/U Ratio

These values are shown in the species concentration display and they represent the number of uncertainty intervals by which the calculated and measured concentrations differ for each chemical species (the residual). If the absolute value of the R/U is much greater than 2 then the residual is significant. A positive value means that either one or more source profiles is contributing too much or the ambient concentration of the particular species is underestimated. A negative value means that there is not contribution by the source profiles to a particular species or the ambient concentration for that species is overestimated. High R/U causes high chi squared and thus reducing high R/U reduces the Chi Squared and thus improves the fit.

APPENDIX K: AMBIENT METEROLOGICAL AND GASEOUS DATA

Please note that each data point represents the average reading for the last hour.

14/07/1995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90
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4
3
2
1
0
wind speed
wind direction
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
Goodwood
PM10 (µg/m3)
300 250 200 150 100 50 0
NOx (µg/m3)
3000 2500 2000 1500 1000 500 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
CBD
PM10 (µg/m3)
300 250 200 150 100 50 0
NOx (µg/m3)
3000 2500 2000 1500 1000 500 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
Tableview
PM10 (µg/m3)
300 250 200 150 100 50 0
NOx (µg/m3)
3000 2500 2000 1500 1000 500 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour
Wynberg
PM10 (µg/m3)
300 250 200 150 100 50 0
NOx (µg/m3)
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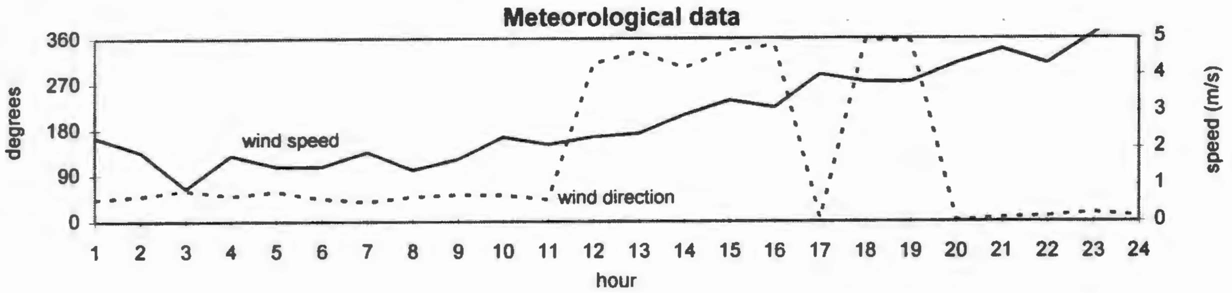
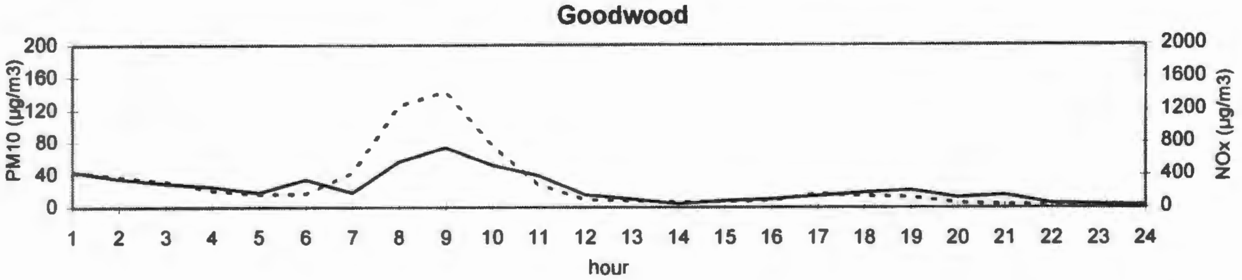
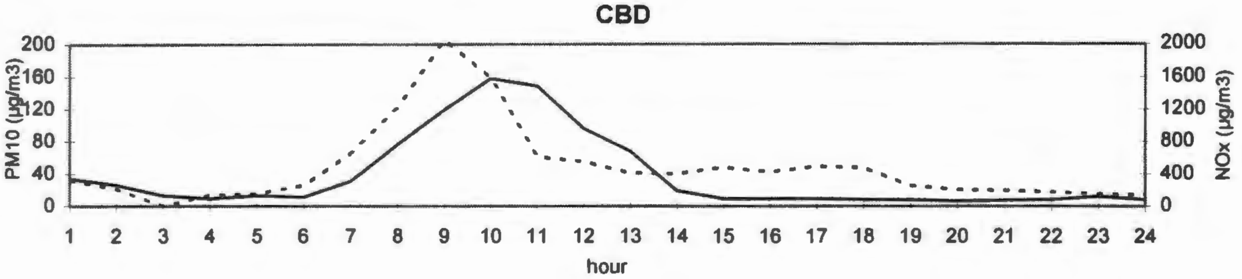
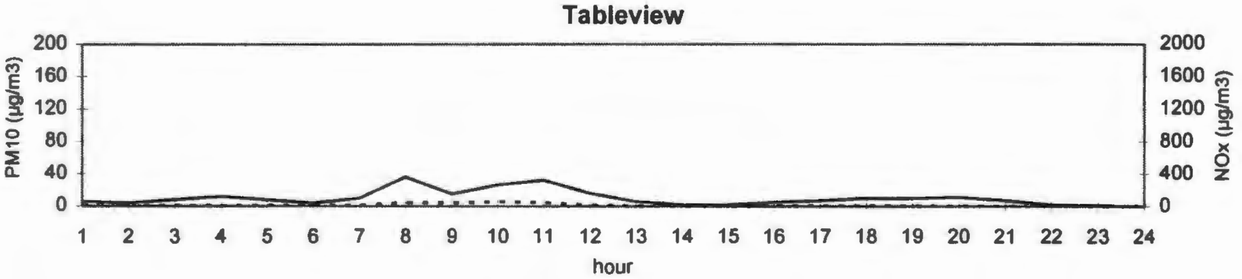
hour
PM10
NOx

25/07/1995


Meteorological data


Goodwood


CBD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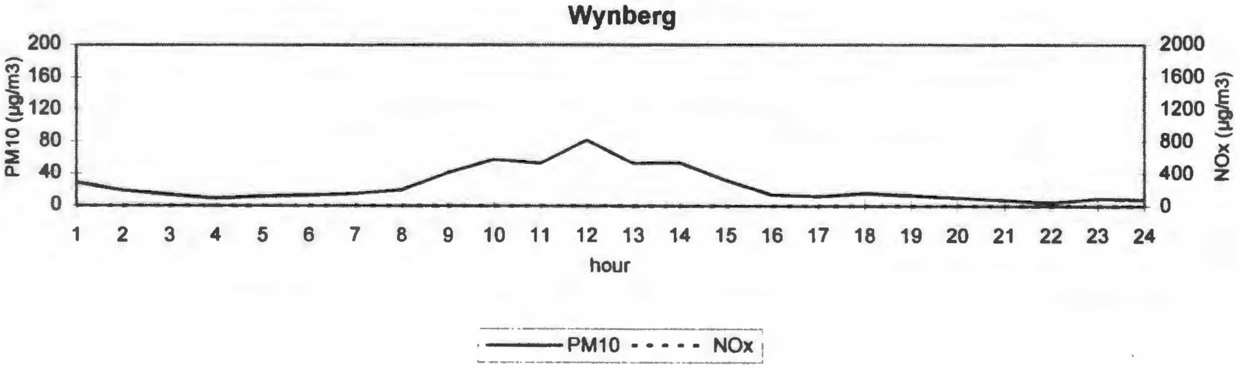
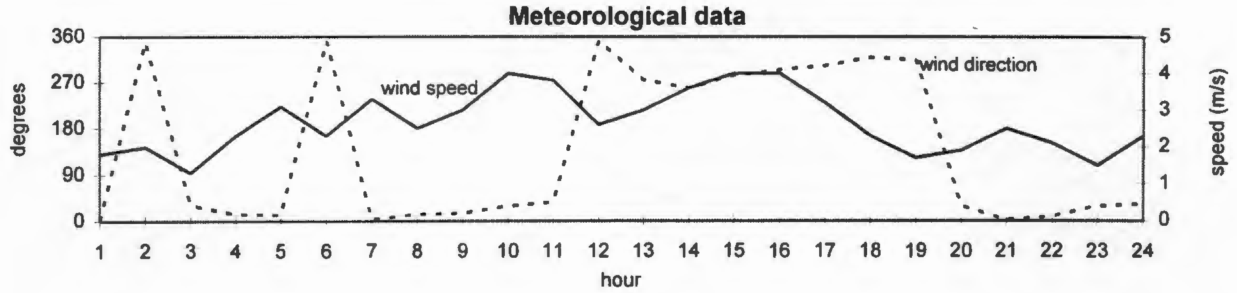

Wynberg

18/08/1995


Meteorological data
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90
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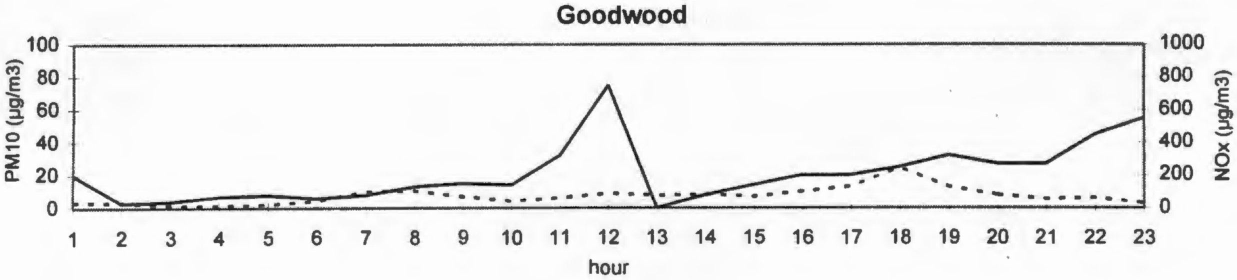
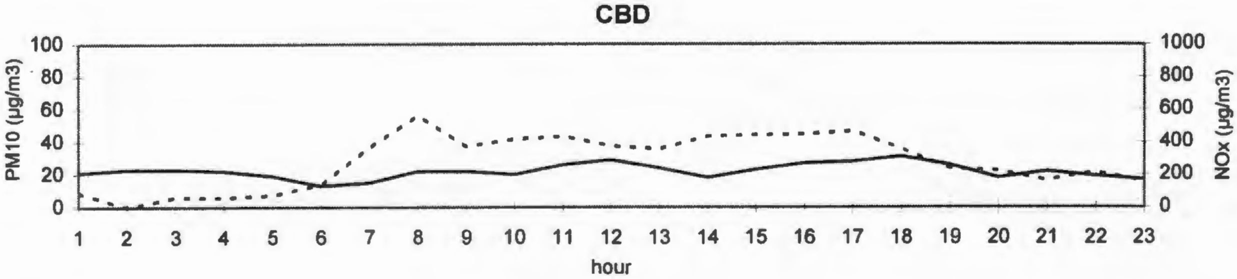
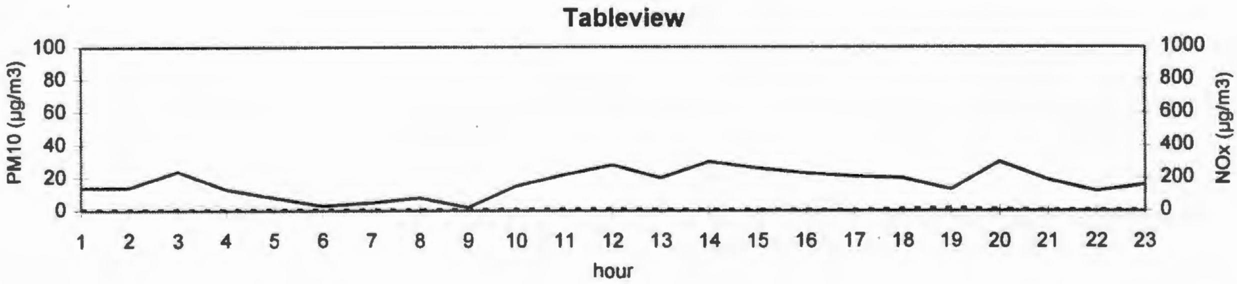
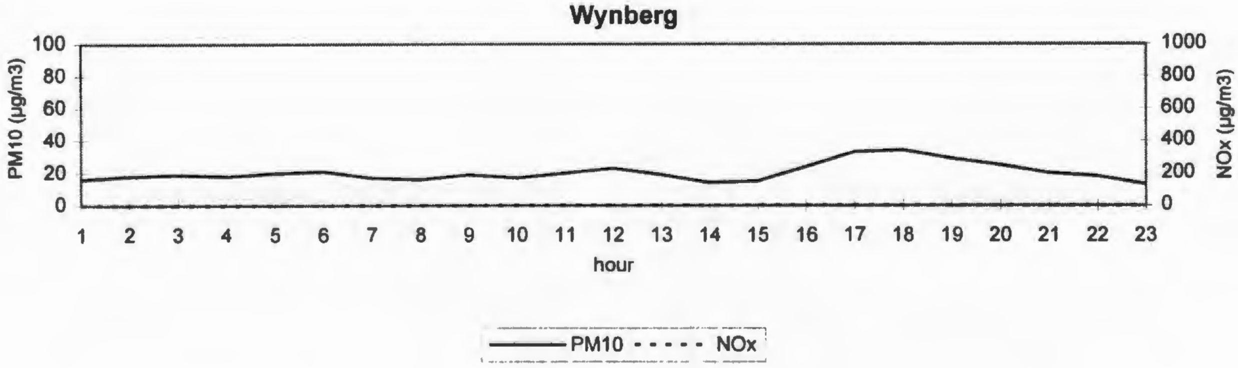
4
3
2
1
0
wind speed
wind direction
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
hour

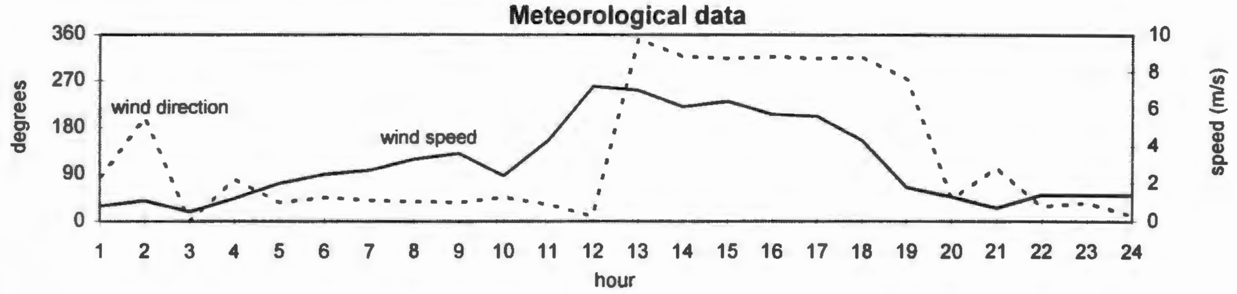

Goodwood
PM10 (µg/m3)
100
80
60
40
20
0
NOx (µg/m3)
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
hour

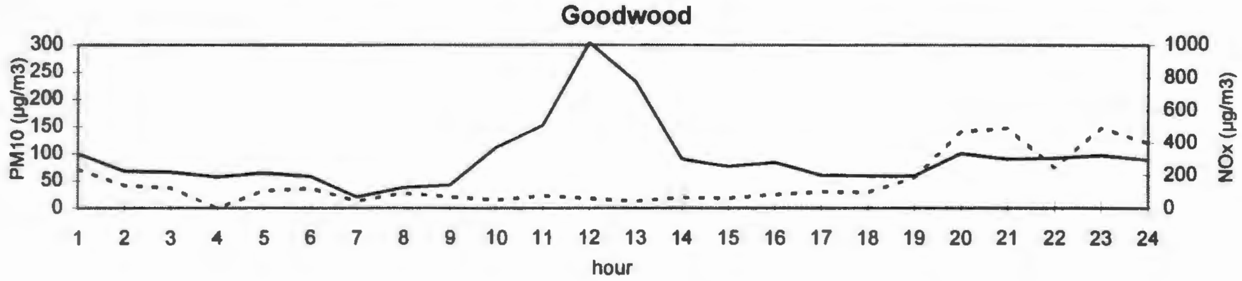

CBD
PM10 (µg/m3)
100
80
60
40
20
0
NOx (µg/m3)
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
hour

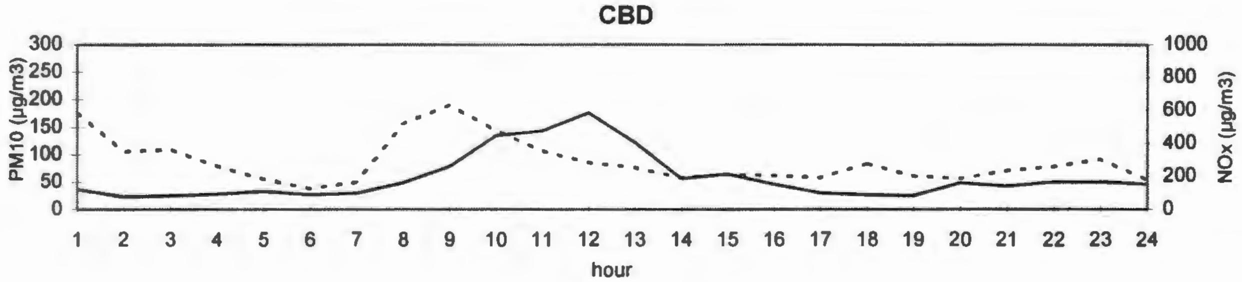

Tableview
PM10 (µg/m3)
100
80
60
40
20
0
NOx (µg/m3)
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
hour

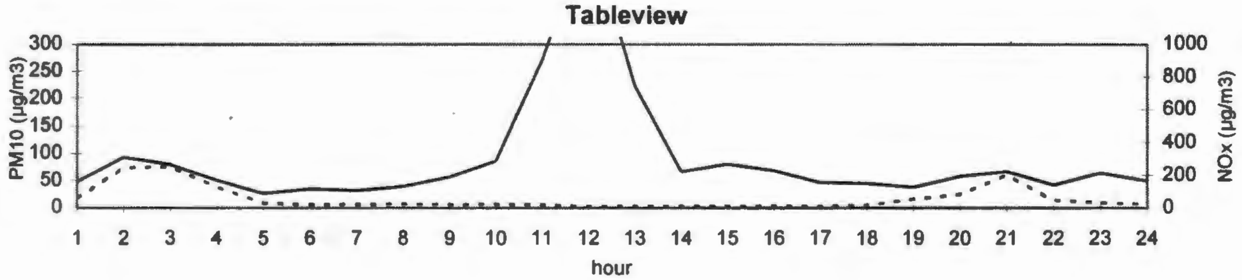

Wynberg
PM10 (µg/m3)
100
80
60
40
20
0
NOx (µg/m3)
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
hour
PM10
NOx

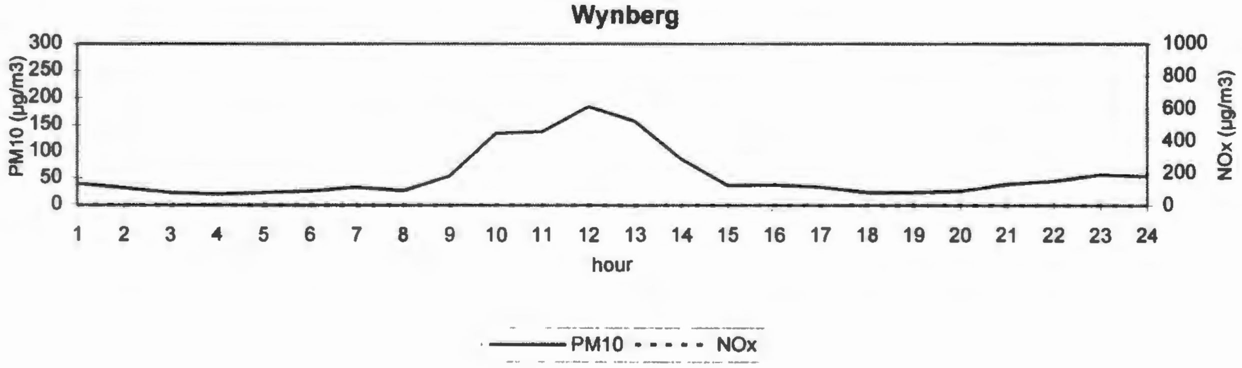
30/04/1996


Meteorological data

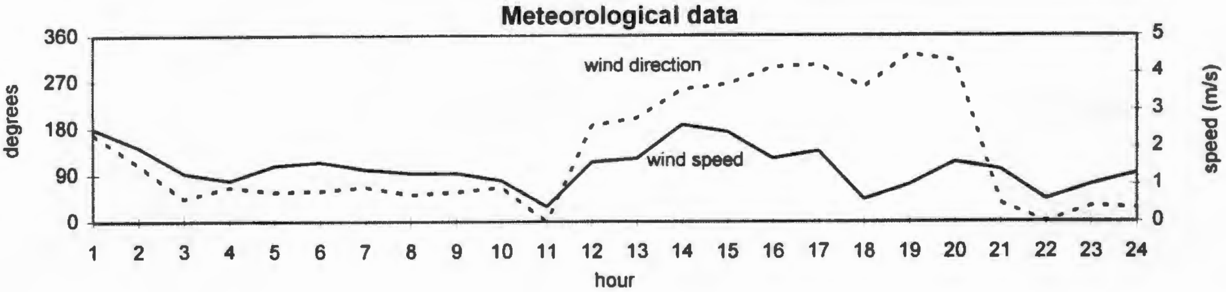

Goodwood


CBD

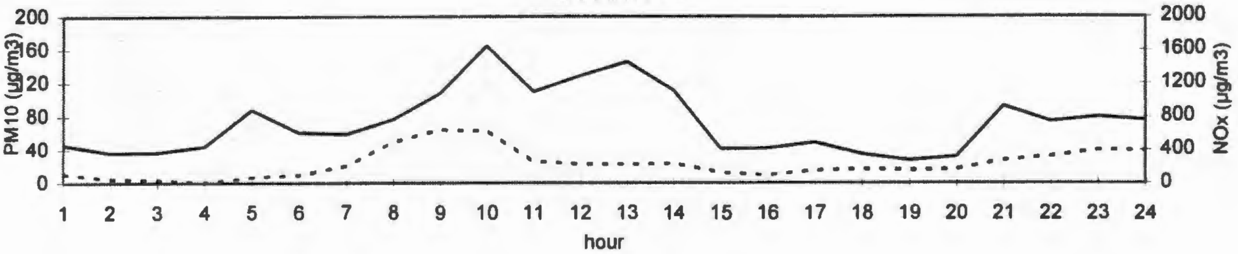

Tableview


Wynberg

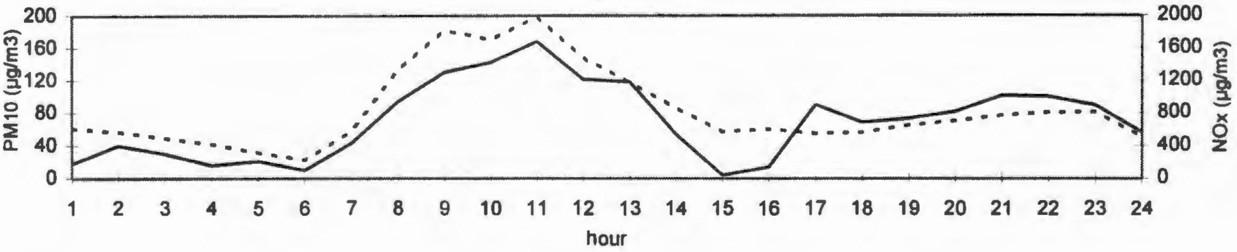
08/05/1996



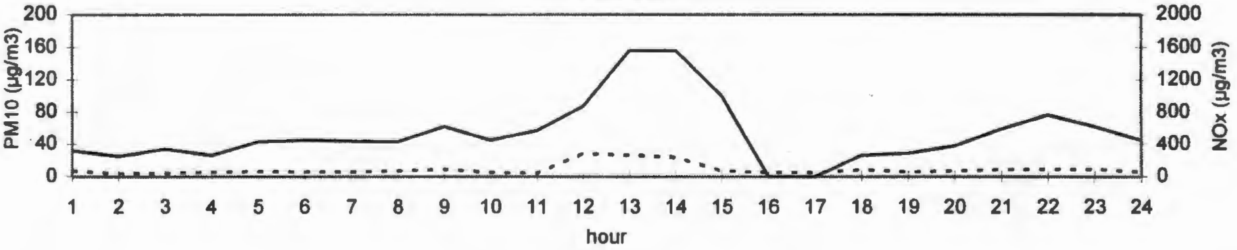
Meteorological data



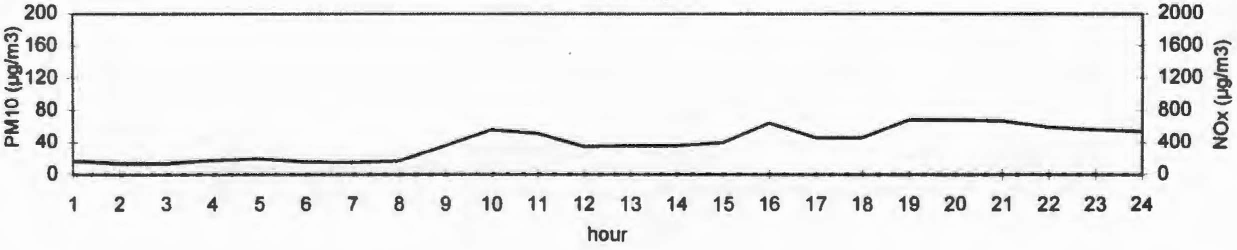
Goodwood



CBD



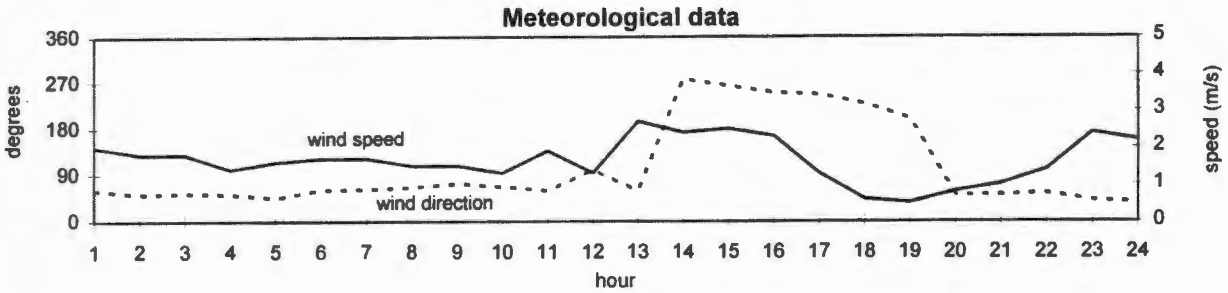
Tableview

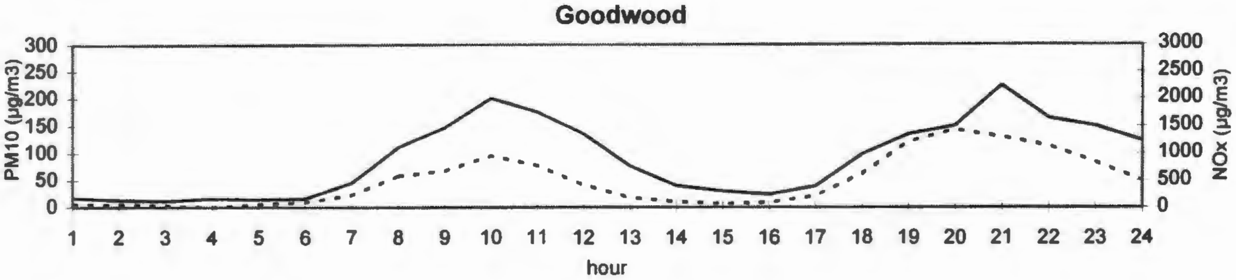


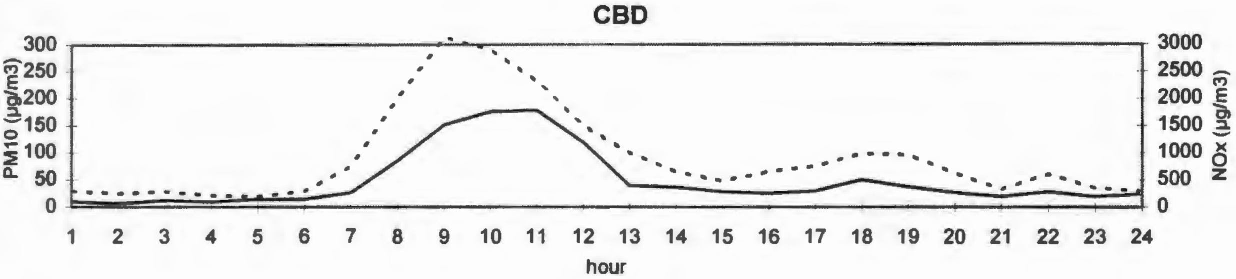
Wynberg

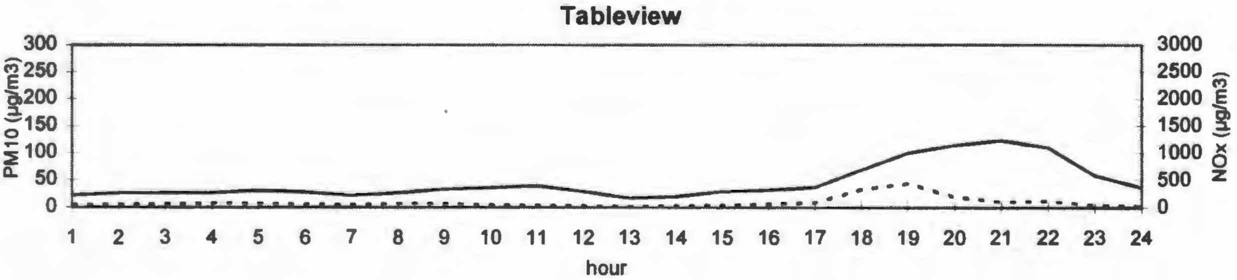
——— PM10 - - - - NOx

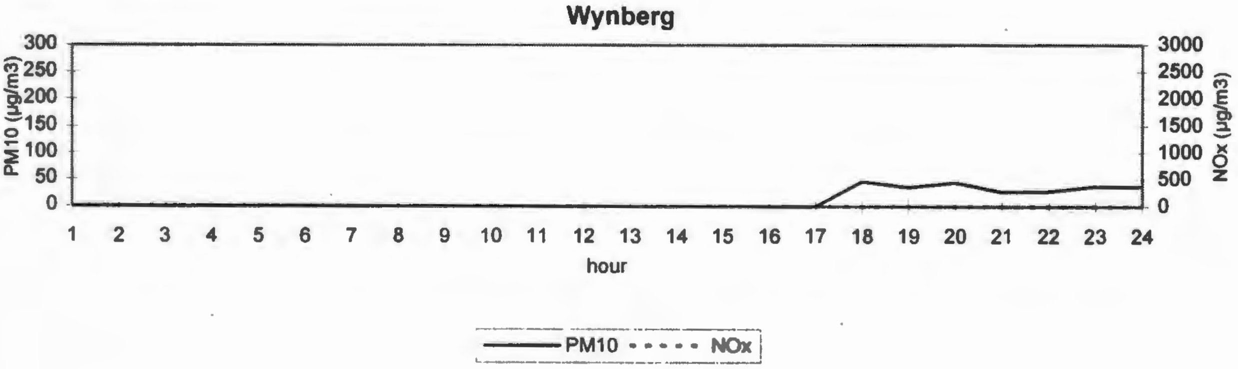
27/05/1996


Meteorological data

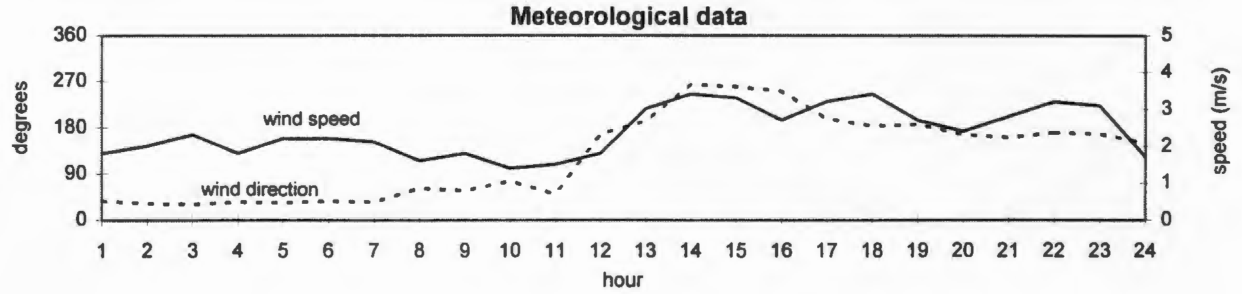

Goodwood

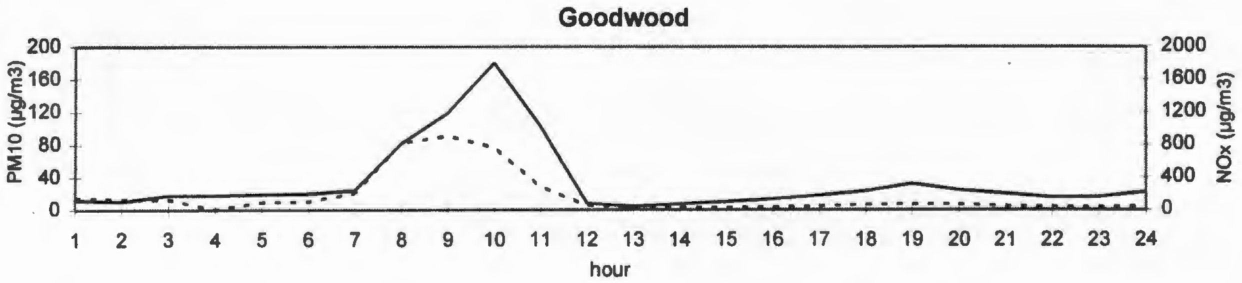

CBD

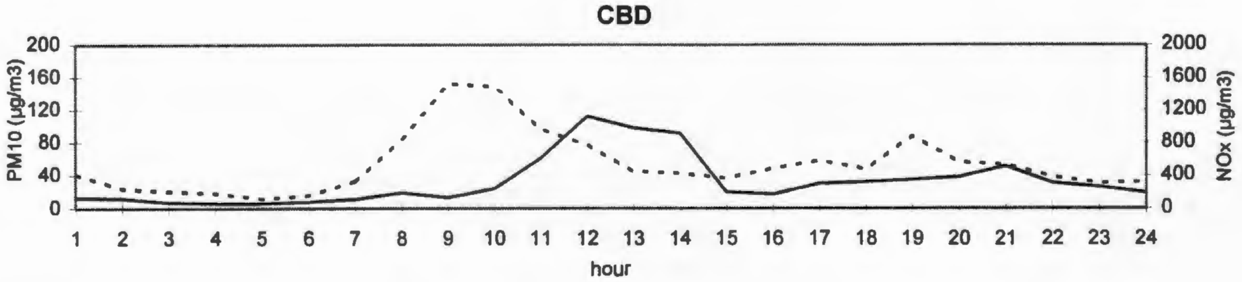

Tableview

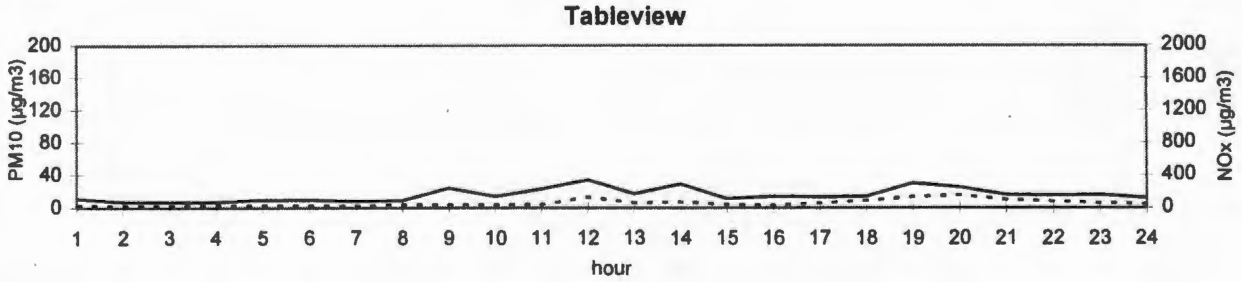

Wynberg

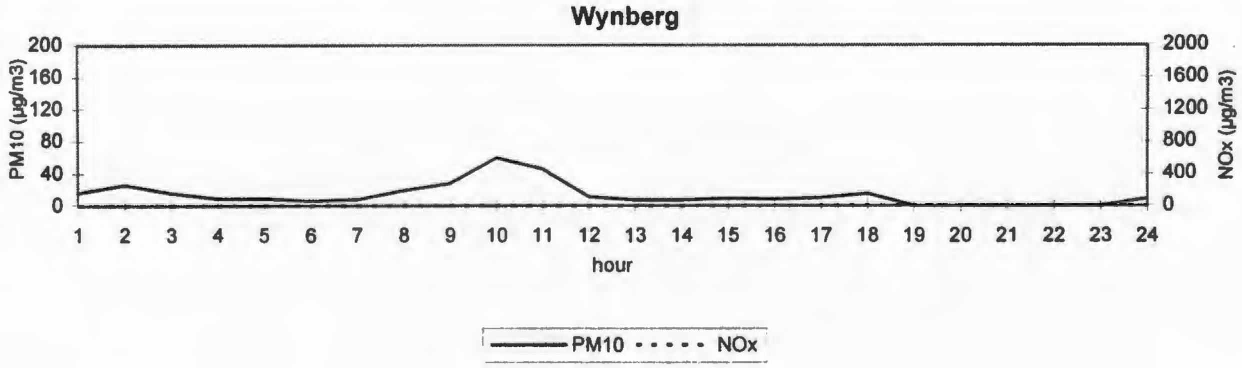
04/06/1996


Meteorological data
degrees
speed (m/s)
wind speed
wind direction
hour
360
270
180
90
0
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Goodwood
PM10 (µg/m3)
NOx (µg/m3)
hour
200
160
120
80
40
0
2000
1600
1200
800
400
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


CBD
PM10 (µg/m3)
NOx (µg/m3)
hour
200
160
120
80
40
0
2000
1600
1200
800
400
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Tableview
PM10 (µg/m3)
NOx (µg/m3)
hour
200
160
120
80
40
0
2000
1600
1200
800
400
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Wynberg
PM10 (µg/m3)
NOx (µg/m3)
hour
200
160
120
80
40
0
2000
1600
1200
800
400
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
PM10
NOx

APPENDIX L: AMBIENT FILTER CONCENTRATIONS

CBD [all concentrations in $\mu g/m^3$

DATE	04/06/96	30/04/96	20/05/96	16/02/96	15/07/95	18/08/95	29/08/95	20/09/95	23/04/96	15/09/95	14/07/95	1/8/95	27/05/96	08/05/96	25/07/95
Total Concentration	6.0978	17.2265	12.4430	11.9155	15.9807	17.8700	20.2617	24.7136	19.7250	24.2144	28.8525	25.3232	25.3126	34.0464	51.2087
Na	0.0857	0.1247	0.0114	0.1611	0.2183	0.2839	0.2130	0.3298	0.2053	0.3270	0.1720	0.1087	0.1146	0.1125	0.2170
Mg	0.0384	0.0532	0.0294	0.0353	0.0625	0.0687	0.0340	0.1151	0.0278	0.0792	0.0495	0.0276	0.0495	0.1206	0.1064
Al	0.1228	0.1520	0.0138	0.0635	0.1190	0.0455	0.0835	0.0000	0.1333	0.1043	0.1670	0.1153	0.1736	0.2747	0.2860
Si	0.0899	0.3584	0.0181	0.0870	0.3102	0.1157	0.0975	0.0292	0.0419	0.0859	0.1015	0.1043	0.0495	0.1329	0.2008
S	0.4273	1.7567	0.0058	0.4765	0.3849	1.5433	0.8582	0.0122	0.5573	1.2874	0.3018	1.5021	0.5042	0.8428	2.4485
Cl	0.0079	0.0000	0.0000	0.0252	0.1578	0.0042	0.0113	0.0059	0.0095	0.0030	0.0334	0.0022	0.0110	0.0228	0.0325
K	0.0854	0.1037	0.0004	0.0837	0.1150	0.0796	0.0752	0.0015	0.0638	0.1039	0.1526	0.0975	0.1092	0.1736	0.1811
Ca	0.0423	0.0560	0.0062	0.0498	0.0959	0.0408	0.0520	0.0186	0.0393	0.0556	0.0395	0.1035	0.0405	0.1038	0.1068
V	0.0020	0.0035	0.0007	0.0079	0.0057	0.0010	0.0191	0.0001	0.0138	0.0225	0.0058	0.0258	0.0023	0.0081	0.0613
Fe	0.1171	0.0814	0.0116	0.0542	0.1060	0.0423	0.0918	0.0008	0.0702	0.0879	0.1277	0.1186	0.1330	0.2845	0.5192
Ni	0.0047	0.0010	0.0002	0.0022	0.0007	0.0002	0.0057	0.0000	0.0052	0.0076	0.0025	0.0087	0.0013	0.0096	0.0215
Cu	0.0064	0.0028	0.0003	0.0025	0.0025	0.0006	0.0066	0.0000	0.0051	0.0072	0.0101	0.0074	0.0087	0.0135	0.0137
Zn	0.0534	0.0081	0.0000	0.0180	0.0152	0.0126	0.0371	0.0000	0.0221	0.0233	0.0358	0.0488	0.0432	0.0707	0.1199
Br	0.2783	0.1651	0.0000	0.1326	0.1502	0.0763	0.3055	0.0000	0.3696	0.2803	0.5974	0.4061	0.6422	0.8396	0.8764
Pb	0.5245	0.3195	0.0016	0.3338	0.2560	0.1888	0.6253	0.0000	0.6542	0.5943	1.0722	0.7522	1.1508	1.5816	1.4652
Cl^-	0.0000	0.1673	0.0471	0.1355	0.5596	0.3406	0.1642	0.6934	0.2099	0.1855	0.9307	0.3852	0.1186	0.5839	1.0036
NO_3^-	0.0000	0.2464	0.5632	0.2023	0.4532	0.6296	0.9428	0.0000	0.5809	1.1648	0.6630	1.6991	0.8343	1.9718	2.7007
SO_4^{2-}	0.0000	4.9088	3.0789	1.3724	1.4446	4.1606	2.7646	2.2810	1.7609	4.3917	1.8674	4.3025	1.3950	5.5403	7.0316
Low Temp. Organic Carbon	0.6590	3.5685	2.4635	2.2842	4.1160	2.7676	4.7344	9.7324	5.2109	5.0588	8.4347	3.6361	5.6569	4.9169	6.2449
Low Temp. Elemental Carbon	0.2433	0.7603	1.5916	1.2662	1.6423	1.2875	2.2607	1.9059	3.0921	3.0312	1.7843	4.1227	5.4643	6.6200	8.9213
High Temp. Organic Carbon	2.6967	5.3933	4.4657	4.4857	5.2616	6.1131	6.5187	9.0633	6.5693	7.5223	10.2595	7.9346	8.9416	11.1618	17.3560
High Temp. Elemental Carbon	0.4968	0.5779	0.7198	1.1644	1.2368	1.6322	1.0848	1.7640	0.7806	1.0645	2.5142	0.7367	0.3650	0.5981	2.5750

Goodwood [all concentrations in $\mu g/m^3$]												
DATE	**4/6/96**	**8/5/96**	**14/07/95**	**14/08/95**	**15/07/95**	**15/09/95**	**16/02/96**	**20/05/96**	**20/09/95**	**27/05/96**	**28/08/95**	**30/04/96**
Total Concentration	21.8025	35.2627	50.9489	15.2620	15.5613	15.0518	8.5608	15.9739	23.6586	38.5805	34.8723	22.5931
Na	0.1628	0.4788	0.1099	0.3204	0.0901	0.3057	0.3373	0.0708	0.3498	0.1826	0.1745	0.2593
Mg	0.0600	0.1159	0.0804	0.0557	0.0221	0.0687	0.0291	0.0257	0.0891	0.0677	0.0940	0.1070
Al	0.1878	0.2025	0.2468	0.0501	0.1208	0.0064	0.0190	0.0833	0.0644	0.3178	0.1982	0.3416
Si	0.0966	0.2632	0.1071	0.0658	0.2221	0.1163	0.0476	0.1404	0.1103	0.1909	0.0618	0.6114
S	0.5304	1.0796	0.7002	1.0737	0.6146	0.7601	0.3713	1.1118	0.6885	1.0109	1.5128	1.7479
Cl	0.0519	0.0310	0.1338	0.0157	0.0368	0.0873	0.3268	0.0023	0.0451	0.2002	0.0185	0.0092
K	0.0912	0.2887	0.3634	0.0556	0.1413	0.1227	0.1389	0.1258	0.0514	0.3377	0.0741	0.2392
Ca	0.0497	0.0973	0.0555	0.0321	0.0679	0.1184	0.0862	0.0431	0.1108	0.1060	0.0361	0.0802
V	0.0107	0.0243	0.0284	0.0000	0.0000	0.0084	0.0035	0.0052	0.0000	0.0142	0.0362	0.0098
Fe	0.1881	0.2623	0.2013	0.0267	0.0872	0.0471	0.0256	0.1030	0.0598	0.3602	0.1158	0.1737
Ni	0.0144	0.0217	0.0164	0.0019	0.0021	0.0021	0.0005	0.0035	0.0033	0.0192	0.0089	0.0074
Cu	0.0309	0.0216	0.0247	0.0022	0.0072	0.0039	0.0022	0.0101	0.0012	0.0229	0.0000	0.0079
Zn	0.1451	0.1995	0.1653	0.0208	0.0253	0.0231	0.0184	0.0425	0.0310	0.2480	0.0817	0.0729
Br	0.4278	0.4327	0.6579	0.0816	0.2261	0.0211	0.0355	0.2095	0.1927	1.0544	0.6538	0.5055
Pb	0.7283	0.9021	1.1501	0.1837	0.3698	0.0749	0.0913	0.3572	0.3486	1.7437	1.1971	0.8029
Cl^-	0.4562	0.3984	1.9100	0.6448	0.7482	0.3863	0.4066	0.2905	0.6995	1.0554	0.6387	0.3863
NO_3^-	0.7522	2.1361	1.9951	0.7634	0.7512	0.6174	0.2481	1.1653	1.1253	1.0168	1.1010	0.7847
SO_4^{2-}	1.5318	4.6431	2.5669	3.0322	2.1381	2.6855	0.9162	4.1129	2.3540	2.7788	4.7993	4.4556
Low Temp. Organic Carbon	5.8496	4.0856	9.0024	4.5316	4.3187	4.3897	1.8897	2.4432	10.3001	7.4108	10.9286	4.5316
Low Temp. Elemental Carbon	3.8017	7.0965	8.0495	0.3650	1.1354	0.7097	0.3945	1.6981	0.7908	5.0892	1.3585	2.0783
High Temp. Organic Carbon	7.1472	11.0706	23.5401	3.9234	5.1703	4.4607	3.1623	4.7090	6.0422	16.8390	8.5564	6.5896
High Temp. Elemental Carbon	0.3345	1.2064	1.6829	1.3078	0.5576	0.8617	0.5726	0.4359	1.2774	0.1926	2.8386	0.5981

Tableview [all concentrations in $\mu g/m^3$

DATE	14/07/95	18/08/95	15/07/95	14/07/95	25/07/95	28/08/95	20/05/96	27/05/96	04/06/96
Total Concentration	18.5093	12.8946	11.3103	27.3857	31.2092	17.3856	10.4655	17.2590	19.1890
Na	0.2795	0.3549	0.1381	0.1457	0.3930	0.4623	0.1170	0.1470	0.1457
Mg	0.0309	0.0656	0.0000	0.0555	0.0371	0.1298	0.0052	0.0356	0.0000
Al	0.0988	0.0555	0.0585	0.1263	0.0191	0.0794	0.0399	0.1036	0.0425
Si	0.2077	0.1529	0.1913	0.1852	0.0787	0.1139	0.0999	0.1665	0.1068
S	0.4291	1.4895	0.2837	0.5293	0.5611	0.6991	0.9142	0.5232	0.4029
Cl	0.0301	0.0016	0.0089	0.0404	0.0000	0.7561	0.0031	0.0997	0.0301
K	0.1224	0.0724	0.0979	0.1828	0.0672	0.0688	0.1396	0.1810	0.0814
Ca	0.0307	0.0345	0.0342	0.0754	0.0000	0.0398	0.0281	0.0461	0.0267
V	0.0047	0.0015	0.0000	0.0096	0.0067	0.0037	0.0032	0.0065	0.0065
Fe	0.0431	0.0462	0.0512	0.0951	0.0143	0.0367	0.0395	0.0736	0.0489
Ni	0.0011	0.0014	0.0007	0.0006	0.0040	0.0008	0.0014	0.0025	0.0054
Cu	0.0018	0.0050	0.0134	0.0106	0.0002	0.0018	0.0067	0.0048	0.0039
Zn	0.0394	0.0091	0.0093	0.0691	0.0219	0.0083	0.0093	0.0513	0.0937
Br	0.0592	0.0075	0.0221	0.2186	0.0171	0.0552	0.0129	0.0864	0.0459
Pb	0.1670	0.0381	0.0587	0.4854	0.0673	0.0949	0.0425	0.2100	0.1266
Cl^-	0.9124	0.5627	0.6144	1.1131	0.7664	1.3260	0.3680	1.9191	3.2908
NO_3^-	1.3625	0.5292	0.4319	2.0925	1.8066	1.0401	0.6635	0.9621	4.6695
SO_4^{2-}	2.0985	4.9240	1.2530	2.1594	8.6496	1.7032	2.9192	1.5805	1.9333
Low Temp. Organic Carbon	3.0008	1.7944	3.2441	7.3804	4.9676	5.4136	2.4584	5.4440	5.6671
Low Temp. Elemental Carbon	1.6423	0.3751	0.6184	2.8589	1.0949	0.1014	0.5525	1.7133	1.1659
High Temp. Organic Carbon	7.2182	3.3455	4.5418	8.9213	11.9424	5.8800	2.9045	5.8496	4.7242
High Temp. Elemental Carbon	2.0479	0.6184	0.4359	1.3990	2.5750	0.9530	0.1419	0.2332	0.4055

Wynberg [all concentrations in $\mu g/m^3$]

DATE	06/07/95	14/07/95	15/07/95	14/07/95	01/08/95	25/07/95	14/08/95	18/08/95	28/08/95	16/02/96	23/04/96	30/04/96	08/05/96	20/05/96	04/06/96
Total Concentration	26.3101	28.9571	16.4765	25.4988	20.2988	32.3146	14.5223	17.4396	23.9668	7.2488	8.3459	17.6128	23.8930	18.0302	14.5341
Na	0.6779	0.0929	0.2395	0.2317	0.1717	0.5579	0.3844	0.1492	0.1976	0.2638	0.3635	0.0813	0.1528	0.1389	0.1972
Mg	0.1596	0.0396	0.0848	0.0631	0.0516	0.0000	0.0643	0.0186	0.1212	0.0369	0.0452	0.0594	0.0390	0.0510	0.0000
Al	0.1662	0.3280	0.1590	0.2038	0.0936	0.2255	0.0571	0.0400	0.2265	0.0233	0.0187	0.2904	0.2583	0.0821	0.0445
Si	0.1986	0.0420	0.3732	0.0301	0.0915	0.1508	0.0759	0.0923	0.0806	0.0383	0.0332	0.9258	0.1981	0.0699	0.0233
S	0.5394	0.3452	0.3740	0.2430	1.3691	1.0633	0.8935	1.5883	0.5915	0.3058	0.1834	1.8922	0.5276	1.1876	0.2356
Cl	0.5749	0.0295	0.1455	0.0547	0.0000	0.0027	0.1909	0.0000	0.0293	0.3989	0.5054	0.0188	0.0223	0.0125	0.0860
K	0.1549	0.0718	0.1121	0.1436	0.1112	0.1452	0.0499	0.0803	0.0871	0.0670	0.0277	0.1484	0.1924	0.1449	0.0570
Ca	0.0941	0.0381	0.1200	0.0422	0.0301	0.0619	0.0261	0.0245	0.0254	0.0444	0.0242	0.0844	0.0870	0.0354	0.0167
V	0.0156	0.0121	0.0053	0.0076	0.0140	0.0319	0.0097	0.0069	0.0053	0.0021	0.0000	0.0037	0.0031	0.0099	0.0057
Fe	0.1341	0.1558	0.1295	0.1215	0.0681	0.1398	0.0328	0.0491	0.0568	0.0141	0.0105	0.1746	0.1653	0.0777	0.0332
Ni	0.0067	0.0030	0.0025	0.0004	0.0058	0.0129	0.0033	0.0028	0.0049	0.0007	0.0002	0.0042	0.0050	0.0087	0.0027
Cu	0.0096	0.0088	0.0054	0.0085	0.0069	0.0110	0.0021	0.0033	0.0066	0.0005	0.0000	0.0025	0.0101	0.0067	0.0054
Zn	0.0385	0.0465	0.0122	0.0216	0.0391	0.0653	0.0118	0.0134	0.0225	0.0029	0.0000	0.0132	0.0429	0.0247	0.0232
Br	0.3240	1.2174	0.1225	0.7607	0.3253	0.6894	0.1088	0.1128	0.4768	0.0172	0.0164	0.0757	0.7489	0.2683	0.1993
Pb	0.5497	1.6094	0.2071	1.0635	0.6223	1.1607	0.2165	0.2592	0.7833	0.0384	0.0329	0.1747	1.2454	0.4173	0.3304
Cl^-	0.9854	0.6083	0.6083	0.7908	0.2413	0.6387	0.4532	0.3832	0.2920	0.3779	0.4836	0.1946	0.0000	0.0852	0.5109
NO_3^-	1.2652	0.7056	0.4380	0.0000	1.0219	1.4538	0.7451	0.9033	0.0000	0.0000	0.0000	0.1582	0.7066	1.7858	0.4298
SO_4^{2-}	1.7518	1.4842	1.6210	1.4355	3.6152	3.4732	2.4453	4.3248	2.4696	0.8303	0.5657	5.3710	2.8761	4.1449	1.2459
Low Temp. Organic Carbon	7.8670	8.5158	3.8220	8.4955	3.8051	3.7916	2.8183	2.4838	8.9213	2.3924	3.5381	3.8727	3.5178	3.2897	5.1703
Low Temp. Elemental Carbon	2.0479	2.2506	1.1354	1.9059	2.1898	4.6431	0.4968	0.5474	0.7097	0.1082	0.1622	0.4055	3.2238	1.6069	1.5207
High Temp. Organic Carbon	8.7997	9.3471	4.9676	9.5093	6.8329	13.0170	5.4846	5.9712	7.6845	2.5578	2.6663	4.7749	8.8808	5.0791	4.9473
High Temp. Elemental Carbon	1.1760	2.8792	1.1557	1.4801	0.8516	2.5547	1.0645	1.2875	2.0884	0.3245	0.2230	0.4157	0.7908	0.1977	0.3041

Guguletu [all concentrations in $\mu g/m^3$]	
DATE	22/08/96
Total Concentration	75.4610
Na	0.3854
Mg	0.0400
Al	0.2284
Si	0.1202
S	1.1697
Cl	3.6129
K	1.1686
Ca	0.0669
V	0.0189
Fe	0.0837
Ni	0.0066
Cu	0.0141
Zn	0.2172
Br	0.6497
Pb	0.9867
Cl^-	7.9941
NO_3^-	3.4695
SO_4^{2-}	4.6088
Low Temp. Organic Carbon	5.8254
Low Temp. Elemental Carbon	19.9092
High Temp. Organic Carbon	30.0861
High Temp. Elemental Carbon	1.1931

APPENDIX M: CHEMICAL MASS BALANCE MODEL RESULTS FOR EACH EPISODE

J.1. Modelling at the Goodwood Site

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SOURCE CONTRIBUTION ESTIMATES - SITE: 67        DATE: 14/07/95   CMB7 33889
SAMPLE DURATION       6      START HOUR      0       SIZE:   FINE
R SQUARE     1.00   PERCENT MASS    121.7    CHI SQUARE     3.26           DF        32

SOURCE    SCE(UG/M3)   STD ERR    TSTAT
-----------------------------------------
8     RDUST       .4117      .1474    2.7922
13    DIVEH     26.3749    4.3778    6.0247
16    SO4        1.1401     .2132    5.3481
17    NO3        1.9065     .2765    6.8954
25    WBURN      7.0834      .5825   12.1597
28    OHC       12.1912    6.8128    1.7895
30    EHC        1.4752     .7989    1.8465
34    VEH2      11.2961      .0870  129.8524
36    COMPB       .1255     .3406     .3684
-----------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE        50.9+-     3.9

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
C1    TOT    T  50.94889+-  3.92273  62.00455+-  7.51705  1.22+-  .17    1.3
C11   Na     *   .10985<    .19100    .10680<    .04700    .97<  1.74    -.0
C12   Mg     *   .08041<    .16983    .03193<    .12723    .40<  1.79    -.2
C13   Al     *   .24676+-   .03157    .19610+-   .01971    .79+-  .13   -1.4
C14   Si     *   .10714+-   .01464    .12547+-   .01255   1.17+-  .20    1.0
C15   P      *   .06409+-   .00947    .01299+-   .00610    .20+-  .10   -4.5
C16   S      *   .70022+-   .03550    .70022+-   .04954   1.00+-  .09     .0
C17   Cl         .13378+-   .01204    .38242+-   .00789   2.86+-  .26   17.3
C19   K      *   .36340+-   .03028    .37888+-   .00487   1.04+-  .09     .5
C20   Ca     *   .05547+-   .00858    .06859+-   .00495   1.24+-  .21    1.3
C22   Ti     *   .00012<    .07997    .00367<    .02249  30.18< *****    .0
C23   V      *   .02843<    .03287    .00272<    .00911    .10<  .34    -.8
C24   Cr     *   .00655<    .00797    .00224<    .00202    .34<  .52    -.5
C25   Mn     *   .01723+-   .00217    .00322+-   .00152    .19+-  .09   -5.3
C26   Fe     *   .20128+-   .02771    .06559+-   .00072    .33+-  .05   -4.9
C27   Co     *   .00000<    .00535    .00020<    .00121    .00<  .00     .0
C28   Ni     *   .01642+-   .00152    .01680+-   .00104   1.02+-  .11     .2
C29   Cu         .02466+-   .00162    .00304+-   .00052    .12+-  .02  -12.7
C30   Zn         .16531+-   .00255    .04567+-   .00052    .28+-  .01  -45.9
C31   Ga     *   .00000<    .01429    .00083<    .01037    .00<  .00     .0
C33   As     *   .00000<    .18149    .00045<    .15292    .00<  .00     .0
C34   Se     *   .00000<    .00683    .00010<    .00437    .00<  .00     .0
C35   Br     *   .65791+-   .00564    .63690+-   .00263    .97+-  .01   -3.4
C48   Cd         .00000<    .03467    .00599<    .00938    .00<  .00     .2
C49   In     *   .00000<    .04039    .00000<    .01063    .00<  .00     .0
C50   Sn     *   .00722<    .05049    .00007<    .01374    .01<  1.90    -.1
C51   Sb     *   .05424<    .06042    .00373<    .01635    .07<  .31    -.8
C56   Ba     *   .00000<    .22297    .00293<    .06009    .00<  .00     .0
C57   La     *   .00000<    .29767    .00861<    .07943    .00<  .00     .0
C79   Au     *   .00000<    .01312    .00081<    .00381    .00<  .00     .1
C80   Hg     *   .00000<    .01054    .00310<    .00443    .00<  .00     .3
C81   Tl     *   .00000<    .03305    .00000<    .02634    .00<  .00     .0
C82   Pb     *  1.15014+-   .01075   1.18775+-   .00290   1.03+-  .01    3.4
C92   U      *   .00000<    .01417    .00001<    .00855    .00<  .00     .0
C201  Cl-       1.90998+-   .19100    .95771+-   .07241    .50+-  .06   -4.7
C202  NO3-   *  1.99513+-   .19951   1.99513+-   .19086   1.00+-  .14     .0
C203  SO4--     2.56691+-   .25669   2.41726+-   .15157    .94+-  .11    -.5
C204  Ca++       .62044+-   .06204    .15508+-   .01344    .25+-  .03   -7.3
C205  K+         .33455+-   .03345    .33787+-   .03362   1.01+-  .14     .1
C206  Mg++       .14599+-   .01460    .00121+-   .00009    .01+-  .00   -9.9
C207  Na+        .57178+-   .05718    .00167+-   .00010    .00+-  .00  -10.0
C208  NH4+       .77251+-   .07725    .29816+-   .02769    .39+-  .05   -5.8
C209  OCTU     32.54258+-  2.04785  18.71979+-   .73433    .58+-  .04   -6.4
C210  ECTU      9.73236+-  1.23682   9.18261+-   .56409    .94+-  .13    -.4
C211  OHTU   * 23.54015+-  2.77778  23.54014+-  6.14330   1.00+-  .29     .0
C212  EHTU   *  1.68289+-   .30414   1.68289+-   .73857   1.00+-  .47     .0
C213  OLTU   *  9.00243+-   .81935   7.37081+-   .72711    .82+-  .11   -1.5
C214  ELTU   *  8.04947+-  1.72248   8.97493+-   .79684   1.11+-  .26     .5
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SOURCE CONTRIBUTION ESTIMATES - SITE: 122       DATE: 16/02/96   CMB7 33889
SAMPLE DURATION      19    START HOUR      0      SIZE:   FINE
R SQUARE      .98   PERCENT MASS     81.4    CHI SQUARE      3.04          DF      32

  SOURCE      SCE(UG/M3)   STD ERR     TSTAT
----------------------------------------------
 8     RDUST        .2590     .0181    14.2709
 13    DIVEH       1.3447     .4799     2.8022
 16    SO4         .9654     .1038    9.3017
 17    NO3         .2436     .0348    6.9977
 20    MARI1        .7626     .1065     7.1608
 23    PCEMT         .1200     .0098    12.2015
 25    WBURN        2.4052     .0867    27.7302
 34    VEH2        .8645     .0195    44.2342
----------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE         8.6+-     .7

SPECIES-------I---MEAS----------------CALC------------RATIO C/M----RATIO R/U
 C1    TOT    T  8.56075+-  .74692  6.96502+-  .47809   .81+-  .09   -1.8
 C11    Na    *   .33732+-  .02950   .32910+-  .03110   .98+-  .13    -.2
 C12    Mg    *   .02912<   .03241   .04124<   .01212  1.42<  1.63     .4
 C13    Al    *  .01905+-   .00602   .03324+-  .00147  1.74+-  .56    2.3
 C14    Si    *  .04763+-   .00428   .04685+-  .00101   .98+-  .09    -.2
 C15    P     *  .01505+-   .00295   .00177+-  .00083   .12+-  .06   -4.3
 C16    S     *  .37127+-   .00547   .37127+-  .03346  1.00+-  .09     .0
 C17    Cl       .32678+-   .00699   .42802+-  .07627  1.31+-  .24    1.3
 C19    K     *  .13891+-   .00391   .14044+-  .00172  1.01+-  .03     .4
 C20    Ca    *  .08618+-   .00316   .08630+-  .00215  1.00+-  .04     .0
 C22    Ti    *  .00103<    .02331   .00192<   .00245  1.87< 42.29     .0
 C23    V     *  .00353<    .00950   .00015<   .00100   .04<  .31    -.4
 C24    Cr    *  .00108<    .00221   .00040<   .00019   .37<  .77    -.3
 C25    Mn    *   .00008<   .00160   .00071<   .00014  8.57< *****    .4
 C26    Fe    *  .02565+-   .00083   .02553+-  .00010  1.00+-  .03    -.1
 C27    Co    *   .00011<   .00127   .00002<   .00027   .16<  2.95    -.1
 C28    Ni    *  .00050<    .00114   .00133<   .00012  2.65<  6.01     .7
 C29    Cu    *   .00218+-  .00041   .00037+-  .00009   .17+-  .05   -4.3
 C30    Zn       .01845+-   .00057   .00504+-  .00005   .27+-  .01  -23.6
 C31    Ga    *   .00081<   .00216   .00007<   .00081   .09<  1.03    -.3
 C33    As    *   .00062<   .01486   .00008<   .01170   .12< 18.99    -.0
 C34    Se    *   .00030<   .00130   .00004<   .00035   .12<  1.27    -.2
 C35    Br       .03552+-   .00278   .05065+-  .00043  1.43+-  .11    5.4
 C47    Ag    *   .00076<   .00961   .00011<   .00099   .14<  2.20    -.1
 C48    Cd        .00000<   .01010   .00036<   .00106   .00<  .00     .0
 C49    In    *  .00509<    .01152   .00000<   .00119   .00<  .23    -.4
 C50    Sn    *   .01495+-  .00492   .00003+-  .00153   .00+-  .10   -2.9
 C51    Sb    *   .00876<   .01726   .00074<   .00185   .08<  .27    -.5
 C56    Ba    *   .00000<   .06470   .00049<   .00677   .00<  .00     .0
 C57    La    *   .00000<   .08668   .00195<   .00902   .00<  .00     .0
 C79    Au    *   .00207<   .00321   .00016<   .00038   .08<  .22    -.6
 C80    Hg    *   .00036<   .00266   .00020<   .00039   .57<  4.41    -.1
 C81    Tl    *  .00000<    .00373   .00000<   .00202   .00<  .00    .0
 C82    Pb    *   .09134+-  .00190   .09128+-  .00032  1.00+-  .02    -.0
 C92    U     *  .00000<    .00261   .00000<   .00068   .00<  .00    .0
 C201   Cl-        .40658+-  .04066   .63019+-  .08013  1.55+-  .25    2.5
 C202   NO3-  *    .24814+-  .02481   .24814+-  .02437  1.00+-  .14     .0
 C203   SO4--      .91623+-  .09162  1.14077+-  .10140  1.25+-  .17    1.6
 C204   Ca++       .22906+-  .02291   .06654+-  .00489   .29+-  .04   -6.9
 C205   K+        .12216+-  .01222   .12542+-  .01152  1.03+-  .14     .2
 C206   Mg++       .06681+-  .00668   .03715+-  .00686   .56+-  .12   -3.1
 C207   Na+       .23287+-  .02329   .30554+-  .07626  1.31+-  .35     .9
 C208   NH4+       .09544+-  .00954   .02192+-  .00157   .23+-  .03   -7.6
 C209   OCTU      5.05197+-  .34995  2.26874+-  .07214   .45+-  .03   -7.8
 C210   ECTU       .96713+-  .12725   .64398+-  .03382   .67+-  .09   -2.5
 C211   OHTU  *  3.16225+-  .40085  1.64687+-  .10426   .52+-  .07   -3.7
 C212   EHTU  *   .57264+-  .10180   .02831+-  .00394   .05+-  .01   -5.3
 C213   OLTU      1.88972+-  .29025   .62187+-  .05906   .33+-  .06   -4.3
 C214   ELTU  *   .39449+-  .14840   .61567+-  .04766  1.56+-  .60    1.4
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SOURCE CONTRIBUTION ESTIMATES - SITE: 139      DATE: 30/04/96   CMB7 33889
SAMPLE DURATION       12    START HOUR     0      SIZE:   FINE
R SQUARE      .99   PERCENT MASS    136.7     CHI SQUARE     4.77           DF       34

  SOURCE   SCE(UG/M3)   STD ERR     TSTAT
------------------------------------------
7    CALCT       2.4244      .0930    26.0559
8    RDUST        1.1526      .0885    13.0179
16    SO4       4.7137      .4830    9.7593
17    NO3        .7478      .1086    6.8891
25    WBURN       4.2926      .1186    36.2044
32    VEH1       4.1532      .0753    55.1201
33    PETVH       2.4273      .3092    7.8493
35    DIES2      10.9653     1.3473     8.1389
------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE        22.6+-     1.7

SPECIES-------I---MEAS-----------------CALC------------RATIO C/M----RATIO R/U
C1    TOT    T  22.59307+-  1.71113  30.87703+-  1.38189   1.37+-  .12     3.8
C11   Na    *   .25935+-   .04331    .06417+-   .02665    .25+-  .11    -3.8
C12   Mg    *   .10703<    .11722    .02137<    .09158    .20<   .88    -.6
C13   Al    *   .34160+-   .02256    .39150+-   .01284   1.15+-  .08    1.9
C14   Si    *   .61144+-   .01326    .60887+-   .00906   1.00+-  .03    -.2
C15   P     *   .01730<    .02023    .01339<    .00291    .77<   .92   -.2
C16   S     *  1.74785+-   .02568   1.74785+-   .15701   1.00+-  .09     .0
C17   Cl        .00925<    .03248    .23241<    .00433  25.14< 88.31     6.8
C19   K     *   .23923+-   .00571    .24133+-   .00240   1.01+-  .03     .3
C20   Ca    *   .08015+-   .00468    .09331+-   .00289   1.16+-  .08     2.4
C22   Ti    *   .01842<    .03943    .01565<    .01041    .85<  1.90    -.1
C23   V     *   .00980<    .01610    .00609<    .00424    .62<  1.11    -.2
C24   Cr    *   .00267<    .00375    .00240<    .00093    .90<  1.32    -.1
C25   Mn    *   .00975+-   .00104    .00252+-   .00070    .26+-  .08    -5.8
C26   Fe    *   .17374+-   .01233    .10874+-   .00038    .63+-  .04    -5.3
C27   Co    *   .00037<    .00354    .00011<    .00119    .30<  4.38    -.1
C28   Ni    *   .00739+-   .00071    .00807+-   .00049   1.09+-  .12     .8
C29   Cu    *   .00791+-   .00073    .00197+-   .00031    .25+-  .05    -7.5
C30   Zn        .07290+-   .00120    .03081+-   .00027    .42+-  .01  -34.3
C31   Ga    *   .00212<    .00935    .00040<    .00745    .19<  3.62    -.1
C33   As    *   .00000<    .12652    .00024<    .11084    .00<   .00     .0
C34   Se    *   .00000<    .00423    .00006<    .00310    .00<   .00     .0
C35   Br    *   .50548+-   .02356    .42700+-   .00188    .84+-  .04   -3.3
C46   Pd    *   .00000<    .01403    .00194<    .00354    .00<   .00     .1
C47   Ag    *   .00422<    .01650    .00086<    .00418    .20<  1.27    -.2
C48   Cd        .00000<    .01687    .00304<    .00447    .00<   .00     .2
C49   In    *   .00000<    .01945    .00008<    .00507    .00<   .00     .0
C50   Sn    *   .00000<    .02521    .00011<    .00653    .00<   .00     .0
C51   Sb    *   .00000<    .02977    .00261<    .00771    .00<   .00     .1
C56   Ba    *   .00000<    .10958    .00351<    .02811    .00<   .00     .0
C57   La    *   .00000<    .14600    .01624<    .03716    .00<   .00     .1
C79   Au    *   .00125<    .00659    .00045<    .00223    .36<  2.61    -.1
C80   Hg    *   .00000<    .00563    .00152<    .00291    .00<   .00     .2
C81   Tl    *   .00000<    .02245    .00000<    .01905    .00<   .00     .0
C82   Pb    *   .80289+-   .00623    .80579+-   .00195   1.00+-  .01      .4
C92   U     *   .00000<    .00938    .00003<    .00602    .00<   .00     .0
C201  Cl-       .38625+-   .03863    .58970+-   .04389   1.53+-  .19    3.5
C202  NO3-  *    .78467+-   .07847    .78467+-   .07487   1.00+-  .14     .0
C203  SO4--     4.45560+-   .44556   5.31843+-   .47329   1.19+-  .16    1.3
C204  Ca++       .28589+-   .02859    .13007+-   .00936    .45+-  .06   -5.2
C205  K+        .23723+-   .02372    .20809+-   .02038    .88+-  .12    -.9
C206  Mg++       .04866+-   .00487    .00307+-   .00025    .06+-  .01   -9.4
C207  Na+        .15511+-   .01551    .00632+-   .00047    .04+-  .01   -9.6
C208  NH4+       .01521+-   .00152    .14089+-   .01159   9.27+- 1.20   10.7
C209  OCTU      11.12125+-   .72993   9.22065+-   .31673    .83+-  .06   -2.4
C210  ECTU       2.67640+-   .34469   3.99392+-   .23570   1.49+-  .21    3.2
C211  OHTU  *  6.58962+-   .80089   5.71606+-   .34331    .87+-  .12   -1.0
C212  EHTU  *    .59813+-   .11152    .67202+-   .01653   1.12+-  .21     .7
C213  OLTU  *  4.53163+-   .65127   3.50459+-   .30952    .77+-  .13   -1.4
C214  ELTU  *  2.07826+-   .47453   3.32190+-   .33292   1.60+-  .40    2.1
```

```
SOURCE CONTRIBUTION ESTIMATES - SITE: 142      DATE: 08/05/96   CMB7 33889
SAMPLE DURATION        12    START HOUR     0      SIZE:  FINE
R SQUARE       .98   PERCENT MASS    123.3    CHI SQUARE     3.17         DF      31

   SOURCE  SCE(UG/M3)   STD ERR     TSTAT
 ---------------------------------------------
 8    RDUST       .5420     .1547    3.5044
 13   DIVEH      22.0925    2.4884    8.8782
 16   SO4       2.1617     .2537    8.5222
 17   NO3       2.0618     .2971    6.9401
 20   MARI1      .9533     .1818    5.2429
 22   SASFA      .7225     .1143    6.3224
 25   WBURN      4.9291      .1676   29.4022
 34   VEH2      8.2403     .1386   59.4511
 36   COMPB      1.7633     .2177    8.1010
 ---------------------------------------------
 MEASURED CONCENTRATION FOR SIZE: FINE       35.3+-    2.1

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
 C1    TOT   T 35.26269+-  2.09488 43.46654+-  2.40708  1.23+-  .10   2.6
 C11   Na    *  .47875+-  .04941   .46967+-  .05332   .98+-  .15    -.1
 C12   Mg    *  .11587<   .12755   .07910<   .09352   .68<  1.10    -.2
 C13   Al    * .20253+-  .01992  .27362+-  .01538  1.35+-  .15    2.8
 C14   Si    * .26319+-  .01068  .25291+-  .00938   .96+-  .05   -.7
 C15   P     *  .06356+-  .00671  .01399+-  .00498   .22+-  .08  -5.9
 C16   S     * 1.07960+-  .02761  1.07960+-  .07614  1.00+-  .08     .0
 C17   Cl       .03103+-  .00877  .64913+-  .09554 20.92+- 6.66    6.4
 C19   K     * .28873+-  .00716  .28937+-  .00440  1.00+-  .03     .1
 C20   Ca    *  .09731+-  .00522  .09818+-  .00436  1.01+-  .07     .1
 C22   Ti    * .01451<   .04180  .00546<  .01851   .38<  1.67    -.2
 C23   V     * .02428+-  .00575  .03090+-  .00748  1.27+-  .43     .7
 C24   Cr    *  .00795+-  .00145  .00211+-  .00185   .27+-  .24   -2.5
 C25   Mn       .01856+-  .00124  .00525+-  .00149   .28+-  .08   -6.9
 C26   Fe       .26227+-  .02283  .07488+-  .00111   .29+-  .03   -8.2
 C27   Co    *  .00000<   .00481  .00017<   .00105   .00<  .00     .0
 C28   Ni    * .02166+-  .00091  .02135+-  .00086   .99+-  .06   -.3
 C29   Cu    *  .02161+-  .00290  .00534+-  .00214   .25+-  .10   -4.5
 C30   Zn       .19949+-  .00178  .03991+-  .00178   .20+-  .01  -63.2
 C31   Ga    *  .00135<   .01041  .00068<   .00760   .51<  6.86    -.1
 C33   As    *  .00000<   .14205  .00036<  .11158   .00<  .00     .0
 C34   Se    *  .00452<   .00477  .00009<   .00321   .02<  .71    -.8
 C35   Br    * .43274+-  .01358  .46755+-  .00199  1.08+-  .03    2.5
 C46   Pd    *  .00074<   .01471  .00227<   .00603  3.06< 61.42     .1
 C48   Cd       .00000<   .01847  .00489<   .00768   .00<  .00     .2
 C49   In    * .01292<  .02137  .00000<  .00871   .00<  .67    -.6
 C50   Sn    *  .00343<   .02705  .00052<   .01126   .15<  3.50    -.1
 C51   Sb    *  .01196<   .03242  .00286<   .01342   .24<  1.30    -.3
 C56   Ba    *  .00000<   .11638  .00248<   .04938   .00<  .00     .0
 C57   La    *  .00000<   .15548  .00694<   .06525   .00<  .00     .0
 C79   Au    *  .00151<   .00972  .00063<   .00300   .42<  3.36    -.1
 C80   Hg    *  .00585<   .00650  .00242<   .00337   .41<  .74    -.5
 C81   Tl    * .00000<  .02514  .00000<  .01924   .00<  .00     .0
 C82   Pb    *  .90207+-  .01663  .87228+-  .00228   .97+-  .02   -1.8
 C92   U     * .00160<   .00870  .00001<   .00631   .01<  3.94    -.1
 C201  Cl-      .39842+-  .03984 1.06164+-  .10784  2.66+-  .38    5.8
 C202  NO3-  *  2.13605+-  .21361  2.13605+-  .20632  1.00+-  .14     .0
 C203  SO4--     4.64315+-  .46431  3.70126+-  .23725   .80+-  .09   -1.8
 C204  Ca++      .15714+-  .01571   .19825+-  .01174  1.26+-  .15    2.1
 C205  K+       .18451+-  .01845  .25883+-  .02349  1.40+-  .19    2.5
 C206  Mg++      .16930+-  .01693  .05185+-  .00859   .31+-  .06   -6.2
 C207  Na+     1.30069+-  .13007  .39460+-  .09534   .30+-  .08   -5.6
 C208  NH4+     2.00020+-  .20002  .25076+-  .02318   .13+-  .02   -8.7
 C209  OCTU     15.15612+- 1.03406 14.78147+-  .60328   .98+-  .08    -.3
 C210  ECTU      8.30292+-  .55758  7.61367+-  .47185   .92+-  .08    -.9
 C211  OHTU   * 11.07056+- 1.30779  8.91040+-  .62182   .80+-  .11   -1.5
 C212  EHTU   *  1.20641+-  .32441   .17096+-  .03120   .14+-  .05   -3.2
 C213  OLTU   *  4.08556+-  .65442  5.87107+-   .59818  1.44+-  .27    2.0
 C214  ELTU   *  7.09651+-  .71872  7.44271+-  .66657  1.05+-  .14     .4
```

```
SOURCE CONTRIBUTION ESTIMATES -  SITE: 150        DATE: 27/05/96   CMB7 33889
SAMPLE DURATION       12    START HOUR      0      SIZE:   FINE
R SQUARE    1.00  PERCENT MASS    111.3    CHI SQUARE     3.23            DF       32

     SOURCE    SCE(UG/M3)   STD ERR     TSTAT
-----------------------------------------------
8     RDUST       1.2966      .1050    12.3490
13     DIVEH     16.7656    2.1330     7.8599
16     SO4        2.1472      .3035     7.0748
17     NO3         .9605      .1402     6.8523
25     WBURN       6.1615      .1459    42.2295
32     VEH1        8.7212      .1053    82.8485
33     PETVH       6.8938      .4175    16.5132
-----------------------------------------------

MEASURED CONCENTRATION FOR SIZE: FINE        38.6+-     2.7

SPECIES------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
C1    TOT   T  38.58053+-  2.69732  42.94631+-  2.07522  1.11+-  .09    1.3
C11   Na    *   .18257+-   .05291    .09687+-   .04885   .53+-  .31   -1.2
C12   Mg    *   .06769<    .23286    .03825<    .19298   .57<  3.45    -.1
C13   Al    *   .31783+-   .03780    .31541+-   .02627   .99+-  .14    -.1
C14   Si    *   .19094+-   .01297    .18367+-   .01880   .96+-  .12    -.3
C15   P     *   .02624+-   .00715    .02151+-   .00481   .82+-  .29    -.5
C16   S     *  1.01089+-   .05077   1.01089+-   .08496  1.00+-  .10     .0
C17   Cl        .20015+-   .01205    .34595+-   .00785  1.73+-  .11   10.1
C19   K     *   .33766+-   .00656    .33934+-   .00386  1.00+-  .02     .2
C20   Ca    *   .10596+-   .00510    .11655+-   .00422  1.10+-  .07    1.6
C22   Ti    *   .00000<    .03778    .00779<    .01701   .00<   .00     .2
C23   V     *   .01415<    .01556    .00079<    .00691   .06<   .49    -.8
C24   Cr    *   .01206+-   .00138    .00207+-   .00153   .17+-  .13   -4.9
C25   Mn        .01923+-   .00120    .00298+-   .00115   .15+-  .06   -9.8
C26   Fe    *   .36021+-   .03324    .10769+-   .00056   .30+-  .03   -7.6
C27   Co    *   .00000<    .00614    .00023<    .00143   .00<   .00     .0
C28   Ni    *   .01923+-   .00083    .01959+-   .00080  1.02+-  .06     .3
C29   Cu        .02290+-   .00086    .00322+-   .00057   .14+-  .03  -19.1
C30   Zn        .24801+-   .00194    .05777+-   .00048   .23+-  .00  -95.4
C31   Ga    *   .00278<    .01886    .00062<    .01571   .22<  5.86    -.1
C33   As    *   .00155<    .27405    .00035<    .23415   .23< *****    .0
C34   Se    *   .00370<    .00808    .00009<    .00652   .02<  1.76    -.3
C35   Br       1.05441+-   .00601    .93282+-   .00397   .88+-  .01  -16.9
C48   Cd        .00467<    .01730    .00505<    .00743  1.08<  4.31     .0
C49   In    *   .00000<    .01904    .00000<    .00848   .00<   .00     .0
C50   Sn    *   .01841<    .02494    .00013<    .01088   .01<   .59    -.7
C51   Sb    *   .02194<    .02897    .00469<    .01273   .21<   .65    -.5
C56   Ba    *   .05057<    .10411    .00529<    .04606   .10<   .94    -.4
C57   La    *   .04151<    .13854    .01135<    .06100   .27<  1.73    -.2
C79   Au    *   .00132<    .01174    .00063<    .00432   .48<  5.36    -.1
C80   Hg    *   .00915+-   .00286    .00323+-   .00591   .35+-  .65    -.9
C81   Tl    *   .00000<    .04749    .00000<    .04021   .00<   .00     .0
C82   Pb    *  1.74369+-   .00901   1.74383+-   .00398  1.00+-  .01     .0
C92   U     *   .00000<    .01748    .00002<    .01266   .00<   .00     .0
C201  Cl-      1.05535+-   .10554    .83439+-   .06299   .79+-  .10   -1.8
C202  NO3-  *  1.01683+-   .10168   1.01683+-   .09622  1.00+-  .14     .0
C203  SO4--    2.77879+-   .27788   3.11370+-   .22486  1.12+-  .14     .9
C204  Ca++      .21188+-   .02119    .16908+-   .01275   .80+-  .10   -1.7
C205  K+        .25750+-   .02575    .29539+-   .02925  1.15+-  .16    1.0
C206  Mg++      .28183+-   .02818    .00270+-   .00027   .01+-  .00   -9.9
C207  Na+      1.85422+-   .18542    .00251+-   .00025   .00+-  .00  -10.0
C208  NH4+      .08719+-   .00872    .19794+-   .01765  2.27+-  .30    5.6
C209  OCTU    24.24980+-  1.61192  15.96494+-   .52730   .66+-  .05   -4.9
C210  ECTU     5.28183+-   .36496   6.17992+-   .36011  1.17+-  .11    1.8
C211  OHTU  * 16.83901+-  1.97689   9.51726+-   .54911   .57+-  .07   -3.6
C212  EHTU  *   .19262+-   .06083    .18952+-   .02518   .98+-  .34    -.0
C213  OLTU  *  7.41079+-  1.13513   6.44768+-   .53143   .87+-  .15    -.8
C214  ELTU  *  5.08921+-   .51254   5.99039+-   .50866  1.18+-  .16    1.2
```

```
SOURCE CONTRIBUTION ESTIMATES - SITE: 154        DATE: 04/06/96   CMB7 33889
SAMPLE DURATION         12    START HOUR      0       SIZE:   FINE
R SQUARE       .99   PERCENT MASS     110.3    CHI SQUARE      3.43          DF       32

  SOURCE     SCE(UG/M3)   STD ERR     TSTAT
 -----------------------------------------
 8     RDUST        .5362      .0673    7.9663
 16     SO4       1.1273     .1507    7.4825
 17     NO3        .7141     .1039    6.8742
 20     MARI1       .2574     .1114    2.3099
 25     WBURN       1.5638      .0924   16.9244
 32     VEH1       3.1155     .0787   39.5697
 33     PETVH      5.3686      .3328   16.1319
 35     DIES2     11.3624    1.2710    8.9399
 -----------------------------------------

 MEASURED CONCENTRATION FOR SIZE: FINE      21.8+-    1.7

SPECIES------I---MEAS----------------CALC------------RATIO C/M----RATIO R/U
 C1     TOT    T  21.80250+-  1.70749  24.04530+-  1.24185   1.10+-  .10     1.1
 C11     Na    *   .16276+-   .03828   .13937+-   .02422    .86+-  .25    -.5
 C12     Mg    *   .06001<    .10336   .02879<    .07262    .48<  1.47    -.2
 C13     Al    *  .18779+-   .01807   .13670+-   .01069    .73+-  .09   -2.4
 C14     Si    *  .09659+-   .00801   .08572+-   .00686    .89+-  .10   -1.0
 C15     P     *  .00546<    .01477   .00789<    .00268   1.44<  3.93     .2
 C16     S     *  .53035+-   .02218   .53035+-   .04341   1.00+-  .09     .0
 C17     Cl       .05186+-   .00648   .20124+-   .02599   3.88+-  .70    5.6
 C19     K     *  .09124+-   .00412   .09242+-   .00205   1.01+-  .05     .3
 C20     Ca    *   .04973+-   .00416   .05551+-   .00148   1.12+-  .10     1.3
 C22     Ti    *  .02178<    .03879   .00313<    .00967    .14<   .51    -.5
 C23     V     *  .01067<    .01588   .00033<    .00392    .03<   .37    -.6
 C24     Cr    *  .00743+-   .00133   .00097+-   .00087    .13+-  .12   -4.1
 C25     Mn    *   .01102+-   .00109   .00128+-   .00066    .12+-  .06   -7.6
 C26     Fe        .18812+-   .01242   .04689+-   .00031    .25+-  .02  -11.4
 C27     Co    *   .00020<    .00375   .00012<    .00068    .58< 11.26    -.0
 C28     Ni    *  .01436+-   .00081   .01502+-   .00045   1.05+-  .07     .7
 C29     Cu        .03092+-   .00395   .00188+-   .00024    .06+-  .01   -7.3
 C30     Zn        .14507+-   .00155   .02468+-   .00024    .17+-  .00  -76.7
 C31     Ga    *   .00187<    .00861   .00037<    .00591    .20<  3.30    -.1
 C33     As    *   .01572<    .11480   .00017<    .08775    .01<  5.58    -.1
 C34     Se    *   .00000<    .00393   .00002<    .00247    .00<   .00     .0
 C35     Br    *  .42778+-   .01329   .39967+-   .00151    .93+-  .03   -2.1
C47     Ag    *  .00000<    .01588   .00089<    .00380    .00<   .00     .1
 C48     Cd        .00000<    .01704   .00276<    .00407    .00<   .00     .2
 C49     In    *  .00000<    .01924   .00000<    .00462    .00<   .00     .0
 C50     Sn    *   .00578<    .02484   .00005<    .00596    .01<  1.03    -.2
 C51     Sb    *   .00379<    .02914   .00154<    .00705    .41<  3.63    -.1
 C56     Ba    *   .03452<    .10736   .00198<    .02583    .06<   .77    -.3
 C57     La    *   .00000<    .14197   .00378<    .03412    .00<   .00     .0
 C79     Au    *   .00000<    .00805   .00027<    .00187    .00<   .00     .0
 C80     Hg    *   .00377<    .00566   .00201<    .00228    .53<  1.00    -.3
 C81     Tl    *  .00000<    .02047   .00000<    .01509    .00<   .00     .0
 C82     Pb    *   .72827+-   .00595   .73195+-   .00155   1.01+-  .01      .6
 C92     U     *  .00106<    .00832   .00001<    .00489    .01<  4.59    -.1
 C201   Cl-        .45620+-   .04562   .31521+-   .03030    .69+-  .10   -2.6
 C202   NO3-  *    .75223+-   .07522   .75223+-   .07151   1.00+-  .14      .0
 C203   SO4--      1.53183+-   .15318   1.69821+-   .12118   1.11+-  .14      .9
 C204   Ca++        .00000+-   .00000   .05502+-   .00371    .00+-  .00    14.8
 C205   K+         .05677+-   .00568   .07905+-   .00744   1.39+-  .19     2.4
 C206   Mg++        .15105+-   .01511   .01347+-   .00232    .09+-  .02    -9.0
 C207   Na+        1.88767+-   .18877   .10401+-   .02574    .06+-  .01    -9.4
 C208   NH4+        .00000+-   .00000   .12540+-   .01191    .00+-  .00    10.5
 C209   OCTU     12.99676+-   .89213   9.06067+-   .35685    .70+-  .06    -4.1
 C210   ECTU      4.13625+-   .28386   3.92662+-   .24237    .95+-  .09     -.6
 C211   OHTU  *   7.14720+-   .87186   5.06305+-   .34654    .71+-  .10    -2.2
 C212   EHTU  *    .33455+-   .10138   .65690+-   .01597   1.96+-  .60     3.1
 C213   OLTU  *   5.84955+-   .91196   3.99762+-   .36948    .68+-  .12    -1.9
 C214   ELTU  *   3.80170+-   .38843   3.26972+-   .34240    .86+-  .13    -1.0
```

J.2 Modelling at the Drill Hall Site

```
SOURCE CONTRIBUTION ESTIMATES -  SITE: 73          DATE: 14/07/95   CMB7 33889
SAMPLE DURATION        6     START HOUR      0      SIZE:   FINE
R SQUARE    1.00   PERCENT MASS    110.5     CHI SQUARE     2.51          DF       35

   SOURCE    SCE(UG/M3)   STD ERR     TSTAT
------------------------------------------
8    RDUST        .3008      .1166     2.5801
16    SO4        .2125     .1455    1.4605
17    NO3        .6044     .0903    6.6933
25    WBURN       2.8400      .1611    17.6335
34    VEH2      10.4656      .0774   135.1366
35    DIES2      17.4480    2.5019     6.9738
------------------------------------------

MEASURED CONCENTRATION FOR SIZE: FINE        28.9+-     2.9

SPECIES-------I---MEAS------------------CALC-------------RATIO C/M----RATIO R/U
C1    TOT    T  28.85247+-  2.92259  31.87129+-  2.38693   1.10+-  .14      .8
C11   Na    *   .17200<   .17271    .05849<   .03464    .34<  .40     -.6
C12   Mg    *   .04949<   .15545   .02365<   .11710    .48<  2.80     -.1
C13   Al    *  .16701+-  .02745   .16923+-  .01690  1.01+-  .19     .1
C14   Si    *  .10154+-  .01283   .08142+-  .01141   .80+-  .15   -1.2
C15   P     *  .01833<   .02208   .01165<   .00405   .64<  .80     -.3
C16   S     *  .30178+-  .03238   .30178+-  .03060  1.00+-  .15     .0
C17   Cl       .03335+-  .00929   .16680+-  .00564  5.00+- 1.40   12.3
C19   K     *  .15255+-  .00781   .15375+-  .00312  1.01+-  .06     .1
C20   Ca    *   .03948+-  .00775   .04791+-  .00233  1.21+-  .25     1.0
C22   Ti    *  .00341<   .07561   .00225<   .01502   .66< 15.33     -.0
C23   V     *  .00578<   .03074   .00037<   .00608   .06<  1.11     -.2
C24   Cr    *  .00154<   .00702   .00137<   .00136   .89<  4.15     -.0
C25   Mn    *   .00294<   .00535   .00184<   .00103   .63<  1.19     -.2
C26   Fe       .12770+-  .01310   .04176+-  .00047   .33+-  .03    -6.6
C27   Co    *   .00116<   .00452   .00016<   .00080   .14<  .88     -.2
C28   Ni    *  .00247<   .00375   .01474<   .00070  5.96<  9.04     3.2
C29   Cu    *   .01010+-  .00138   .00224+-  .00038   .22+-  .05    -5.5
C30   Zn       .03585+-  .00166   .03665+-  .00037  1.02+-  .05     .5
C31   Ga    *   .00049<   .01340   .00054<   .00954  1.12< 36.44       .0
C33   As    *  .00000<   .16924   .00025<   .14164   .00<  .00     .0
C34   Se    *  .00000<   .00631   .00004<   .00398   .00<  .00     .0
C35   Br    *  .59742+-  .00535   .58628+-  .00242   .98+-  .01    -1.9
C48   Cd        .00000<   .03309   .00430<   .00634   .00<  .00     .1
C49   In    *  .00000<   .03753   .00000<   .00719   .00<  .00    .0
C50   Sn    *   .00000<   .04787   .00003<   .00928   .00<  .00     .0
C51   Sb    *   .02912<   .05689   .00257<   .01097   .09<  .41     -.5
C56   Ba    *   .00000<   .21099   .00262<   .04015   .00<  .00     .0
C57   La    *  .00000<   .27954   .00578<   .05306   .00<  .00     .0
C79   Au    *   .00217<   .01083   .00043<   .00298   .20<  1.69     -.2
C80   Hg    *   .00069<   .01004   .00253<   .00376  3.67< 53.64       .2
C81   Tl    *  .00000<   .03088   .00000<   .02435   .00<  .00    .0
C82   Pb    *  1.07216+-  .01034  1.09158+-  .00249  1.02+-  .01     1.8
C92   U     *  .00280<   .01322   .00001<   .00777   .00<  2.78     -.2
C201  Cl-      .93066+-  .09307   .38392+-  .02903   .41+-  .05   -5.6
C202  NO3-  *   .66302+-  .06630   .66302+-  .06072  1.00+-  .14     .0
C203  SO4--     1.86740+-  .18674  1.05357+-  .06991   .56+-  .07   -4.1
C204  Ca++       .74818+-  .07482   .06575+-  .00548   .09+-  .01   -9.1
C205  K+        .29805+-  .02981   .13548+-  .01348   .45+-  .06   -5.0
C206  Mg++       .12774+-  .01277   .00063+-  .00006   .00+-  .00  -10.0
C207  Na+        .35280+-  .03528   .00058+-  .00006   .00+-  .00  -10.0
C208  NH4+      1.04015+-  .10401   .19190+-  .01828   .18+-  .03   -8.0
C209  OCTU      18.69424+-  1.25710  12.49645+-   .49570    .67+-  .05    -4.6
C210  ECTU      4.29846+-   .54745  5.99514+-   .37218  1.39+-  .20     2.6
C211  OHTU   *  10.25953+-  1.29765  7.16324+-   .49666    .70+-  .10    -2.2
C212  EHTU   *   2.51419+-   .44607  1.00845+-   .02446    .40+-  .07    -3.4
C213  OLTU   *   8.43471+-  1.21519  5.33321+-   .50028    .63+-  .11    -2.4
C214  ELTU   *   1.78427+-   .63279  4.98669+-   .52578   2.79+- 1.03     3.9
```

```
SOURCE CONTRIBUTION ESTIMATES - SITE: 78        DATE: 25/07/95    CMB7 33889
SAMPLE DURATION       6     START HOUR      0      SIZE:   FINE
R SQUARE      1.00   PERCENT MASS     120.2    CHI SQUARE        .67            DF        31

    SOURCE    SCE(UG/M3)   STD ERR      TSTAT
-------------------------------------------
6     RKBRN       5.6793      .3165    17.9462
8     RDUST       1.1062      .1483     7.4593
13     DIVEH     22.0804     4.1107     5.3715
16     SO4       6.4079      .6747     9.4975
17     NO3       2.6266      .3771     6.9659
28     OHC       6.6893     2.4623     2.7166
30     EHC       2.4042      .5258     4.5721
34     VEH2     14.0320       .1291   108.6630
36     COMPB        .5515      .3282     1.6805
-------------------------------------------

MEASURED CONCENTRATION FOR SIZE: FINE        51.2+-     3.9

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
C1     TOT    T  51.20867+-  3.85697  61.57735+-  3.89815  1.20+-  .12    1.9
C11    Na     *   .21697<   .25227    .12670<   .04524    .58<  .71    -.4
C12    Mg     *   .10641<   .21847    .03398<   .15705    .32<  1.61   -.3
C13    Al     *  .28601+-  .03852   .27404+-  .02249    .96+-  .15    -.3
C14    Si     *  .20081+-  .01811   .19112+-  .01532    .95+-  .11    -.4
C15    P      *  .03275<   .03629   .01778<   .00554    .54<  .63    -.4
C16    S      * 2.44852+-  .04647  2.44852+-   .21520  1.00+-  .09     .0
C17    Cl        .03254<   .04998   .27138<   .00774   8.34< 12.81    4.7
C19    K      *  .18114+-  .00827   .18243+-  .00422   1.01+-  .05     .1
C20    Ca     *   .10683+-  .00872   .10971+-  .00225  1.03+-  .09     .3
C22    Ti     *  .00401<   .08749   .00795<   .01993  1.98< 43.43     .0
C23    V      *  .06129+-  .01807   .01038+-  .00808    .17+-  .14   -2.6
C24    Cr     *  .00057<   .01709   .00222<   .00175  3.91< *****     .1
C25    Mn     *   .01328+-  .00268   .00412+-  .00131    .31+-  .12   -3.1
C26    Fe        .51918+-  .04562   .11218+-  .00071    .22+-  .02   -8.9
C27    Co     *   .00000<   .00953   .00024<   .00146    .00<  .00     .0
C28    Ni     *  .02147+-  .00156   .02288+-  .00093  1.07+-  .09     .8
C29    Cu        .01371+-  .00150   .00354+-  .00050    .26+-  .05   -6.4
C30    Zn        .11989+-  .00229   .05270+-  .00050    .44+-  .01  -28.7
C31    Ga     *   .00136<   .01738   .00080<   .01279    .59< 12.06   -.0
C33    As     *   .00631<   .23086   .00041<   .18990    .06< 30.21   -.0
C34    Se     *   .00000<   .00797   .00009<   .00533    .00<  .00     .0
C35    Br     *  .87638+-  .06663   .78667+-  .00324    .90+-  .07   -1.3
C48    Cd        .00485<   .03467   .00559<   .00844   1.15<  8.44     .0
C49    In     *  .00000<   .03982   .00000<   .00959    .00<  .00     .0
C50    Sn     *   .00253<   .05201   .00025<   .01237    .10<  5.30   -.0
C51    Sb     *   .03550<   .06091   .00479<   .01462    .13<  .47    -.5
C56    Ba     *   .00000<   .22117   .00435<   .05348    .00<  .00     .0
C57    La     *  .10568<   .29556   .01293<   .07081    .12<  .75    -.3
C79    Au     *   .00000<   .01281   .00054<   .00398    .00<  .00     .0
C80    Hg     *   .00000<   .01142   .00333<   .00503    .00<  .00     .3
C81    Tl     *  .00000<   .04130   .00000<   .03265    .00<  .00     .0
C82    Pb     *  1.46523+-  .01200  1.46586+-   .00331  1.00+-  .01     .1
C92    U      *  .00000<   .01713   .00002<   .01041    .00<  .00     .0
C201   Cl-       1.00365+-  .10036  1.06756+-   .10609  1.06+-  .15     .4
C202   NO3-   *  2.70073+-  .27007  2.70073+-   .26276  1.00+-  .14     .0
C203   SO4--     7.03163+-  .70316  7.66910+-   .64648  1.09+-  .14     .7
C204   Ca++       .48054+-  .04805   .28089+-  .02194    .58+-  .07   -3.8
C205   K+        .29197+-  .02920   .54485+-  .05391   1.87+-  .26    4.1
C206   Mg++       .12774+-  .01277   .00386+-  .00027    .03+-  .00   -9.7
C207   Na+        .47445+-  .04745   .00596+-  .00035    .01+-  .00   -9.9
C208   NH4+      1.87348+-  .18735   .26882+-  .02335    .14+-  .02   -8.5
C209   OCTU     23.60097+- 1.52068  17.60942+-   .66156    .75+-  .06   -3.6
C210   ECTU     11.49635+- 1.45985   7.86221+-   .47511    .68+-  .10   -2.4
C211   OHTU   * 17.35604+- 2.06813  17.35605+-   .97851  1.00+-  .13     .0
C212   EHTU   *  2.57502+-  .46634   2.57502+-   .24245  1.00+-  .20     .0
C213   OLTU   *  6.24493+-  .58974   6.94262+-   .66819  1.11+-  .15     .8
C214   ELTU   *  8.92133+- 2.01119   7.69134+-   .24283    .86+-  .20    -.6
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SOURCE CONTRIBUTION ESTIMATES - SITE: 123      DATE: 16/02/96   CMB7 33889
SAMPLE DURATION      19    START HOUR      0      SIZE:   FINE
R SQUARE      .99  PERCENT MASS    120.4    CHI SQUARE     2.76          DF      33

  SOURCE   SCE(UG/M3)   STD ERR     TSTAT
-------------------------------------------
8     RDUST        .7814      .0235    33.2668
13     DIVEH      6.0132    1.1072     5.4310
16     SO4       1.1682      .1271     9.1941
17     NO3        .1821      .0276     6.6109
20     MARI1       .2527     .0673     3.7580
25     WBURN       1.3865      .0733    18.9068
28     OHC       2.0332      .6496     3.1298
32     VEH1      1.7381      .0419    41.4801
33     PETVH        .7870      .1761     4.4696
-------------------------------------------

MEASURED CONCENTRATION FOR SIZE: FINE       11.9+-     1.0

SPECIES--------I---MEAS-------------------CALC--------------RATIO C/M----RATIO R/U
C1    TOT    T  11.91546+-   .98694  14.34247+-  1.02166  1.20+-  .13     1.7
C11    Na     *    .16114+-   .02321    .12508+-   .01569    .78+-  .15    -1.3
C12    Mg     *    .03533<    .05100    .02178<    .03835    .62<  1.40     -.2
C13    Al     *   .06350+-   .00807   .09151+-   .00556  1.44+-  .20     2.9
C14    Si     *   .08702+-   .00508   .09116+-   .00380  1.05+-  .08      .7
C15    P      *   .00765<    .00937   .00570<    .00140   .74<   .93    -.2
C16    S      *   .47650+-   .01089   .47650+-   .03966  1.00+-  .09      .0
C17    Cl         .02520+-   .00414   .17806+-   .02535  7.07+- 1.54     6.0
C19    K      *   .08371+-   .00351   .08472+-   .00123  1.01+-  .04      .3
C20    Ca     *    .04981+-   .00281    .06072+-   .00115   1.22+-  .07     3.6
C22    Ti     *  .00291<    .02438   .00408<    .00522  1.40< 11.89      .0
C23    V      *   .00792<    .01000   .00025<    .00213   .03<   .27    -.8
C24    Cr     *   .00207<    .00239   .00065<    .00047   .31<   .43    -.6
C25    Mn     *    .00221+-   .00060    .00093+-   .00036    .42+-  .20    -1.8
C26    Fe     *   .05420+-   .00110   .05210+-   .00020   .96+-  .02   -1.9
C27    Co     *    .00066<    .00160   .00005<    .00072   .07<  1.10     -.4
C28    Ni     *   .00220+-   .00043   .00234+-   .00024  1.06+-  .23      .3
C29    Cu     *    .00246+-   .00043    .00101+-   .00013    .41+-  .09    -3.2
C30    Zn          .01797+-   .00058   .01398+-   .00013   .78+-  .03   -6.7
C31    Ga     *    .00123<    .00422    .00021<    .00312    .17<  2.61     -.2
C33    As     *   .00169<    .05263   .00011<    .04626   .07< 27.41     -.0
C34    Se     *   .00000<    .00199   .00002<    .00130   .00<   .00     .0
C35    Br     *  .13265+-   .01151   .17461+-   .00080  1.32+-  .11     3.6
C48    Cd         .00213<    .01078   .00152<    .00220   .72<  3.78    -.1
C49    In     *  .00737<    .01237   .00000<    .00250   .00<   .34   -.6
C50    Sn     *   .00000<    .01551   .00008<    .00323   .00<   .00     .0
C51    Sb     *   .00113<    .01806   .00103<    .00382   .91< 15.02      .0
C56    Ba     *   .00000<    .06796   .00167<    .01400   .00<   .00     .0
C57    La     *  .00000<    .08997   .00295<    .01850   .00<   .00     .0
C79    Au     *   .00004<    .00351   .00018<    .00100  4.12< *****      .0
C80    Hg     *   .00036<    .00321   .00066<    .00126  1.81< 16.34       .1
C81    Tl     *  .00000<    .00963   .00000<    .00795   .00<   .00     .0
C82    Pb     *   .33384+-   .00324    .33162+-   .00082    .99+-  .01    -.7
C92    U      *  .00000<    .00354   .00001<    .00253   .00<   .00     .0
C201   Cl-        .13553+-   .01355   .28998+-   .02898  2.14+-  .30    4.8
C202   NO3-  *    .20233+-   .02023    .20233+-   .01832   1.00+-  .13      .0
C203   SO4--      1.37243+-   .13724  1.49286+-   .11948  1.09+-  .14      .7
C204   Ca++        .18897+-   .01890   .06168+-   .00416   .33+-  .04   -6.6
C205   K+         .09735+-   .00973   .07113+-   .00660   .73+-  .10   -2.2
C206   Mg++        .03627+-   .00363   .01376+-   .00228   .38+-  .07    -5.3
C207   Na+        .12598+-   .01260   .10261+-   .02528   .81+-  .22    -.8
C208   NH4+        .03436+-   .00344   .06980+-   .00631  2.03+-  .27    4.9
C209   OCTU       6.76989+-   .44539  4.03638+-   .16189   .60+-  .05   -5.8
C210   ECTU       2.43055+-   .30541  2.07397+-   .12844   .85+-  .12   -1.1
C211   OHTU  *  4.48569+-   .54083  4.48569+-   .26396  1.00+-  .13      .0
C212   EHTU  *  1.16437+-   .20997    .05039+-   .00853   .04+-  .01   -5.3
C213   OLTU  *  2.28420+-   .32287  1.58389+-   .15962   .69+-  .12   -1.9
C214   ELTU  *  1.26617+-   .37744  2.02358+-   .18145  1.60+-  .50     1.8
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SOURCE CONTRIBUTION ESTIMATES - SITE: 138       DATE: 30/04/96    CMB7 33889
SAMPLE DURATION      12    START HOUR      0      SIZE:   FINE
R SQUARE     .99   PERCENT MASS    118.3     CHI SQUARE     2.42          DF      33

  SOURCE    SCE(UG/M3)   STD ERR     TSTAT
 ----------------------------------------
 7    CALCT      1.2429     .0614    20.2516
 8    RDUST      1.0620     .0346    30.7145
 13   DIVEH      2.2139     .7747     2.8576
 16   SO4        5.1266     .5155     9.9453
 17   NO3         .2389     .0344     6.9403
 25   WBURN      1.7487     .0852    20.5154
 28   OHC        3.3749     .7847     4.3008
 29   OLC        2.3688     .5994     3.9521
 34   VEH2       2.9966     .0293   102.3086
 ----------------------------------------
 MEASURED CONCENTRATION FOR SIZE: FINE       17.2+-    1.4

SPECIES-------I---MEAS------------------CALC-------------RATIO C/M----RATIO R/U
 C1    TOT   T  17.22648+-  1.39425  20.37333+-  1.18060  1.18+-  .12    1.7
 C11   Na    *    .12473+-   .04018    .02462+-   .00933   .20+-  .10   -2.4
 C12   Mg    *    .05320<    .06589    .00945<    .03345   .18<   .67   -.6
 C13   Al    *    .15197+-   .01402    .21567+-   .00457  1.42+-  .13    4.3
 C14   Si    *    .35837+-   .01059    .34699+-   .00330   .97+-  .03   -1.0
 C15   P     *    .00347<    .01884    .00680<    .00089  1.96< 10.66     .2
 C16   S     *   1.75674+-   .01457   1.75674+-   .16939  1.00+-  .10     .0
 C17   Cl         .00000<    .02949    .09612<    .00145   .00<   .00    3.3
 C19   K     *    .10371+-   .00439    .10467+-   .00077  1.01+-  .04     .2
 C20   Ca    *    .05596+-   .00449    .07166+-   .00116  1.28+-  .10    3.4
 C22   Ti    *    .00528<    .04248    .01021<    .00285  1.93< 15.55     .1
 C23   V     *    .00355<    .01726    .00319<    .00123   .90<  4.38   -.0
 C24   Cr    *    .00208<    .00398    .00114<    .00025   .55<  1.06   -.2
 C25   Mn    *    .00327+-   .00102    .00117+-   .00019   .36+-  .13   -2.0
 C26   Fe    *    .08141+-   .00175    .07843+-   .00018   .96+-  .02   -1.7
 C27   Co    *    .00000<    .00254    .00004<    .00094   .00<   .00     .0
 C28   Ni    *    .00100<    .00209    .00483<    .00014  4.81< 10.01    1.8
 C29   Cu    *    .00279+-   .00074    .00104+-   .00011   .37+-  .11   -2.3
 C30   Zn         .00810+-   .00082    .01282+-   .00008  1.58+-  .16    5.7
 C31   Ga    *    .00000<    .00506    .00013<    .00272   .00<   .00     .0
 C33   As    *    .00000<    .05081    .00009<    .04055   .00<   .00     .0
 C34   Se    *    .00000<    .00274    .00003<    .00113   .00<   .00     .0
 C35   Br    *    .16506+-   .00202    .16731+-   .00069  1.01+-  .01    1.1
 C48   Cd         .00145<    .01788    .00085<    .00130   .58<  7.27   -.0
 C49   In    *    .00000<    .02116    .00004<    .00147   .00<   .00     .0
 C50   Sn    *    .00000<    .02716    .00010<    .00188   .00<   .00     .0
 C51   Sb    *    .00239<    .03235    .00106<    .00220   .44<  6.03   -.0
 C56   Ba    *    .01896<    .11838    .00208<    .00794   .11<   .80   -.1
 C57   La    *    .00000<    .15870    .00815<    .01049   .00<   .00     .1
 C79   Au    *    .00000<    .00591    .00016<    .00075   .00<   .00     .0
 C80   Hg    *    .00000<    .00528    .00059<    .00101   .00<   .00     .1
 C81   Tl    *    .00000<    .01024    .00000<    .00696   .00<   .00     .0
 C82   Pb    *    .31951+-   .00429    .31308+-   .00070   .98+-  .01   -1.5
 C92   U     *    .00000<    .00575    .00003<    .00220   .00<   .00     .0
 C201  Cl-        .16727+-   .01673    .24241+-   .01788  1.45+-  .18    3.1
 C202  NO3-  *    .24635+-   .02464    .24635+-   .02390  1.00+-  .14     .0
 C203  SO4--     4.90876+-   .49088   5.29312+-   .51275  1.08+-  .15     .5
 C204  Ca++       .34367+-   .03437    .07752+-   .00546   .23+-  .03   -7.6
 C205  K+         .17336+-   .01734    .08630+-   .00830   .50+-  .07   -4.5
 C206  Mg++       .06691+-   .00669    .00256+-   .00022   .04+-  .01   -9.6
 C207  Na+        .12774+-   .01277    .00415+-   .00029   .03+-  .00   -9.7
 C208  NH4+       .18248+-   .01825    .03700+-   .00245   .20+-  .02   -7.9
 C209  OCTU      8.96188+-   .60827   3.21821+-   .09194   .36+-  .03   -9.3
 C210  ECTU      1.33820+-   .18248    .92948+-   .04902   .69+-  .10   -2.2
 C211  OHTU  *   5.39335+-   .67924   5.39335+-   .35309  1.00+-  .14     .0
 C212  EHTU  *    .57786+-   .11152    .04440+-   .00427   .08+-  .02   -4.8
 C213  OLTU  *   3.56853+-   .52785   3.56853+-   .25367  1.00+-  .16     .0
 C214  ELTU  *    .76034+-   .23273    .88509+-   .06919  1.16+-  .37     .5
```

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SOURCE CONTRIBUTION ESTIMATES - SITE: 141       DATE: 08/05/96   CMB7 33889
SAMPLE DURATION       12    START HOUR      0       SIZE:   FINE
R SQUARE      1.00  PERCENT MASS    117.9    CHI SQUARE      1.65          DF       34

  SOURCE     SCE(UG/M3)   STD ERR     TSTAT
-----------------------------------------------
6     RKBRN        5.4974     .2216   24.8028
8     RDUST        1.0005     .0887   11.2846
13    DIVEH       20.2469    1.9633   10.3125
14    PETVE        1.3783     .1725    7.9913
16    SO4          1.6040     .2518    6.3712
17    NO3          1.9038     .2743    6.9418
32    VEH1         8.5038     .1036   82.1192
-----------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE          34.0+-    2.5

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
C1    TOT    T  34.04638+-  2.47373  40.13466+-  1.91417   1.18+-  .10    1.9
C11   Na     *    .11247<    .12299    .12248<    .04863   1.09<  1.27     .1
C12   Mg     *    .12063<    .21074    .03415<    .18650    .28<  1.62    -.3
C13   Al     *    .27466+-   .03074    .27306+-   .02573    .99+-  .15    -.0
C14   Si     *    .13287+-   .01133    .17068+-   .01837   1.28+-  .18    1.8
C15   P      *    .02571+-   .00637    .02045+-   .00529    .80+-  .28    -.6
C16   S      *    .84283+-   .04603    .84283+-   .06770   1.00+-  .10     .0
C17   Cl          .02279<    .02791    .25918<    .00813  11.37< 13.93    8.1
C19   K      *    .17364+-   .00510    .17517+-   .00412   1.01+-  .04     .2
C20   Ca     *    .10383+-   .00482    .10127+-   .00218    .98+-  .05    -.5
C22   Ti     *    .00051<    .04480    .00721<    .01924  14.21< *****     .1
C23   V      *    .00806<    .02761    .00082<    .00781    .10<  1.03    -.3
C24   Cr     *    .00400<    .00868    .00203<    .00168    .51<  1.18    -.2
C25   Mn     *    .00912+-   .00137    .00388+-   .00127    .43+-  .15   -2.8
C26   Fe          .28448+-   .02292    .10043+-   .00068    .35+-  .03   -8.0
C27   Co     *    .00000<    .00508    .00021<    .00137    .00<   .00     .0
C28   Ni     *    .00958+-   .00075    .00979+-   .00090   1.02+-  .12     .2
C29   Cu     *    .01345+-   .00180    .00294+-   .00055    .22+-  .05   -5.6
C30   Zn          .07073+-   .00120    .05552+-   .00051    .78+-  .02  -11.7
C31   Ga     *    .00303<    .01722    .00075<    .01518    .25<  5.20    -.1
C33   As     *    .00000<    .24815    .00038<    .22602    .00<   .00     .0
C34   Se     *    .00000<    .00730    .00008<    .00631    .00<   .00     .0
C35   Br     *    .83960+-   .00543    .83667+-   .00384   1.00+-  .01    -.4
C48   Cd          .00000<    .01762    .00559<    .00829    .00<   .00     .3
C49   In     *    .00341<    .02068    .00000<    .00942    .00<  2.77    -.1
C50   Sn     *    .00722<    .02619    .00010<    .01212    .01<  1.68    -.2
C51   Sb     *    .00379<    .03063    .00518<    .01424   1.37< 11.67     .0
C56   Ba     *    .00000<    .11261    .00485<    .05183    .00<   .00     .0
C57   La     *    .06982<    .15124    .01353<    .06867    .19<  1.07    -.3
C79   Au     *    .00000<    .00754    .00050<    .00437    .00<   .00     .1
C80   Hg     *    .00936+-   .00274    .00265+-   .00586    .28+-  .63   -1.0
C81   Tl     *    .00000<    .04313    .00000<    .03883    .00<   .00     .0
C82   Pb     *   1.58158+-   .00861   1.58505+-   .00385   1.00+-  .01     .4
C92   U      *    .00000<    .01439    .00002<    .01222    .00<   .00     .0
C201  Cl-         .58394+-   .05839   1.02922+-   .10269   1.76+-  .25    3.8
C202  NO3-   *   1.97182+-   .19718   1.97182+-   .19050   1.00+-  .14     .0
C203  SO4--      5.54035+-   .55403   2.69853+-   .17890    .49+-  .06   -4.9
C204  Ca++        .00000+-   .00000    .24783+-   .02108    .00+-  .00   11.8
C205  K+          .05373+-   .00537    .52412+-   .05218   9.75+- 1.38    9.0
C206  Mg++        .05981+-   .00598    .00209+-   .00021    .03+-  .00   -9.6
C207  Na+        1.30069+-   .13007    .00194+-   .00019    .00+-  .00  -10.0
C208  NH4+        .33354+-   .03335    .24715+-   .02143    .74+-  .10   -2.2
C209  OCTU      16.07867+-  1.09489  13.51342+-   .56237    .84+-  .07   -2.1
C210  ECTU       7.21817+-   .48662   7.52458+-   .43692   1.04+-  .09     .5
C211  OHTU   *  11.16180+-  1.32806   8.58116+-   .63390    .77+-  .11   -1.8
C212  EHTU   *    .59813+-   .16221    .16421+-   .02880    .27+-  .09   -2.6
C213  OLTU   *   4.91687+-   .79613   4.93225+-   .23024   1.00+-  .17     .0
C214  ELTU   *   6.62003+-   .66879   7.36037+-   .22756   1.11+-  .12    1.0
```

```
SOURCE CONTRIBUTION ESTIMATES -  SITE: 149        DATE: 27/05/96   CMB7 33889
SAMPLE DURATION          12     START HOUR      0       SIZE:    FINE
R SQUARE       1.00   PERCENT MASS     103.1      CHI SQUARE      2.29              DF        35

  SOURCE    SCE(UG/M3)    STD ERR      TSTAT
 ------------------------------------------
 6     RKBRN        3.6475       .1788     20.4002
 8     RDUST         .2450       .0736      3.3296
 16     SO4        .8895      .1683     5.2850
 17     NO3        .7922      .1152     6.8751
 32     VEH1       6.4097       .1601     40.0435
 33     PETVH        1.5755       .7268      2.1677
 35     DIES2      12.5374     1.4267      8.7877
 ------------------------------------------
 MEASURED CONCENTRATION FOR SIZE: FINE          25.3+-      2.1

SPECIES--------I---MEAS------------------CALC-------------RATIO C/M----RATIO R/U
 C1     TOT     T  25.31260+-  2.05790  26.09684+-  1.44112   1.03+-  .10      .3
 C11    Na     *    .11456+-   .03744    .08112+-   .03456     .71+-  .38      -.7
 C12    Mg     *    .04949<    .15568    .02269<    .14013     .46<  3.18      -.1
 C13    Al     *   .17355+-   .02466   .16752+-   .01902     .97+-  .18     -.2
 C14    Si     *   .04948+-   .00912   .07168+-   .01380   1.45+-  .39      1.3
 C15    P      *   .01886+-   .00526   .01401+-   .00347     .74+-  .28     -.8
 C16    S      *   .50422+-   .03372   .50422+-   .04286   1.00+-  .11       .0
 C17    Cl         .01096<    .02168   .17146<    .00571  15.65< 30.96      7.2
 C19    K      *   .10920+-   .00453   .11189+-   .00272   1.02+-  .05       .5
 C20    Ca     *    .04052+-   .00439    .04191+-   .00143   1.03+-  .12       .3
 C22    Ti     *   .00166<    .04161   .00274<    .01260   1.65< 41.91       .0
 C23    V      *   .00227<    .01689   .00047<    .00511     .21<  2.72     -.1
 C24    Cr     *   .00097<    .00382   .00123<    .00110   1.26<  5.08       .1
 C25    Mn     *    .00476+-   .00102    .00240+-   .00084     .50+-  .21     -1.8
 C26    Fe     *    .13304+-   .02210    .04255+-   .00043     .32+-  .05     -4.1
 C27    Co     *    .00000<    .00306    .00014<    .00073     .00<   .00      .0
 C28    Ni     *   .00126<    .00202   .00469<    .00060   3.73<  6.01      1.6
 C29    Cu     *    .00875+-   .00177    .00163+-   .00039     .19+-  .06     -3.9
 C30    Zn          .04317+-   .00104    .03814+-   .00035     .88+-  .02     -4.6
 C31    Ga     *    .00000<    .01285    .00046<    .01141     .00<   .00      .0
 C33    As     *    .00000<    .18080    .00023<    .17000     .00<   .00      .0
 C34    Se     *    .00000<    .00561    .00005<    .00473     .00<   .00      .0
 C35    Br     *   .64216+-   .01439   .60847+-   .00288     .95+-  .02    -2.3
 C48    Cd          .00000<    .01760    .00369<    .00551     .00<   .00      .2
 C49    In     *   .00662<    .02020   .00000<    .00626    .00<   .95     -.3
 C50    Sn     *    .00740<    .02607    .00002<    .00804     .00<  1.09      -.3
 C51    Sb     *    .01097<    .03145    .00367<    .00940     .33<  1.29      -.2
 C56    Ba     *    .02626<    .11591    .00306<    .03405     .12<  1.40      -.2
 C57    La     *    .00000<    .15448    .00906<    .04513     .00<   .00      .1
 C79    Au     *    .00000<    .00671    .00031<    .00315     .00<   .00      .0
 C80    Hg     *    .00720+-   .00237    .00167+-   .00434     .23+-  .61     -1.1
 C81    Tl     *   .00000<    .03169   .00000<    .02919    .00<   .00      .0
 C82    Pb     *  1.15075+-   .00742  1.15625+-   .00286   1.00+-  .01       .7
 C92    U      *   .00000<    .01151   .00000<    .00915    .00<   .00      .0
 C201   Cl-         .11861+-   .01186    .68193+-   .06814   5.75+-  .81      8.1
 C202   NO3-  *    .83435+-   .08343    .83435+-   .07933   1.00+-  .14       .0
 C203   SO4--       1.39497+-   .13950   1.58866+-   .10202   1.14+-  .14      1.1
 C204   Ca++         .04765+-   .00476    .14724+-   .01376   3.09+-  .42      6.8
 C205   K+          .10848+-   .01085    .34680+-   .03462   3.20+-  .45      6.6
 C206   Mg++         .27879+-   .02788    .00051+-   .00005    .00+-  .00    -10.0
 C207   Na+         .00000+-   .00000    .00047+-   .00005    .00+-  .00     10.0
 C208   NH4+         .00000+-   .00000    .15306+-   .01329    .00+-  .00     11.5
 C209   OCTU       14.59854+-   .99351   9.35297+-   .35628    .64+-  .05     -5.0
 C210   ECTU        5.82928+-   .39538   4.48991+-   .27046    .77+-  .07     -2.8
 C211   OHTU   *  8.94161+-  1.07461   5.81763+-   .40449    .65+-  .09     -2.7
 C212   EHTU   *   .36496+-   .10138    .73613+-   .01799   2.02+-  .56      3.6
 C213   OLTU   *  5.65693+-   .90517   3.53533+-   .35321    .62+-  .12     -2.2
 C214   ELTU   *  5.46431+-   .54988   3.75377+-   .38207    .69+-  .10     -2.6
```

J.3. Modelling at the Tableview Site

```
SOURCE CONTRIBUTION ESTIMATES - SITE: 59        DATE: 14/07/95   CMB7 33889
SAMPLE DURATION        6     START HOUR      0       SIZE:    FINE
R SQUARE       .96   PERCENT MASS     111.9     CHI SQUARE      2.77            DF        32

 SOURCE    SCE(UG/M3)   STD ERR     TSTAT
 ------------------------------------------
 3    CALOB       2.3527    1.7042     1.3805
 5    TVDST       1.1612     .0920    12.6150
 13    DIVEH      7.4880    1.7491     4.2811
 16    SO4         .7022     .2488     2.8228
 17    NO3        1.3374     .1910     7.0010
 20    MARI1       .4951     .1350     3.6688
 25    WBURN       2.0232     .1507    13.4283
 28    OHC        4.0973    1.1691     3.5048
 34    VEH2       1.0634     .0352    30.1804
 ------------------------------------------
 MEASURED CONCENTRATION FOR SIZE: FINE       18.5+-    2.1

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
 C1     TOT    T  18.50928+-  2.09051  20.72040+-  2.09825  1.12+-  .17     .7
 C11    Na     *    .27946+-   .04925    .22963+-   .02526    .82+-  .17    -.9
 C12    Mg     *    .03094<    .06805    .03555<    .01443   1.15<  2.57     .1
 C13    Al     *   .09884+-   .01385    .05105+-   .00358    .52+-  .08   -3.3
 C14    Si     *   .20773+-   .01148    .20564+-   .00190    .99+-  .06    -.2
 C15    P      *   .01792<    .01857    .00334<    .00223    .19<   .23    -.8
 C16    S      *   .42906+-   .01067    .42906+-   .02427   1.00+-  .06     .0
 C17    Cl         .03013+-   .00752    .30378+-   .04959  10.08+- 3.01     5.5
 C19    K      *   .12245+-   .00740    .12266+-   .00191   1.00+-  .06     .0
 C20    Ca     *    .03070+-   .00762    .04923+-   .00212   1.60+-  .40    2.3
 C22    Ti     *   .00000<    .07818    .00425<    .00754    .00<   .00     .1
 C23    V      *   .00470<    .03173    .01648<    .00265   3.50< 23.64     .4
 C24    Cr     *   .00223<    .00710    .00086<    .00089    .38<  1.29    -.2
 C25    Mn     *    .00375<    .00539    .00107<    .00052    .29<   .43    -.5
 C26    Fe         .04315+-   .00225    .03143+-   .00028    .73+-  .04   -5.2
 C27    Co     *   .00057<    .00385    .00009<    .00048    .16<  1.39    -.1
 C28    Ni     *   .00114<    .00369    .00624<    .00032   5.50< 17.87     1.4
 C29    Cu     *   .00176<    .00383    .00104<    .00025    .59<  1.29    -.2
 C30    Zn         .03936+-   .00168    .00805+-   .00016    .20+-  .01  -18.5
 C31    Ga     *    .00069<    .00655    .00022<    .00114    .32<  3.46    -.1
 C33    As     *   .00260<    .02835    .00012<    .01447    .05<  5.60    -.1
 C34    Se     *   .00041<    .00408    .00003<    .00056    .07<  1.54    -.1
 C35    Br     *   .05921+-   .00189    .06331+-   .00043   1.07+-  .03    2.1
 C48    Cd         .00000<    .03305    .00145<    .00319    .00<   .00     .0
 C49    In     *  .00000<    .03759    .00018<    .00361    .00<   .00     .0
 C50    Sn     *   .03392<    .04884    .00126<    .00469    .04<   .15    -.7
 C51    Sb     *   .02512<    .05710    .00066<    .00558    .03<   .23    -.4
 C56    Ba     *   .00000<    .21397    .00023<    .02069    .00<   .00     .0
 C57    La     *   .00000<    .28352    .00152<    .02750    .00<   .00     .0
 C79    Au     *   .00140<    .01048    .00023<    .00103    .16<  1.44    -.1
 C80    Hg     *   .00000<    .00886    .00057<    .00094    .00<   .00     .1
 C81    Tl     *  .00000<    .01018   .00002<    .00262    .00<   .00     .0
 C82    Pb     *   .16697+-   .00927    .11835+-   .00079    .71+-  .04   -5.2
 C92    U      *  .00000<    .00866    .00000<    .00114    .00<   .00     .0
 C201   Cl-        .91241+-   .09124    .50910+-   .05374    .56+-  .08   -3.8
 C202   NO3-  *   1.36253+-   .13625   1.36253+-   .13376   1.00+-  .14     .0
 C203   SO4--     2.09854+-   .20985   1.93322+-   .11611    .92+-  .11    -.7
 C204   Ca++       .51703+-   .05170    .25116+-   .01824    .49+-  .06   -4.8
 C205   K+         .29197+-   .02920    .13500+-   .00997    .46+-  .06   -5.1
 C206   Mg++        .12774+-   .01277    .03969+-   .00462    .31+-  .05   -6.5
 C207   Na+        .36496+-   .03650    .22295+-   .04956    .61+-  .15   -2.3
 C208   NH4+        .20073+-   .02007    .09447+-   .00791    .47+-  .06   -4.9
 C209   OCTU      10.21898+-   .81103   4.86662+-   .20381    .48+-  .04   -6.4
 C210   ECTU       3.69019+-   .48662   2.60239+-   .16035    .71+-  .10   -2.1
 C211   OHTU   *  7.21817+-   .99351   7.21817+-   .46284   1.00+-  .15     .0
 C212   EHTU   *  2.04785+-   .36496    .07249+-   .01184    .04+-  .01   -5.4
 C213   OLTU   *  3.00081+-   .57313   1.74572+-   .19882    .58+-  .13   -2.1
 C214   ELTU   *  1.64234+-   .58343   2.52991+-   .22646   1.54+-  .56    1.4
```

```
SOURCE CONTRIBUTION ESTIMATES - SITE: 68      DATE: 18/08/95   CMB7 33889
SAMPLE DURATION        12    START HOUR      0      SIZE:   FINE
R SQUARE      .95   PERCENT MASS     96.1    CHI SQUARE     3.81          DF       32

  SOURCE    SCE(UG/M3)   STD ERR     TSTAT
 ------------------------------------------
 3    CALOB       2.0254     .8917    2.2713
 6    RKBRN       2.0461     .1527   13.4000
 7    CALCT        .4299     .0456    9.4248
 8    RDUST        .4620     .0424   10.9027
 13    DIVEH      1.7903     .5218    3.4313
 16    SO4       4.0807     .4284    9.5256
 17    NO3        .5232     .0744    7.0284
 20    MARI1       .7034     .1127    6.2423
 34    VEH2        .3256     .0242   13.4720
 ------------------------------------------
 MEASURED CONCENTRATION FOR SIZE: FINE        12.9+-     1.1

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
 C1    TOT    T  12.89459+-  1.06869  12.38671+-   .96803    .96+-  .11    -.4
 C11   Na    *    .35493+-   .04069    .31615+-   .02968    .89+-  .13    -.8
 C12   Mg    *    .06557+-   .01532    .03967+-   .00861    .61+-  .19   -1.5
 C13   Al    *   .05554+-   .00954   .07859+-   .00129   1.42+-  .24    2.4
 C14   Si    *   .15290+-   .00809   .14730+-   .00090    .96+-  .05    -.7
 C15   P     *   .00000<    .01690   .00243<    .00156    .00<   .00     .1
 C16   S     *  1.48953+-   .01025  1.48953+-   .13498   1.00+-  .09     .0
 C17   Cl        .00160<    .02596   .36862<    .07037  *****< *****    4.9
 C19   K     *   .07245+-   .00388   .07691+-   .00176   1.06+-  .06    1.0
 C20   Ca    *    .03453+-   .00408    .04391+-   .00180   1.27+-  .16    2.1
 C22   Ti    *   .00620<    .04122   .00468<    .00457    .75<  5.07    -.0
 C23   V     *   .00154<    .01672   .01518<    .00124   9.85< *****     .8
 C24   Cr    *   .00066<    .00377   .00073<    .00062   1.11<  6.42     .0
 C25   Mn    *    .00548+-   .00101    .00124+-   .00029    .23+-  .07   -4.0
 C26   Fe    *    .04619+-   .00143   .04503+-   .00021    .97+-  .03    -.8
 C27   Co    *    .00000<    .00220   .00006<    .00050    .00<   .00     .0
 C28   Ni    *   .00136<    .00202   .00473<    .00017   3.48<  5.17    1.7
 C29   Cu    *    .00505+-   .00073    .00052+-   .00019    .10+-  .04   -6.0
 C30   Zn         .00905+-   .00080   .00484+-   .00009    .53+-  .05   -5.2
 C31   Ga    *    .00000<    .00330   .00011<    .00047    .00<   .00     .0
 C33   As    *   .00000<    .00762   .00008<    .00445    .00<   .00     .0
 C34   Se    *    .00003<    .00213   .00003<    .00027    .96< 67.46     .0
 C35   Br        .00752+-   .00073   .02095+-   .00040   2.79+-  .28   16.1
C48   Cd        .00000<    .01711   .00040<    .00195    .00<   .00     .0
 C49   In    *  .00000<    .02009   .00001<    .00219    .00<   .00     .0
 C50   Sn    *    .00000<    .02551   .00103<    .00287    .00<   .00     .0
 C51   Sb    *    .00000<    .03029   .00086<    .00339    .00<   .00     .0
 C56   Ba    *    .00000<    .11277   .00067<    .01263    .00<   .00     .0
 C57   La    *   .00000<    .15127   .00460<    .01694    .00<   .00     .0
 C79   Au    *    .00126<    .00550   .00010<    .00062    .08<   .61    -.2
 C80   Hg    *    .00098<    .00476   .00014<    .00053    .14<   .89    -.2
 C81   Tl    *   .00000<    .00471   .00000<    .00091    .00<   .00     .0
 C82   Pb    *    .03812+-   .00233   .03810+-   .00057   1.00+-  .06     .0
 C92   U     *   .00000<    .00460   .00001<    .00056    .00<   .00     .0
 C201  Cl-        .56265+-   .05627   .69082+-   .08009   1.23+-  .19    1.3
 C202  NO3-  *    .52920+-   .05292    .52920+-   .05232   1.00+-  .14     .0
 C203  SO4--     4.92397+-   .49240  5.00319+-   .41573   1.02+-  .13     .1
 C204  Ca++       .55961+-   .05596   .25714+-   .01711    .46+-  .06   -5.2
 C205  K+        .18248+-   .01825   .22583+-   .01958   1.24+-  .16    1.6
 C206  Mg++       .08212+-   .00821   .04477+-   .00641    .55+-  .10   -3.6
 C207  Na+       .39842+-   .03984   .30006+-   .07036    .75+-  .19   -1.2
 C208  NH4+       .59611+-   .05961   .04158+-   .00235    .07+-  .01   -9.3
 C209  OCTU      5.13990+-   .40551  2.37410+-   .09393    .46+-  .04   -6.6
 C210  ECTU       .99351+-   .14193   .77942+-   .04561    .78+-  .12   -1.4
 C211  OHTU  *  3.34550+-   .46634  1.79981+-   .14186    .54+-  .09   -3.2
 C212  EHTU  *   .61841+-   .12165   .02609+-   .00507    .04+-  .01   -4.9
 C213  OLTU  *  1.79440+-   .33378   .57429+-   .08979    .32+-  .08   -3.5
 C214  ELTU  *   .37510+-   .15965   .75333+-   .06430   2.01+-  .87    2.2
```

```
SOURCE CONTRIBUTION ESTIMATES - SITE: 71        DATE: 14/07/95   CMB7 33889
SAMPLE DURATION      6    START HOUR      0     SIZE:   FINE
R SQUARE      .98   PERCENT MASS    113.4    CHI SQUARE      2.51            DF       33

 SOURCE     SCE(UG/M3)   STD ERR     TSTAT
-------------------------------------------
8    RDUST      1.3872     .0579   23.9617
13    DIVEH      11.0476    2.4922    4.4329
16    SO4      1.1657     .1452    8.0295
17    NO3      2.0553     .2934    7.0041
25    WBURN       3.2213     .1629   19.7703
28    OHC      4.5278    1.3935    3.2491
29    OLC      4.8897    1.2824    3.8130
32    VEH1      2.7605     .0591   46.6726
-------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE        27.4+-    2.7

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
C1    TOT    T  27.38568+-  2.65768  31.05515+-  2.29527  1.13+- .14    1.0
C11   Na    *   .14570<   .17249   .04820<   .02114   .33<  .42    -.6
C12   Mg    *   .05545<   .09424   .01646<   .06071   .30<  1.21    -.3
C13   Al    *  .12626+-  .01865   .14795+-  .00908   1.17+- .19    1.0
C14   Si    *  .18518+-  .01249   .16353+-  .00609   .88+- .07   -1.6
C15   P     *  .01354<   .02214   .00948<   .00259   .70<  1.16    -.2
C16   S     *  .52926+-  .01782   .52926+-  .04072   1.00+- .08     .0
C17   Cl       .04041+-  .00860   .17122+-  .00349   4.24+- .91    14.1
C19   K     *  .18279+-  .00825   .18398+-  .00212   1.01+- .05     .1
C20   Ca    *   .07541+-  .00829   .10155+-  .00225   1.35+- .15    3.0
C22   Ti    *  .00355<   .08096   .00733<   .00960   2.07< 47.21     .0
C23   V     *  .00957<   .03295   .00043<   .00392   .05<  .44    -.3
C24   Cr    *  .00182<   .00748   .00120<   .00086   .66<  2.74    -.1
C25   Mn    *   .00689+-  .00197   .00178+-  .00065   .26+- .12    -2.5
C26   Fe    *  .09513+-  .00288   .09340+-  .00036   .98+- .03    -.6
C27   Co    *  .00057<   .00442   .00007<   .00129   .12<  2.45    -.1
C28   Ni    *  .00065<   .00391   .00032<   .00044   .49<  3.04    -.1
C29   Cu    *   .01062+-  .00146   .00163+-  .00024   .15+- .03    -6.1
C30   Zn       .06914+-  .00197   .02315+-  .00023   .33+- .01   -23.2
C31   Ga    *   .00000<   .00868   .00039<   .00495   .00<  .00     .0
C33   As    *   .00000<   .07772   .00022<   .07315   .00<  .00     .0
C34   Se    *   .00223<   .00501   .00005<   .00207   .02<  .93    -.4
C35   Br       .21863+-  .00318   .24985+-  .00125   1.14+- .02     9.1
C48   Cd       .00517<   .03459   .00269<   .00403   .52<  3.57    -.1
C49   In    *  .00000<   .03907   .00000<   .00457   .00<  .00     .0
C50   Sn    *   .00000<   .05065   .00013<   .00590   .00<  .00     .0
C51   Sb    *   .01476<   .06117   .00188<   .00702   .13<  .71    -.2
C56   Ba    *   .00000<   .22571   .00282<   .02574   .00<  .00     .0
C57   La    *   .03773<   .30217   .00542<   .03403   .14<  1.46    -.1
C79   Au    *   .00292<   .01150   .00037<   .00172   .13<  .78    -.2
C80   Hg    *   .00000<   .00961   .00086<   .00208   .00<  .00     .1
C81   Tl    *  .00000<   .01652   .00000<   .01259   .00<  .00     .0
C82   Pb    *   .48544+-  .00956   .48484+-  .00135   1.00+- .02    -.1
C92   U     *  .00000<   .00996   .00003<   .00403   .00<  .00     .0
C201  Cl-      1.11314+-  .11131   .43785+-  .03293   .39+- .05    -5.8
C202  NO3-  *  2.09246+-  .20925  2.09246+-  .20557  1.00+- .14     .0
C203  SO4--     2.15937+-  .21594  1.71012+-  .12392   .79+- .10   -1.8
C204  Ca++      .72384+-  .07238   .11751+-  .00831   .16+- .02   -8.3
C205  K+        .31630+-  .03163   .15605+-  .01529   .49+- .07   -4.6
C206  Mg++      .13382+-  .01338   .00289+-  .00029   .02+- .00   -9.8
C207  Na+       .45012+-  .04501   .00268+-  .00027   .01+- .00   -9.9
C208  NH4+      .97324+-  .09732   .12999+-  .01161   .13+- .02   -8.6
C209  OCTU     16.30170+-  1.11517  6.88424+-  .29673   .42+- .03   -8.2
C210  ECTU     4.25791+-  .54745  3.81775+-  .23643   .90+- .13   -.7
C211  OHTU  *  8.92133+-  1.15572  8.92133+-  .55212  1.00+- .14     .0
C212  EHTU  *  1.39903+-  .26358   .09219+-  .01590   .07+- .02   -4.9
C213  OLTU  *  7.38037+-  1.07308  7.38037+-  .56804  1.00+- .16     .0
C214  ELTU  *  2.85888+-  .72795  3.72555+-  .33398  1.30+- .35    1.1
```

```
SOURCE CONTRIBUTION ESTIMATES -  SITE: 151        DATE: 27/05/96   CMB7 33889
SAMPLE DURATION       12    START HOUR      0      SIZE:   FINE
R SQUARE       .97  PERCENT MASS    104.5    CHI SQUARE      4.45           DF      32

  SOURCE    SCE(UG/M3)   STD ERR     TSTAT
-------------------------------------------
7    CALCT        .5188      .0673     7.7083
8    RDUST        .4927      .1053     4.6792
13    DIVEH      5.6821      .8060     7.0501
16    SO4       1.2031      .1460    8.2424
17    NO3        .9430     .1348    6.9978
20    MARI1      1.5346      .4312     3.5586
25    WBURN       2.9462      .1631    18.0686
28    OHC        2.7520      .8257     3.3328
34    VEH2        1.9679      .0356    55.2696
-------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE        17.3+-     1.3

SPECIES-------I---MEAS----------------CALC-------------RATIO C/M----RATIO R/U
C1    TOT    T  17.25903+-  1.29592  18.04037+-  1.06675  1.05+-  .10     .5
C11   Na        .14698+-   .03363   .64972+-   .06239   4.42+- 1.10    7.1
C12   Mg    *   .03563<    .04753   .08231<    .02638   2.31<  3.17     .9
C13   Al    *  .10361+-   .00968   .10731+-   .00374   1.04+-  .10     .4
C14   Si    *  .16645+-   .00737   .16719+-   .00228   1.00+-  .05     .1
C15   P     *  .01580+-   .00438   .00379+-   .00152    .24+-  .12   -2.6
C16   S     *  .52315+-   .00933   .52315+-   .04479   1.00+-  .09     .0
C17   Cl       .09968+-   .00640   .76717+-   .15347   7.70+- 1.62    4.3
C19   K     *  .18095+-   .00584   .18267+-   .00334   1.01+-  .04     .3
C20   Ca    *   .04611+-   .00414   .06199+-   .00362   1.34+-  .14    2.9
C22   Ti    *  .00458<    .03676   .00497<    .00530   1.08<  8.77     .0
C23   V     *  .00654<    .01495   .00143<    .00215    .22<   .60    -.3
C24   Cr    *  .00134<    .00334   .00093<    .00046    .70<  1.77    -.1
C25   Mn    *   .00453+-   .00088   .00122+-   .00035    .27+-  .09   -3.5
C26   Fe    *  .07356+-   .00760   .04480+-   .00019    .61+-  .06   -3.8
C27   Co    *   .00000<    .00216   .00004<    .00052    .00<   .00     .0
C28   Ni    *  .00250+-   .00059   .00314+-   .00025   1.25+-  .31    1.0
C29   Cu    *   .00479+-   .00063   .00088+-   .00014    .18+-  .04   -6.1
C30   Zn       .05130+-   .00102   .01077+-   .00012    .21+-  .00  -39.3
C31   Ga    *   .00237<    .00391   .00021<    .00183    .09<   .78    -.5
C33   As    *   .00000<    .03377   .00014<    .02665    .00<   .00     .0
C34   Se    *   .00259+-   .00076   .00004+-   .00078    .02+-  .30   -2.3
C35   Br       .08635+-   .00149   .11506+-   .00090   1.33+-  .03   16.5
C48   Cd        .00565<    .01594   .00128<    .00222    .23<   .75    -.3
C49   In    *  .00712<    .01828   .00002<    .00250    .00<   .35    -.4
C50   Sn    *   .00921<    .02346   .00005<    .00324    .01<   .35    -.4
C51   Sb    *   .00000<    .02697   .00109<    .00388    .00<   .00     .0
C56   Ba    *   .00000<    .10079   .00108<    .01426    .00<   .00     .0
C57   La    *   .00000<    .13287   .00496<    .01888    .00<   .00     .0
C79   Au    *   .00279<    .00544   .00027<    .00082    .10<   .35    -.5
C80   Hg    *   .00204<    .00440   .00060<    .00087    .29<   .76    -.3
C81   Tl    *  .00000<    .00730   .00000<    .00461    .00<   .00     .0
C82   Pb    *   .20999+-   .00348   .20996+-   .00060   1.00+-  .02     .0
C92   U     *  .00000<    .00428   .00001<    .00154    .00<   .00     .0
C201  Cl-       1.91910+-   .19191  1.01420+-   .15639    .53+-  .10   -3.7
C202  NO3-  *   .96208+-   .09621   .96208+-   .09432   1.00+-  .14     .0
C203  SO4--      1.58049+-   .15805  1.64550+-   .13678   1.04+-  .14     .3
C204  Ca++        .00000+-   .00000   .09755+-   .00665    .00+-  .00   14.7
C205  K+         .15714+-   .01571   .16281+-   .01432   1.04+-  .14     .3
C206  Mg++        .16930+-   .01693   .07483+-   .01381    .44+-  .09   -4.3
C207  Na+   *  1.92113+-   .19211   .61567+-   .15346    .32+-  .09   -5.3
C208  NH4+        .19972+-   .01997   .07178+-   .00601    .36+-  .05   -6.1
C209  OCTU      11.29359+-   .79075  4.73578+-   .16863    .42+-  .03   -8.1
C210  ECTU       1.94647+-   .14193  2.08868+-   .12297   1.07+-  .10     .8
C211  OHTU  *   5.84955+-   .72993  5.84955+-   .33575   1.00+-  .14     .0
C212  EHTU  *    .23317+-   .07097   .05733+-   .00890    .25+-  .08   -2.5
C213  OLTU  *   5.44404+-   .84723  1.63822+-   .16065    .30+-  .06   -4.4
C214  ELTU  *   1.71330+-   .18776  2.03135+-   .17368   1.19+-  .16    1.2
```

J.4. Modelling at the Wynberg Site

```
SOURCE CONTRIBUTION ESTIMATES - SITE: 63        DATE: 14/07/95   CMB7 33889
SAMPLE DURATION      6      START HOUR      0      SIZE:   FINE
R SQUARE     1.00   PERCENT MASS    103.8    CHI SQUARE     2.05          DF       33

 SOURCE    SCE(UG/M3)  STD ERR    TSTAT
-------------------------------------------
6    RKBRN      2.2111     .2571    8.6013
13    DIVEH     13.7419    2.3141    5.9382
16    SO4       .1791     .2244     .7984
17    NO3       .6594     .0970   6.7983
22    SASFA       .5855     .1672    3.5019
30    EHC       2.7470    1.4713    1.8670
32    VEH1       9.4356     .0789  119.6221
36    COMPB       .4941     .6541     .7553
-------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE       29.0+-    3.2

SPECIES-------I---MEAS-----------------CALC------------RATIO C/M----RATIO R/U
C1    TOT    T  28.95708+-  3.20274  30.05359+-  2.70474   1.04+-  .15     .3
C11   Na    *    .09294<   .17257    .07343<   .04763    .79<  1.55    -.1
C12   Mg    *    .03960<   .22301    .03411<   .20573    .86<  7.11    -.0
C13   Al    *   .32802+-  .04560    .29529+-  .02761    .90+-  .15    -.6
C14   Si    *   .04195<   .04240    .14775<   .02026   3.52<  3.59    2.3
C15   P     *   .00501<   .02336    .02249<   .00400   4.49< 20.96     .7
C16   S     *   .34521+-  .04730    .34521+-  .04580   1.00+-  .19     .0
C17   Cl        .02946<   .03197    .11447<   .00752   3.89<  4.22    2.6
C19   K     *   .07182+-  .00663    .07385+-  .00320   1.03+-  .10     .3
C20   Ca    *    .03812+-  .00754    .04356+-  .00201   1.14+-  .23     .7
C22   Ti    *   .00627<   .07362    .00225<   .01484    .36<  4.84    -.1
C23   V     *   .01206<   .03003    .00896<   .00602    .74<  1.91    -.1
C24   Cr    *   .00337<   .00702    .00133<   .00137    .40<   .92    -.3
C25   Mn    *    .00395<   .00531    .00407<   .00103   1.03<  1.41     .0
C26   Fe        .15584+-  .01333    .03084+-  .00046    .20+-  .02   -9.4
C27   Co    *   .00024<   .00468    .00017<   .00077    .70< 13.87    -.0
C28   Ni    *   .00304<   .00369    .00304<   .00070   1.00<  1.24     .0
C29   Cu    *   .00878+-  .00134    .00371+-  .00057    .42+-  .09   -3.5
C30   Zn        .04647+-  .00170    .05281+-  .00048   1.14+-  .04    3.6
C31   Ga    *    .00708<   .01863    .00047<   .01675    .07<  2.37    -.3
C33   As    *   .00000<   .25375    .00020<   .24991    .00<   .00     .0
C34   Se    *   .00000<   .00831    .00004<   .00693    .00<   .00     .0
C35   Br    *  1.21742+-  .09756    .84152+-  .00423    .69+-  .06   -3.8
C48   Cd        .00032<   .03220    .00458<   .00669  14.10< *****     .1
C49   In    *  .00000<   .03749    .00000<   .00761    .00<   .00     .0
C50   Sn    *   .01371<   .04848    .00013<   .00973    .01<   .71    -.3
C51   Sb    *   .02553<   .05564    .00425<   .01124    .17<   .57    -.4
C56   Ba    *   .00000<   .20505    .00410<   .04032    .00<   .00     .0
C57   La    *   .00000<   .27222    .00956<   .05343    .00<   .00     .0
C79   Au    *   .00099<   .01117    .00028<   .00440    .29<  5.47    -.1
C80   Hg    *   .00000<   .01089    .00175<   .00626    .00<   .00     .1
C81   Tl    *  .00000<   .04493    .00000<   .04290    .00<   .00     .0
C82   Pb    *  1.60941+-  .01243   1.61370+-  .00420   1.00+-  .01     .3
C92   U     *  .00000<   .02137    .00000<   .01339    .00<   .00     .0
C201  Cl-       .60827+-  .06083    .41737+-  .04131    .69+-  .10   -2.6
C202  NO3-  *   .70560+-  .07056    .70560+-  .06610   1.00+-  .14     .0
C203  SO4--    1.48418+-  .14842   1.09218+-  .06036    .74+-  .08   -2.4
C204  Ca++      .57786+-  .05779    .10277+-  .00852    .18+-  .02   -8.1
C205  K+        .25547+-  .02555    .21277+-  .02099    .83+-  .12   -1.3
C206  Mg++      .11557+-  .01156    .00139+-  .00012    .01+-  .00   -9.9
C207  Na+       .33455+-  .03345    .00342+-  .00025    .01+-  .00   -9.9
C208  NH4+      .15815+-  .01582    .15747+-  .01444   1.00+-  .14    -.0
C209  OCTU    17.86294+-  1.21654   8.73977+-  .36527    .49+-  .04   -7.2
C210  ECTU     5.12977+-  .64882   4.77317+-  .29375    .93+-  .13    -.5
C211  OHTU  *  9.34712+-  1.19627   5.17682+-  .38729    .55+-  .08   -3.3
C212  EHTU  *  2.87916+-  .52717   2.87916+-  1.37363   1.00+-  .51     .0
C213  OLTU  *  8.51581+-  1.23649   3.56295+-  .36246    .42+-  .07   -3.8
C214  ELTU  *  2.25061+-  .75102   4.64100+-  .41498   2.06+-  .71    2.8
```

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SOURCE CONTRIBUTION ESTIMATES -  SITE: 75         DATE: 14/07/95   CMB7 33889
SAMPLE DURATION       6     START HOUR      0       SIZE:   FINE
R SQUARE      .99   PERCENT MASS    117.8    CHI SQUARE     2.12            DF        32

  SOURCE    SCE(UG/M3)   STD ERR     TSTAT
-------------------------------------------------
6     RKBRN        4.6846     .2754    17.0117
8     RDUST         .6592     .1173     5.6180
13     DIVEH       4.5896    1.8705     2.4537
16     SO4          .2342     .1722    1.3599
28     OHC         5.2533    2.9444     1.7841
29     OLC         6.6907    3.5790     1.8694
30     EHC         1.3999     .7554     1.8532
32     VEH1        6.2575     .0650    96.3250
36     COMPB        .2776     .7148      .3883
-------------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE          25.5+-      2.9

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
C1     TOT    T  25.49884+-  2.85547  30.04664+-  4.81864   1.18+-  .23     .8
C11    Na     *    .23165+-   .06490   .08727+-   .03043    .38+-  .17    -2.0
C12    Mg     *    .06310<    .15908   .02113<    .13645    .33<  2.32     -.2
C13    Al     *   .20375+-   .03268   .17845+-   .01800    .88+-  .17    -.7
C14    Si     *   .03013<    .03654   .09658<    .01342   3.21<  3.91     1.7
C15    P      *   .02277+-   .00730   .01485+-   .00276    .65+-  .24   -1.0
C16    S      *   .24298+-   .03206   .24298+-   .03109   1.00+-  .18     .0
C17    Cl         .05470+-   .00959   .21116+-   .00518   3.86+-  .68    14.4
C19    K      *   .14361+-   .00779   .14692+-   .00220   1.02+-  .06     .4
C20    Ca     *    .04219+-   .00803   .05993+-   .00124   1.42+-  .27     2.2
C22    Ti     *   .00053<    .08372   .00509<    .00912   9.65< *****     .1
C23    V      *   .00764<    .03406   .00536<    .00371    .70<  3.16     -.1
C24    Cr     *   .00221<    .00781   .00109<    .00073    .49<  1.77     -.1
C25    Mn     *    .00091<    .00584   .00253<    .00055   2.77< 17.73      .3
C26    Fe     *   .12149+-   .01314   .06435+-   .00038    .53+-  .06    -4.3
C27    Co     *    .00000<    .00462   .00012<    .00082    .00<  .00      .0
C28    Ni     *   .00043<    .00408   .00187<    .00045   4.39< 42.01      .4
C29    Cu     *    .00845+-   .00150   .00122+-   .00036    .14+-  .05    -4.7
C30    Zn         .02159+-   .00166   .03505+-   .00030   1.62+-  .13     8.0
C31    Ga     *    .00000<    .01367   .00029<    .01110    .00<  .00      .0
C33    As     *    .00000<    .16819   .00019<    .16573    .00<  .00      .0
C34    Se     *    .00000<    .00667   .00007<    .00460    .00<  .00      .0
C35    Br     *   .76073+-   .05588   .55775+-   .00280    .73+-  .05    -3.6
C48    Cd         .01162<    .03583   .00229<    .00422    .20<   .71     -.3
C49    In     *   .00000<    .04041   .00000<    .00481    .00<  .00      .0
C50    Sn     *    .00107<    .05306   .00014<    .00614    .13<  8.53     -.0
C51    Sb     *    .00000<    .06221   .00407<    .00707    .00<  .00      .1
C56    Ba     *    .00000<    .23360   .00349<    .02521    .00<  .00      .0
C57    La     *    .00000<    .31204   .01066<    .03362    .00<  .00      .0
C79    Au     *    .00000<    .01172   .00024<    .00288    .00<  .00      .0
C80    Hg     *    .00000<    .01105   .00094<    .00413    .00<  .00      .1
C81    Tl     *   .00000<    .03106   .00000<    .02845    .00<  .00      .0
C82    Pb     *  1.06346+-   .01050  1.06770+-   .00275   1.00+-  .01      .4
C92    U      *   .00000<    .01582   .00001<    .00887    .00<  .00      .0
C201   Cl-        .79075+-   .07908   .87869+-   .08751   1.11+-  .16     .7
C202   NO3-        .00000+-   .00000   .01542+-   .00154    .00+-  .00    10.0
C203   SO4--      1.43552+-   .14355   .71756+-   .03443    .50+-  .06    -4.9
C204   Ca++        .48054+-   .04805   .21426+-   .01786    .45+-  .06    -5.2
C205   K+         .32238+-   .03224   .44781+-   .04447   1.39+-  .20     2.3
C206   Mg++        .13382+-   .01338   .00216+-   .00015    .02+-  .00    -9.8
C207   Na+        .38929+-   .03893   .00320+-   .00019    .01+-  .00    -9.9
C208   NH4+        .13382+-   .01338   .07785+-   .00551    .58+-  .07    -3.9
C209   OCTU      18.00487+-  1.21654  6.06084+-   .21229    .34+-  .03    -9.7
C210   ECTU       3.38605+-   .44607  2.04292+-   .11260    .60+-  .09    -2.9
C211   OHTU   *   9.50933+-  1.21654  9.50933+-  2.64640   1.00+-  .31      .0
C212   EHTU   *   1.48013+-   .28386  1.48013+-   .69999   1.00+-  .51      .0
C213   OLTU   *   8.49554+-  1.21654  8.49554+-  3.35166   1.00+-  .42      .0
C214   ELTU   *   1.90592+-   .56336  1.96265+-   .15900   1.03+-  .32      .1
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```
SOURCE CONTRIBUTION ESTIMATES - SITE: 82        DATE: 25/07/95    CMB7 33889
SAMPLE DURATION      6     START HOUR      0       SIZE:   FINE
R SQUARE      .99   PERCENT MASS    114.5    CHI SQUARE      3.76            DF       34

  SOURCE    SCE(UG/M3)   STD ERR     TSTAT
------------------------------------------
6    RKBRN       4.3641     .3003    14.5308
8    RDUST        .8144     .1145     7.1130
13    DIVEH     13.3274    2.4237     5.4989
16    SO4       2.4826     .2958    8.3931
17    NO3       1.4090     .2027    6.9523
20    MARI1       .8880     .1915    4.6361
30    EHC       2.4367    1.3047     1.8676
34    VEH2      11.2901      .1046  107.9700
------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE        32.3+-     3.0

SPECIES-------I---MEAS----------------CALC------------RATIO C/M----RATIO R/U
C1    TOT   T  32.31464+-  2.95231  37.01228+-  2.66845  1.15+-  .13    1.2
C11   Na    *   .55795+-   .06073   .44853+-   .04832   .80+-  .12   -1.4
C12   Mg    *   .00000<    .17887   .06805<    .12633   .00<   .00     .3
C13   Al    *   .22551+-   .03234   .21337+-   .01747   .95+-  .16    -.3
C14   Si    *   .15083+-   .01543   .13402+-   .01224   .89+-  .12    -.9
C15   P     *   .06302+-   .00989   .01402+-   .00373   .22+-  .07   -4.6
C16   S     *  1.06328+-   .03629  1.06328+-   .08875  1.00+-  .09     .0
C17   Cl        .00274<    .03116   .56431<    .08897  *****< *****    6.0
C19   K     *   .14524+-   .00777   .15218+-   .00334  1.05+-  .06     .8
C20   Ca    *   .06190+-   .00803   .09124+-   .00234  1.47+-  .19    3.5
C22   Ti    *   .00770<    .07906   .00595<    .01302   .77<  8.10    -.0
C23   V     *   .03193<    .03246   .00070<    .00529   .02<   .17    -.9
C24   Cr    *   .00373<    .00760   .00153<    .00111   .41<   .89    -.3
C25   Mn    *   .00629+-   .00191   .00297+-   .00084   .47+-  .20   -1.6
C26   Fe    *   .13978+-   .01324   .08123+-   .00048   .58+-  .06   -4.4
C27   Co    *   .00264<    .00479   .00018<    .00102   .07<   .41    -.5
C28   Ni    *   .01288+-   .00142   .01600+-   .00062  1.24+-  .15    2.0
C29   Cu    *   .01101+-   .00142   .00252+-   .00037   .23+-  .04   -5.8
C30   Zn        .06535+-   .00191   .03997+-   .00035   .61+-  .02  -13.1
C31   Ga    *   .00647<    .01444   .00052<    .01026   .08<  1.60    -.3
C33   As    *   .00215<    .18319   .00028<    .15277   .13< 71.92     .0
C34   Se    *   .00000<    .00673   .00006<    .00427   .00<   .00     .0
C35   Br    *   .68942+-   .01576   .63120+-   .00315   .92+-  .02   -3.6
C48   Cd        .00000<    .03437   .00371<    .00562   .00<   .00     .1
C49   In    *   .00000<    .03871   .00000<    .00639   .00<   .00     .0
C50   Sn    *   .00000<    .04943   .00008<    .00822   .00<   .00     .0
C51   Sb    *   .00000<    .05971   .00372<    .00965   .00<   .00     .1
C56   Ba    *   .00000<    .21849   .00340<    .03513   .00<   .00     .0
C57   La    *   .00000<    .29284   .00995<    .04658   .00<   .00     .0
C79   Au    *   .00424<    .01164   .00036<    .00296   .08<   .74    -.3
C80   Hg    *   .00241<    .01056   .00245<    .00391  1.02<  4.74     .0
C81   Tl    *   .00000<    .03333   .00000<    .02624   .00<   .00     .0
C82   Pb    *  1.16073+-   .01077  1.17401+-   .00260  1.01+-  .01     1.2
C92   U     *   .00000<    .01450   .00001<    .00832   .00<   .00     .0
C201  Cl-       .63869+-   .06387  1.17227+-   .12054  1.84+-  .26    3.9
C202  NO3-  *  1.45377+-   .14538  1.45377+-   .14097  1.00+-  .14     .0
C203  SO4--    3.47324+-   .34732  3.30963+-   .25620   .95+-  .12    -.4
C204  Ca++      .46229+-   .04623   .20999+-   .01684   .45+-  .06   -5.1
C205  K+        .27981+-   .02798   .42855+-   .04146  1.53+-  .21    3.0
C206  Mg++      .11557+-   .01156   .04432+-   .00799   .38+-  .08   -5.1
C207  Na+       .39538+-   .03954   .35676+-   .08880   .90+-  .24    -.4
C208  NH4+      .13382+-   .01338   .16753+-   .01418  1.25+-  .16    1.7
C209  OCTU    16.80860+-  1.15572 12.29177+-   .43477   .73+-  .06   -3.7
C210  ECTU     7.19789+-   .91241  4.89841+-   .28866   .68+-  .10   -2.4
C211  OHTU  * 13.01703+-  1.60178  7.46633+-   .47916   .57+-  .08   -3.3
C212  EHTU  *  2.55474+-   .46634  2.55474+-  1.21853  1.00+-  .51     .0
C213  OLTU  *  3.79157+-   .32504  4.82544+-   .44316  1.27+-  .16    1.9
C214  ELTU  *  4.64315+-  1.20312  4.78041+-   .40777  1.03+-  .28     .1
```

```
SOURCE CONTRIBUTION ESTIMATES - SITE: 140        DATE: 30/04/96   CMB7 33889
SAMPLE DURATION        12    START HOUR      0      SIZE:   FINE
R SQUARE     .98   PERCENT MASS    117.0    CHI SQUARE      5.50            DF       33

  SOURCE    SCE(UG/M3)   STD ERR     TSTAT
------------------------------------------
6    RKBRN       4.5254     .1695    26.6925
7    CALCT       3.7707     .0798    47.2668
8    RDUST       1.3676     .0716    19.1004
13    DIVEH        .5715     .5287     1.0810
16    SO4       5.5203     .5536     9.9709
17    NO3        .1562     .0223     7.0052
29    OLC       3.0651    1.6462     1.8620
32    VEH1        .8191     .0595    13.7597
33    PETVH        .8088     .2681     3.0170
------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE        17.6+-     1.4

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
C1    TOT    T  17.61283+-  1.38603  20.60488+-  1.78961   1.17+-  .14     1.3
C11   Na     *   .08127<    .12102    .07348<    .01044    .90<  1.35     -.1
C12   Mg     *   .05939<    .05966    .00946<    .01952    .16<   .37     -.8
C13   Al     *   .29044+-   .01495    .44144+-   .00324   1.52+-   .08     9.9
C14   Si     *   .92575+-   .01426    .87037+-   .00254    .94+-   .01    -3.8
C15   P      *   .00500<    .01989    .00818<    .00186   1.64<  6.52      .2
C16   S      *  1.89217+-   .01253   1.89217+-   .18223   1.00+-   .10      .0
C17   Cl         .01878<    .03253    .19518<    .00246  10.40< 18.01     5.4
C19   K      *   .14838+-   .00483    .15370+-   .00146   1.04+-   .04     1.1
C20   Ca     *   .08441+-   .00466    .09346+-   .00098   1.11+-   .06     1.9
C22   Ti     *   .02783<    .04150    .02265<    .00516    .81<  1.23     -.1
C23   V      *   .00370<    .01686    .00930<    .00218   2.51< 11.46      .3
C24   Cr     *   .00396+-   .00131    .00252+-   .00024    .64+-   .22    -1.1
C25   Mn     *   .00548+-   .00103    .00311+-   .00018    .57+-   .11    -2.3
C26   Fe     *   .17456+-   .00835    .13433+-   .00038    .77+-   .04    -4.8
C27   Co     *   .00000<    .00356    .00004<    .00138    .00<   .00      .0
C28   Ni     *   .00416+-   .00070    .00413+-   .00026    .99+-   .18     -.0
C29   Cu     *   .00253+-   .00070    .00125+-   .00010    .49+-   .14    -1.8
C30   Zn     *   .01320+-   .00082    .01200+-   .00013    .91+-   .06    -1.4
C31   Ga     *   .00000<    .00399    .00017<    .00154    .00<   .00      .0
C33   As     *   .00000<    .02825    .00016<    .02217    .00<   .00      .0
C34   Se     *   .00000<    .00234    .00007<    .00067    .00<   .00      .0
C35   Br         .07574+-   .00137    .09258+-   .00039   1.22+-   .02    11.8
C48   Cd         .00000<    .01748    .00049<    .00226    .00<   .00      .0
C49   In     *   .00000<    .02054    .00013<    .00258    .00<   .00      .0
C50   Sn     *   .00000<    .02660    .00013<    .00334    .00<   .00      .0
C51   Sb     *   .00000<    .03133    .00211<    .00398    .00<   .00      .1
C56   Ba     *   .00000<    .11475    .00251<    .01459    .00<   .00      .0
C57   La     *   .00000<    .15332    .02193<    .01936    .00<   .00      .1
C79   Au     *   .00000<    .00572    .00021<    .00082    .00<   .00      .0
C80   Hg     *   .00000<    .00499    .00030<    .00079    .00<   .00      .1
C81   Tl     *   .00000<    .00700    .00000<    .00385    .00<   .00      .0
C82   Pb     *   .17472+-   .00342    .17435+-   .00045   1.00+-   .02     -.1
C92   U      *   .00000<    .00499    .00004<    .00133    .00<   .00      .0
C201  Cl-        .19465+-   .01946    .86067+-   .08455   4.42+-   .62     7.7
C202  NO3-   *   .15815+-   .01582    .15815+-   .01562   1.00+-   .14      .0
C203  SO4--     5.37105+-   .53710   5.67194+-   .55210   1.06+-   .15      .4
C204  Ca++       .42275+-   .04227    .22952+-   .01793    .54+-   .07    -4.2
C205  K+         .16423+-   .01642    .43538+-   .04296   2.65+-   .37     5.9
C206  Mg++       .06691+-   .00669    .00389+-   .00030    .06+-   .01    -9.4
C207  Na+        .12470+-   .01247    .00901+-   .00069    .07+-   .01    -9.3
C208  NH4+       .41971+-   .04197    .05182+-   .00309    .12+-   .01    -8.7
C209  OCTU      8.64761+-   .58800   3.91494+-   .17291    .45+-   .04    -7.7
C210  ECTU       .82117+-   .12165    .68502+-   .05557    .83+-   .14    -1.0
C211  OHTU   *  4.77494+-   .60827   3.10736+-   .28993    .65+-   .10    -2.5
C212  EHTU   *   .41565+-   .08110    .04607+-   .00637    .11+-   .03    -4.5
C213  OLTU   *  3.87267+-   .56700   3.87267+-  1.54143   1.00+-   .42      .0
C214  ELTU   *   .40551+-   .15173    .63895+-   .07833   1.58+-   .62     1.4
```

```
SOURCE CONTRIBUTION ESTIMATES - SITE: 143        DATE: 08/05/96    CMB7 33889
SAMPLE DURATION        12    START HOUR      0       SIZE:    FINE
R SQUARE       .99   PERCENT MASS     116.6     CHI SQUARE      3.89              DF        34

  SOURCE     SCE(UG/M3)   STD ERR      TSTAT
------------------------------------------------
6     RKBRN       6.1218      .2036    30.0656
8     RDUST       1.0827      .0792    13.6744
13     DIVEH      10.2623     1.3388     7.6651
16     SO4        .9504       .1802    5.2736
17     NO3        .6721       .0977    6.8805
32     VEH1       6.8990      .0843    81.8843
33     PETVH       1.8815      .3293     5.7135
------------------------------------------------
MEASURED CONCENTRATION FOR SIZE: FINE        23.9+-     1.9

SPECIES-------I---MEAS-----------------CALC-------------RATIO C/M----RATIO R/U
C1    TOT    T  23.89296+-  1.90801  27.86988+-  1.30516  1.17+- .11    1.7
C11   Na    *   .15284+-   .04032   .11641+-   .03599   .76+- .31     -.7
C12   Mg    *   .03897<    .16825   .02735<    .15088   .70< 4.92     -.1
C13   Al    *  .25831+-   .02803   .23310+-   .02023   .90+- .13    -.7
C14   Si    *  .19806+-   .01045   .15715+-   .01485   .79+- .09   -2.3
C15   P     *  .02713+-   .00555   .01738+-   .00379   .64+- .19   -1.5
C16   S     *  .52765+-   .03638   .52765+-   .04604  1.00+- .11     .0
C17   Cl       .02227<    .02230   .27786<    .00628  12.48< 12.50   11.0
C19   K     *  .19236+-   .00525   .19444+-   .00298  1.01+- .03     .3
C20   Ca    *   .08695+-   .00465   .09451+-   .00169  1.09+- .06    1.5
C22   Ti    *  .00000<    .03983   .00779<    .01280   .00<  .00     .2
C23   V     *   .00308<   .01627   .00082<    .00521   .27< 2.20     -.1
C24   Cr    *   .00486+-   .00128   .00162+-   .00102   .33+- .23   -2.0
C25   Mn    *    .00343+-   .00096   .00357+-   .00078  1.04+- .37     .1
C26   Fe        .16535+-   .00728   .09957+-   .00054   .60+- .03   -9.0
C27   Co    *   .00000<    .00339   .00016<    .00124   .00<  .00     .0
C28   Ni    *  .00505+-   .00068   .00572+-   .00062  1.13+- .20     .7
C29   Cu    *   .01014+-   .00075   .00216+-   .00042   .21+- .04   -9.3
C30   Zn        .04287+-   .00101   .04386+-   .00037  1.02+- .03     .9
C31   Ga    *   .00128<    .01377   .00049<    .01228   .38< 10.46    -.0
C33   As    *   .00000<    .19568   .00030<    .18303   .00<  .00     .0
C34   Se    *   .00000<    .00594   .00009<    .00509   .00<  .00     .0
C35   Br    *  .74895+-   .02472   .65881+-   .00310   .88+- .03   -3.6
C48   Cd        .00000<    .01699   .00347<    .00568   .00<  .00     .2
C49   In    *  .00463<    .01938   .00000<    .00647   .00< 1.40    -.2
C50   Sn    *   .01589<    .02573   .00010<    .00831   .01<  .52    -.6
C51   Sb    *   .00518<    .02991   .00485<    .00968   .94< 5.72    -.0
C56   Ba    *   .06370<    .10950   .00425<    .03497   .07<  .56    -.5
C57   La    *   .00000<    .14533   .01314<    .04654   .00<  .00     .1
C79   Au    *   .00000<    .00660   .00037<    .00335   .00<  .00     .1
C80   Hg    *   .00731+-   .00237   .00167+-   .00464   .23+- .64   -1.1
C81   Tl    *  .00000<    .03416   .00000<    .03143   .00<  .00     .0
C82   Pb    *  1.24538+-   .00766  1.25106+-   .00307  1.00+- .01     .7
C92   U     *   .00000<    .01294   .00002<    .00984   .00<  .00     .0
C201  Cl-       .00000+-   .00000  1.14605+-   .11436   .00+- .00   10.0
C202  NO3-  *    .70661+-   .07066   .70661+-   .06730  1.00+- .14     .0
C203  SO4--     2.87612+-   .28761  1.62930+-   .10448   .57+- .07   -4.1
C204  Ca++      4.35118+-   .43512   .27468+-   .02345   .06+- .01   -9.4
C205  K+       1.10604+-   .11060   .58358+-   .05811   .53+- .07   -4.2
C206  Mg++       1.99412+-   .19941   .00226+-   .00023   .00+- .00  -10.0
C207  Na+       9.37551+-   .93755   .00209+-   .00021   .00+- .00  -10.0
C208  NH4+      1.02088+-   .10209   .14650+-   .01131   .14+- .02   -8.5
C209  OCTU     12.39862+-   .86172  10.34875+-   .35739   .83+- .06   -2.2
C210  ECTU      4.01460+-   .27372  4.02945+-   .23041  1.00+- .09     .0
C211  OHTU  *   8.88078+-  1.06448  6.88334+-   .47723   .78+- .11   -1.7
C212  EHTU  *    .79075+-   .21290   .11549+-   .01624   .15+- .04   -3.2
C213  OLTU  *   3.51784+-   .59330  3.46540+-   .35102   .99+- .19    -.1
C214  ELTU  *   3.22384+-   .32330  3.91396+-   .32546  1.21+- .16    1.5
```

J.5. Modelling at Guguletu

```
SOURCE CONTRIBUTION ESTIMATES -  SITE: 159        DATE: 22/08/96   CMB7 33889
 SAMPLE DURATION        10     START HOUR       0        SIZE:   FINE
 R SQUARE        .99   PERCENT MASS     103.7  CHI SQUARE       3.24              DF        34

 SOURCE      SCE(UG/M3)   STD ERR      TSTAT
 ----------------------------------------------
 13    DIVEH        40.5698     4.5463     8.9237
 16    SO4         1.7914       .2959    6.0536
 17    NO3         3.3332       .4816    6.9217
 20    MARI1        3.8984      .8133    4.7936
 25    WBURN       21.1713      .4697   45.0714
 32    VEH1        5.1160      .1822   28.0857
 33    PETVH        2.3669     .8100     2.9220
 ----------------------------------------------
 MEASURED CONCENTRATION FOR SIZE: FINE  75.5+-     4.4

 SPECIES-------I---MEAS-----------------CALC------------RATIO C/M----RATIO R/U
 C1    TOT    T  75.46102+-  4.42659  78.24702+-  4.37443   1.04+-  .08      .4
 C11   Na           .38543+-  .09328   1.80127+-   .17332   4.67+- 1.22     7.2
 C12   Mg     *     .03998<   .16550    .23262<    .12270   5.82< 24.28      .9
 C13   Al     *    .22843+-  .03360    .16323+-   .02227    .71+-  .14   -1.6
 C14   Si     *    .12018+-  .01741    .15745+-   .01239   1.31+-  .22    1.7
 C15   P      *    .04087+-  .01303    .01130+-   .01075    .28+-  .28   -1.8
 C16   S      *   1.16973+-  .03418   1.16973+-   .08215   1.00+-  .08      .0
 C17   Cl     *   3.61288+-  .04216   2.64087+-   .39008    .73+-  .11    -2.5
 C19   K      *   1.16861+-  .01783   1.17208+-   .01212   1.00+-  .02      .2
 C20   Ca     *    .06686+-  .01132    .12463+-   .01575   1.86+-  .39     3.0
 C22   Ti     *    .00826<   .08586    .00443<    .03750    .54<  7.20     -.0
 C23   V      *    .01890<   .03505    .00091<    .01519    .05<   .81    -.5
 C24   Cr     *    .00283<   .00805    .00410<    .00326   1.45<  4.28      .1
 C25   Mn     *     .00807+-  .00208    .00660+-   .00245    .82+-  .37     -.5
 C26   Fe          .08366+-  .00292    .08552+-   .00129   1.02+-  .04      .6
 C27   Co     *     .00000<   .00449    .00023<    .00204    .00<   .00      .0
 C28   Ni     *    .00660+-  .00145    .00774+-   .00174   1.17+-  .37      .5
 C29   Cu     *     .01411+-  .00157    .00364+-   .00094    .26+-  .07    -5.7
 C30   Zn          .21720+-  .00299    .05500+-   .00082    .25+-  .01   -52.2
 C31   Ga     *     .00419<   .01324    .00132<    .00958    .32<  2.50     -.2
 C33   As     *     .02920<   .15647    .00091<    .13639    .03<  4.67     -.1
 C34   Se     *     .00030<   .00660    .00030<    .00421    .99< 25.53      .0
 C35   Br     *    .64973+-  .02585    .52708+-   .00817    .81+-  .03    -4.5
 C48   Cd           .00931<   .03743    .00835<    .01561    .90<  3.97     -.0
 C49   In     *    .00229<   .04183    .00000<    .01763    .00<  7.69     -.1
 C50   Sn     *     .01708<   .05521    .00000<    .02284    .00<  1.34     -.3
 C51   Sb     *     .04969<   .06649    .00677<    .02739    .14<   .58     -.6
 C56   Ba     *     .00000<   .23954    .00222<    .10079    .00<   .00      .0
 C57   La     *     .00000<   .32145    .01554<    .13349    .00<   .00      .0
 C79   Au     *     .00000<   .01458    .00183<    .00540    .00<   .00      .1
 C80   Hg     *     .01514+-  .00388    .00307+-   .00537    .20+-  .36    -1.8
 C81   Tl     *    .00000<   .02929    .00000<    .02374    .00<   .00      .0
 C82   Pb     *     .98669+-  .01081    .99874+-   .00367   1.01+-  .01     1.1
 C92   U      *    .00000<   .01455    .00000<    .00833    .00<   .00      .0
 C201   Cl-      7.99410+-   .79941   4.41626+-   .44589    .55+-  .08    -3.9
 C202   NO3-  *   3.46949+-   .34695   3.46949+-   .33360   1.00+-  .14      .0
 C203   SO4--     4.60883+-   .46088   4.13002+-   .28286    .90+-  .11     -.9
 C204   Ca++        .00000+-   .00000    .45273+-   .04057    .00+-  .00    11.2
 C205   K+       4.46144+-   .44614   1.05942+-   .10079    .24+-  .03    -7.4
 C206   Mg++        .00000+-   .00000    .18713+-   .03509    .00+-  .00     5.3
 C207   Na+        .00000+-   .00000   1.55938+-   .38984    .00+-  .00     4.0
 C208   NH4+      2.94544+-   .29454    .48538+-   .04290    .16+-  .02    -8.3
 C209   OCTU      35.91147+-  2.43309  30.23867+-  1.17966    .84+-  .07    -2.1
 C210   ECTU      21.10238+-  1.42710  14.71583+-   .87810    .70+-  .06    -3.8
 C211   OHTU   *  30.08609+-  3.55605  20.30387+-  1.35982    .67+-  .09    -2.6
 C212   EHTU   *   1.19315+-   .32753    .35997+-   .06338    .30+-  .10    -2.5
 C213   OLTU   *   5.82538+-   .89759   9.93481+-  1.11387   1.71+-  .32     2.9
 C214    ELTU  *  19.90923+-  1.99147 14.35585+-  1.24019    .72+-  .10    -2.4
```

APPENDIX N: APPORTIONMENT RESULTS FOR EACH EPISODE

Date	14/07/95	14/07/95	25/07/95	18/08/95	16/02/96	30/04/96	05/08/96	27/05/96	06/04/96	22/08/96
Tableview										
Crustal	6	5		4				6		
Diesel Vehicles	40	40		14				33		
Petrol Vehicles	6	10		3				11		
Woodburning	11	12		16				17		
Sea Salt	3	0		5				9		
Boilers	13	0		16				0		
Sulphate	4	4		32				7		
Nitrate	7	8		4				5		
Carbon	22	34		0				16		
% mass	112	113		94				104		
Chi Square	2.77	2.51		3.81				4.45		
Drill Hall										
Crustal		1	2		7	13	3	1		
Diesel Vehicles		60	43		50	13	60	50		
Petrol Vehicles		36	27		21	17	29	32		
Woodburning		10	11		12	10	16	14		
Sea Salt		0	0		2	0	0	0		
Boilers		0	1		0	0	0	0		
Sulphate		1	13		10	30	5	4		
Nitrate		2	5		2	1	6	3		
Carbon		0	18		17	33	0	0		
% mass		110	120		121	117	119	104		
Chi Square		2.51	0.67		2.76	2.42	1.65	2.29		
Goodwood										
Crustal		1			4	16	4	3	2	
Diesel Vehicles		52			16	49	63	43	52	
Petrol Vehicles		22			10	29	23	40	39	
Woodburning		14			28	19	14	16	7	
Sea Salt		0			9	0	3	0	1	
Boilers		0			0	0	5	0	0	
Sulphate		2			11	21	6	6	5	
Nitrate		4			3	3	6	2	3	
Carbon		27			0	0	0	0	0	
% mass		122			81	137	124	110	109	
Chi Square		3.26			3.04	4.77	3.17	3.23	3.43	
Wynberg										
Crustal	0	2	3			29	5			
Diesel Vehicles	47	37	41			3	43			
Petrol Vehicles	33	24	35			9	37			
Woodburning	8	19	14			26	26			
Sea Salt	0	0	3			0	0			
Boilers	4	1	0			0	0			
Sulphate	1	1	8			31	4			
Nitrate	2	0	4			1	3			
Carbon	9	5	8			17	0			
% mass	104	89	116			116	118			
Chi Square	2.05	3.12	3.76			5.5	3.89			
Guguletu										
Crustal										0
Diesel Vehicles										54
Petrol Vehicles										10
Woodburning										28
Sea Salt										5
Boilers										0
Sulphate										2.4
Nitrate										4.4
Carbon										0
% mass										104
Chi Square										3.24

Date	14/07/95	14/07/95	25/07/95	18/08/95	16/02/96	30/04/96	05/08/96	27/05/96	06/04/96	22/08/96
Tableview										
Crustal	5	4		4				6		
Diesel	36	36		18				33		
Petrol	9	13		7				14		
Wood	10	11		17				16		
Sea salt	3	0		5				9		
Boilers	16	5		47				7		
Unknown	20	31		1				16		
Total	100	100		100				100		
Drill Hall										
Crustal		1	2		6	11	3	1		
Diesel		55	37		42	13	51	49		
Petrol		34	26		19	16	28	33		
Wood		9	9		10	9	14	14		
Sea salt		0	0		2	0	0	0		
Boilers		1	11		7	22	5	4		
Unknown		0	16		14	29	1	0		
Total		100	100		100	100	100	100		
Goodwood										
Crustal		1			5	12	3	3	2	
Diesel		43			21	37	52	40	48	
Petrol		20			15	23	22	38	38	
Wood		12			35	14	11	15	6	
Sea salt		0			11	0	2	0	1	
Boilers		2			12	13	9	5	4	
Unknown		23			1	1	1	0	0	
Total		100			100	100	100	100	100	
Wynberg										
Crustal	0	2	3			25	4			
Diesel	45	42	36			5	37			
Petrol	33	27	33			10	33			
Wood	8	21	12			22	22			
Sea salt	0	0	3			0	0			
Boilers	5	2	7			23	3			
Unknown	9	6	7			15	0			
Total	100	100	100			100	100			
Guguletu										
Crustal										0
Diesel										52
Petrol										12
Wood										27
Sea salt										5
Boilers										3
Unknown										1
Total										100

Tableview							
Date	14/07/95	14/07/95	18/08/95	27/05/96			Average
Crustal	2	2	1	2			2
Diesel Vehicles	36	42	7	38			39
Petrol Vehicles	2	4	1	6			4
Woodburning	6	8	6	13			9
Sea Salt	1	0	2	4			2
Boilers	15	0	13	0			5
Sulphate	11	8	64	13			11
Nitrate	13	7	6	5			8
Carbon	12	24	4	12			16
NO2	2	5	1	6			4
Total	100	100	105	99			100
bext [Mm^-1]	182	196	203	110			173
Drill Hall							
Date	14/07/95	25/07/95	16/02/96	30/04/96	05/08/96	27/05/96	Average
Crustal	0	0	2	3	1	0	1
Diesel Vehicles	65	30	51	12	57	54	51
Petrol Vehicles	18	9	9	7	12	14	12
Woodburning	7	5	7	6	10	11	8
Sea Salt	0	0	1	0	0	0	0
Boilers	0	1	0	0	0	0	0
Sulphate	1	33	17	49	8	6	13
Nitrate	2	9	1	1	5	3	4
Carbon	0	11	11	21	0	0	4
NO2	6	1	5.01	5.01	7	12	6
Total	99	99	104.01	104.01	100	100	100
bext [Mm^-1]	199	599	79	124	302	202	276
Goodwood							
Date	14/07/95	16/02/96	30/04/96	05/08/96	27/05/96	06/04/96	Average
Crustal	0	2	4	0	1	1	1
Diesel Vehicles	48	22	42	58	49	54	46
Petrol Vehicles	10	7	11	10	20	18	13
Woodburning	8	25	10	8	11	5	11
Sea Salt	0	5	0	1	0	1	1
Boilers	0	0	0	3	0	0	1
Sulphate	4	34	31	10	10	13	14
Nitrate	3	5	3	5	2	5	4
Carbon	20	0	0	0	0	0	4
NO2	6	5.01	5.01	4	5	3	5
Total	99	105.01	106.01	99	98	100	100
bext [Mm^-1]	391	45	157	298	261	168	233
Wynberg							
Date	14/07/95	14/07/95	25/07/95	05/08/96	30/04/96		Average
Crustal	0	1	1	2	8		1
Diesel Vehicles	51	51	34	50	3		47
Petrol Vehicles	14	13	13	18	4		15
Woodburning	6	18	7	20	17		13
Sea Salt	0	0	1	0	0		0
Boilers	2	1	0	0	0		1
Sulphate	2	1	24	8	55		9
Nitrate	5	0	9	3	1		4
Carbon	19	15	11	0	12		11
NO2	5.01	5.01	5.01	5.01	5.01		5
Total	104.01	105.01	105.01	106.01	105.01		105
bext [Mm^-1]	217	156	337	163	121		218
Guguletu							
Date	22/08/96						
Crustal	0						
Diesel Vehicles	62						
Petrol Vehicles	5						
Woodburning	21						
Sea Salt	2						
Boilers	0						
Sulphate	5						
Nitrate	5						
Carbon	0						
NO2	5.01						
Total	105.01						
bext [Mm^-1]	301						

Tableview						
Date	14/07/95	14/07/95	18/08/95	27/05/96		
Crustal	2	2	1	2		
Diesel	38	43	12	40		
Petrol	11	12	8	13		
Wood	6	8	6	13		
Sea salt	1	0	2	4		
Boilers	28	9	65	13		
Unknown	14	25	6	14		
Total	100	100	100	100		
bext [Mm^-	182	196	203	110		
Drill Hall						
Date	14/07/95	25/07/95	16/02/96	30/04/96	05/08/96	27/05/96
Crustal	0	0	2	3	1	0
Diesel	66	34	51	16	58	55
Petrol	23	17	13	12	20	23
Wood	7	5	7	6	10	11
Sea salt	0	0	1	0	0	0
Boilers	3	31	15	41	9	8
Unknown	1	13	12	22	1	2
Total	100	100	100	100	100	100
bext [Mm^-	199	599	79	124	302	202
Goodwood						
Date	14/07/95	16/02/96	30/04/96	05/08/96	27/05/96	06/04/96
Crustal	0	2	4	0	1	1
Diesel	49	24	43	60	51	56
Petrol	16	14	16	16	25	23
Wood	8	24	10	8	11	5
Sea salt	0	5	0	1	0	1
Boilers	5	29	26	14	10	13
Unknown	21	2	2	1	1	1
Total	100	100	100	100	100	100
bext [Mm^-	391	45	157	298	261	168
Wynberg						
Date	14/07/95	14/07/95	25/07/95	05/08/96	30/04/96	
Crustal	0	1	1	2	8	
Diesel	50	49	35	48	8	
Petrol	19	15	21	22	10	
Wood	6	17	7	19	16	
Sea salt	0	0	1	0	0	
Boilers	6	3	22	8	45	
Unknown	19	15	12	1	13	
Total	100	100	100	100	100	
bext [Mm^-	217	156	337	163	121	
Guguletu						
Date	22/08/96					
Crustal	0					
Diesel	60					
Petrol	11					
Wood	20					
Sea salt	2					
Boilers	6					
Unknown	1					
Total	100					
bext [Mm^-	301					

REPORT NO. GEN 182

CAPE TOWN BROWN HAZE STUDY

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