REAL-TIME ANALYSIS OF ATMOSPHERIC POLLUTION AND ITS IMPLICATIONS IN PIETERMARITZBURG

by

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ABSTRACT

Air pollution control is an increasing problem throughout the world. South Africa is no exception, especially in the light of increasing urban and industrial development being sought by the new political dispensation. With this background, Pietermaritzburg is examined as a case study of air pollution and control in South Africa through a threefold approach. A review of all existing information on the dispersion climatology, the degree of atmospheric pollution and the measures taken to control it forms the base of the research. Data obtained through real-time monitoring of meteorological and pollutant parameters in central Pietermaritzburg are then analysed to supplement and improve existing knowledge. Finally, the scenario is holistically assessed to offer recommendations for future management of the atmospheric resource at both the national and local level.

Analysis of the data reveals that while the air pollution problem in Pietermaritzburg has not yet reached alarming proportions, high levels of some pollutants occur under certain circumstances. These observations and the known adverse effects of such pollutants elsewhere make it imperative that planning and management strategies control and ultimately reduce the level of atmospheric pollution. Participation of the local community and industrialists, combined with effective monitoring and research will be essential to the achievement of sustainable air quality in Pietermaritzburg.

PREFACE

Recent studies of atmospheric pollution in South Africa have focused largely on the major urban centres of Pretoria-Witwatersrand-Vereeniging or on the industrial complex of the Eastern Transvaal Highveld. While these areas are sources of significant emissions in the country and merit research, there has been a consequent lack of attention to the smaller urban centres which often have their own severe pollution problems. Research into the air quality of these towns and cities has thus been conducted only on an *ad hoc* basis by local municipalities and environmentally conscious industrialists.

In Pietermaritzburg, a potential problem with atmospheric dispersion was identified over 30 years ago and little real progress has been made in improving the city's air quality since. The City Health Division has monitored pollution as part of the Council for Scientific and Industrial Research National Air Pollution Monitoring Programme for more than ten years. It has been established that the local air quality meets the standards laid down by national guidelines but has not convinced the public who are still deeply concerned and critical. The purchase of an advanced monitoring station in 1989 also did little to improve the situation owing to poor management and inadequate communication of results.

During the past year, the monitoring station has been recommissioned to record data for the present study which aims to provide an holistic assessment of atmospheric pollution in Pietermaritzburg. Considerable experience gained by the writer during the recommissioning of the monitoring station will be used to examine the hypotheses that

a. pollution concentrations are primarily controlled by the local topography in combination with the seasonal climatology,
b. the highest pollution concentrations are the direct result of a fumigation effect,
c. more effective planning and control strategies are required at both a national and local level, and

d. effective management, utilisation of local skills and open communication of results to the public are essential if real-time monitoring of atmospheric pollution is to be of benefit to Pietermaritzburg.

In order to confirm these hypotheses the thesis deals with the general background to the study in the introductory chapter, including the characteristics of air pollution in South Africa. Chapter Two then discusses the progress and problems of air pollution monitoring in Pietermaritzburg and the instruments used for the investigation. A model of local climatology and dispersion is developed in Chapter Three as a preliminary to Chapter Four, which analyses and relates the pollution data to this model. The fumigation effect on pollution concentrations is examined in some detail near the end of Chapter Three because of its special relevance to dispersion and pollution levels. In Chapter Five, the implications of the preceding analysis are explored to consider plans for improved air quality. Finally, Chapter Six presents a summary of the important conclusions from the research.

The monitoring and results described in this dissertation were based on research undertaken in the Department of Geography, University of Natal, Pietermaritzburg from January 1993 to December 1994, under the supervision of Prof. O.S. McGee (Department of Geography) and Dr C. Southway (Department of Chemistry).

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any university. Where use has been made of the work of others, it is duly acknowledged in the text.

It is with thanks that I acknowledge the City Health Division, Pietermaritzburg for allowing me to set up and use their monitoring equipment. The study would not have been possible without their assistance and I am especially grateful to Mr Paul Sherry for the beneficial working relationship that developed. I should also like to thank Dr N. Boegman of the National Association for Clean Air for his valued suggestions.

To the many technical people who assisted with the continual equipment problems, I am extremely grateful. In particular, I should like to acknowledge the willing help of Mr Martin Watson of the Department of Chemistry, University of Natal.

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Finally, it is acknowledged that this investigation might not have taken place without the determination of Councillor Yvonne Spain to initiate the project.

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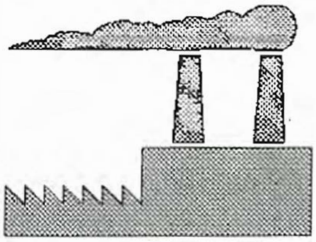
Chapter One



General Background

1. GENERAL BACKGROUND

1.1 INTRODUCTION

Throughout the world there has been a rise of environmental concern over the past three decades. Numerous influential publications, as cited by Fuggle (1992), argue that the world will become more crowded and more polluted in the years ahead. These trends are a direct result of rapidly increasing human population and in turn could decrease the quality of life for all people. Bockris (1977) states bluntly that *'Man is the original and basic pollutant'.*

Life on this planet existed for millions of years in a natural balance with the environment until man unintentionally upset this relationship in less than a century. The 20th century is different from any other time in history because of the rates at which people are using resources, modifying natural systems and increasing in number (Fuggle, 1992). Many of these changes are the direct result of urban and industrial growth which were seen as the benchmarks of progress. Pollution was therefore seen as unavoidable, until an environmental consciousness arose, firstly in the United States and then throughout the western world in the 1960's (Preston-Whyte, 1992).

Human concern for the environment became official on 1 January 1970 when the United States' Environmental Policy Act (NEPA) was made law, recognizing that human-environment relationships had to be addressed proactively and holistically. In 1972, the United Nations Conference on the Human Environment and the publication of *Limits to growth* (Meadows *et al.*, 1972) and *Blueprint for survival* (Anon, 1972) demonstrated growing international concern. The 1970s thus became a decade of environmental awareness with environmental protection placed high on political agendas.

Recent initiatives have continued to stress the link between overpopulation and environmental degradation. *Caring for the earth, A strategy for sustainable living* (World Conservation Union, 1991) states:

> *'Humanity must take no more from nature than nature can replenish. This in turn means adopting life-styles and development paths that respect and work within nature's limits. It can be done without rejecting the many benefits that modern technology has brought, provided that technology also works within those limits.'*

Atmospheric pollution is one of the major consequences of technology's not working within nature's limits. Man is feeding back into the atmosphere in a short space of geological time the fossil fuels that have slowly accumulated over the past 500 million years (Revelle, 1987 as quoted in Grove, 1987). Hence, natural cleansing mechanisms cannot cope with this excess contamination which is dependent upon the number of people in the world and their living standards (Bockris, 1977).

Environmental deterioration need not be seen as the inevitable by-product of advancing technology, but rather a lack of planning for the side effects of development, and placing short-term interests above broader responsibility to the earth's resources. A further reason for the occurrence of environmental problems is their insidious nature where a problem arises from the impact of many small actions (Fuggle, 1992). Both of these explanations can be closely related to atmospheric pollution in Pietermaritzburg.

Pollution of air by products of combustion, thermal pollution and noise disturbance are classified as degradable wastes according to Fuggle (1992). It is argued that these problems can largely be solved by adequate dilution or dispersion and can be controlled within existing legal, economic and societal frameworks if there is a genuine willingness to do so. However, it is this willingness that forms the basis of a public policy debate on how atmospheric pollution can be curbed. Industrialised nations have met with varied and limited success in their attempts to implement effective control policies, largely because of the conflict between the citizen who wants clean air, the entrepreneur who wants to make profits, the employee who wants to be assured of employment and the overall need for national prosperity (Kirstein, 1984). This conflict of interests and the willingness of the local government to solve it was tested during the initial stages of the research and will be examined in Chapters Two and Five.

A further reason for the occurrence of environmental problems is the present-day emphasis on specialization. Scientists have become dependent upon specialization to solve complex problems and yet human relationships with their physical surroundings require holistic analysis. Pollution of the atmosphere involves climatological, technical, economic, social, legal and moral aspects making the geographer ideally placed to assess such issues. The geographer is also trained to include people in perspectives of the environment who are ultimately responsible for the successful management of the earth (Gamble, 1992).

Attempts are being made throughout the world to alert people to the problems being encountered in the environment and their social effects. Nowhere are these problems more evident than where the land is most densely populated. The proliferation of mankind has necessitated greater concentration of people in urban areas and these are continually expanding, such that by the year 2000, it is estimated that 60 percent of the world's people will live in towns with 5000 or more inhabitants (Oke,1987). Thus, the study of urban environments becomes ever more significant. Oliver (1973), referring specifically to urban climatology argues that, *'the city climate is an important measure of man's ultimate impact on the [global] ecosphere'* and secondly, *'the nature of the urban climate can be used as an input into the plans concerned with mitigation of effects caused through urban industrialization'.*

The rationale and objectives of the present study are derived as a geographer's response to a specific environmental issue. Pietermaritzburg is a classic case of a city being located and developed long before climatological implications of urban development were even thought of, let alone incorporated into the planning process. Much is already known about the local climate of the city through the research of academics (Chapter 2), but the knowledge has rarely been put into use during the growth of the city. This has been allowed to happen because of the diverse skills and interests that cooperate and conflict (as discussed above) in the face of large economic values. In this context of complexity, it is hardly surprising that those who are concerned with the physical environment are often neglected in spite of the wisdom they offer.

Inadequate communication between climatologists and the other professions has been the weak link in the past. The current research aims to cross that barrier by portraying the climatology and atmospheric pollution of Pietermaritzburg in a manner that can be interpreted easily by engineers and planners who are largely ignorant of the atmospheric implications of their activities. It is conceptually endorsed by the World Meteorological Organization which is trying to force the other professions to utilize the contribution from the climatological field towards more rational urban planning. The development of towns without due recognition to the existence of the environment is a luxury and a waste that can no longer be tolerated. Future programmes must take advantage of climatic potentials and mitigate or eliminate climatic stresses caused by such development based on sound research and reasoned opinions. It is geographers who are best equipped to form these opinions as their concern is with the spatial characteristics of the climate modification and its relationship with man as a city dweller.

The above discussion has identified the broad background to the thesis which is both reactive and proactive to a controversial local environmental issue. Pietermaritzburg's atmospheric pollution highlights many of the issues surrounding air pollution in South Africa and the next section reviews recent literature on this subject to place the study in a global and national perspective.

1.2 RECENT LITERATURE ON AIR POLLUTION IN SOUTH AFRICA

1.2.1 South Africa in the global context

Air, and the pollutants that travel with it, do not respect political boundaries. It is therefore essential to review the position of South Africa in the context of current global environmental concerns which clearly focus on air pollution.

It is a common misconception that South Africa is one of the most polluted regions in the world (Lennon and Turner, 1992). The basis of this fallacy is that South African public concern for the environment is not high by western standards, but this is not surprising given the country's turbulent history and the emphasis on basic needs for the majority of the population (Preston-Whyte, 1992). Environmental problems do beset the country, such as air and water pollution produced by centres of industrialisation and urbanisation, requiring the state to deal with problems characteristic of both developed and underdeveloped countries. A balance needs to be achieved between environmental care and necessary economic development.

Comparisons of major air pollutants based on scientifically validated facts present a mixed picture of South Africa's international standing. Fig. 1 shows South Africa's total national anthropogenic emissions of sulphur dioxide and oxides of nitrogen compared to recent emissions in the United Kingdom (UK), Germany, the United States of America (USA) and worldwide.

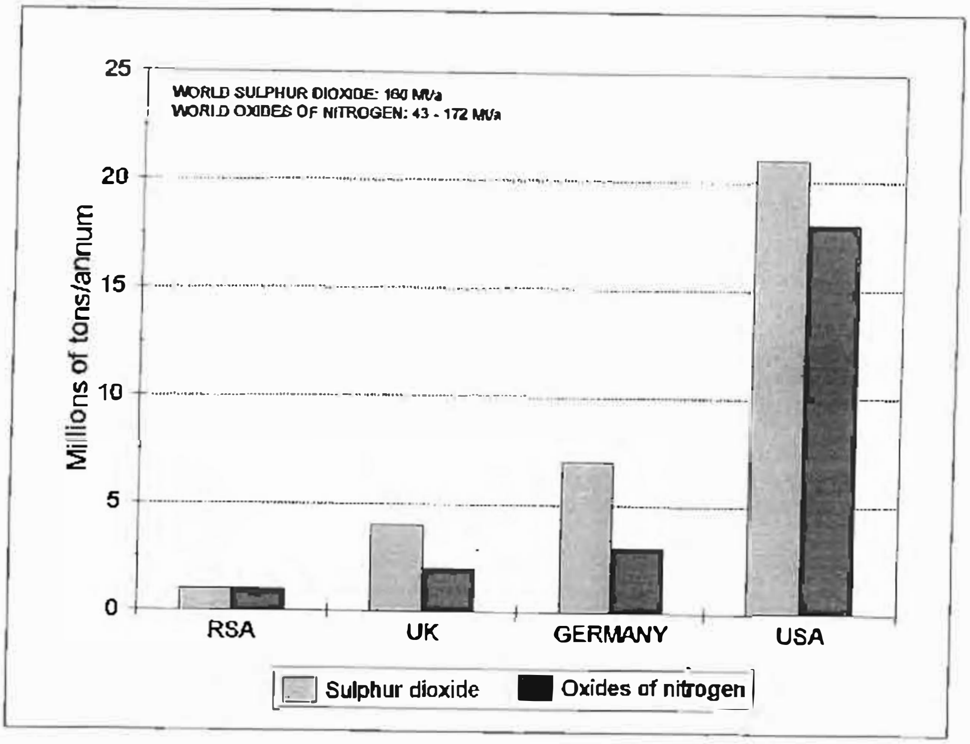


Figure 1: Total national anthropogenic emissions of sulphur dioxide (SO_2) and oxides of nitrogen (NO_X) for South Africa, the UK, Germany and the USA in millions of tons per annum (after Lennon and Turner, 1992).

It is clear that South Africa is a minor player in terms of these emissions. However, the presentation of total emissions does not reflect air quality as no cognisance is taken of aspects of dispersion and dilution. A more accurate reflection is given by comparisons of ambient air quality. Fig. 2 illustrates the ambient long term concentrations of sulphur dioxide and oxides of nitrogen in South Africa compared to typical values for the UK.

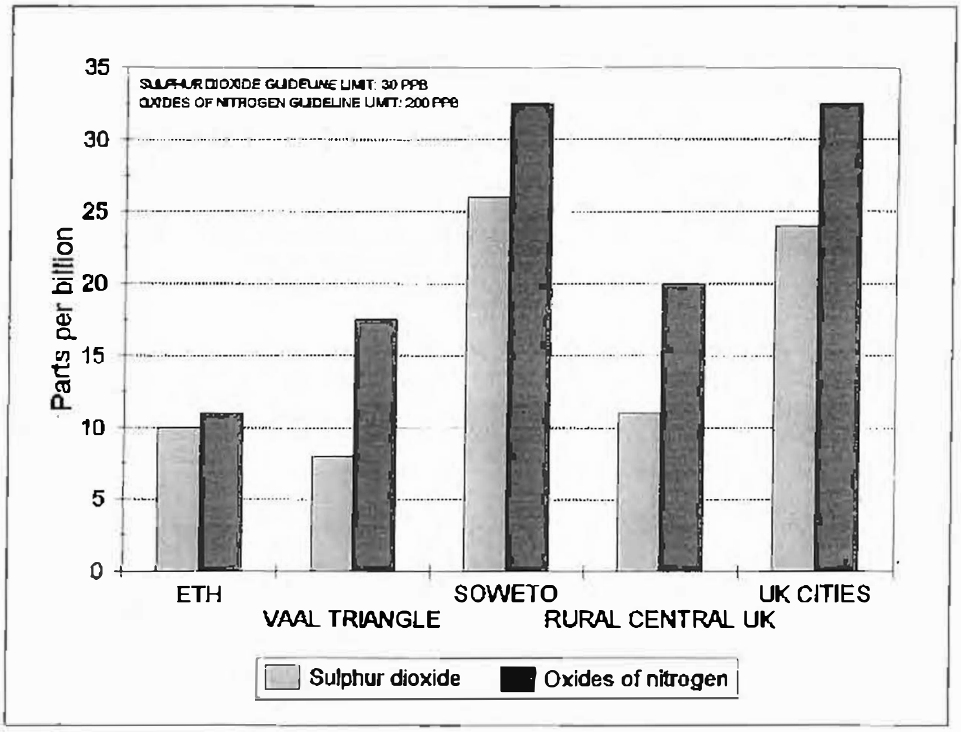


Figure 2: Ambient long term concentrations of sulphur dioxide (SO_2) and oxides of nitrogen (NO_X) in three regions of South Africa recognized as having air pollution problems (the Eastern Transvaal Highveld (ETH), the Vaal Triangle and Soweto) compared to rural and urban concentrations in the UK. Concentrations are measured in parts per billion where one billion equals 10^9. Internationally accepted guideline values are also shown (after Lennon and Turner, 1992).

The effect of South Africa's poor dispersion climatology can immediately be seen with levels now looking similar. It also becomes apparent that gaseous pollutant levels in Soweto are markedly higher than those of the Eastern Transvaal Highveld (ETH). When fine particulate mass is compared, the disparity is even greater and such concentrations would be totally unacceptable overseas (Fig. 3). The high pollutant levels recorded in such less developed cities with low level emission sources are central to this thesis and will be discussed in greater detail later.

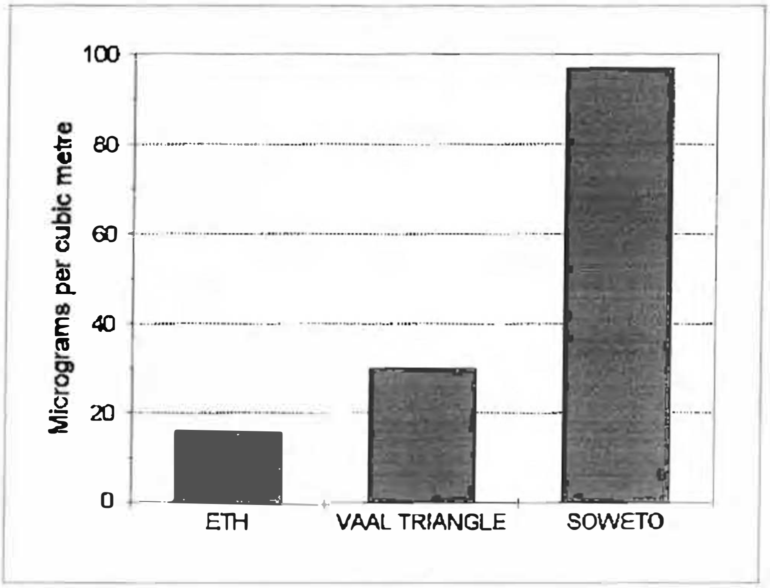


Figure 3: Ambient fine particulate mass concentrations in South Africa expressed in micrograms per cubic metre ($\mu g/m^3$)(after Lennon and Turner, 1992).

South Africa's contribution to global environmental problems, such as ozone depletion and greenhouse warming, is minor. In terms of chlorofluorocarbons (CFC's), Sub-Saharan Africa uses less than 1 percent of the world's production (Lennon and Turner, 1992) and the South African total of 597 Mt carbon dioxide equivalent represents only 1.14 percent of the global total based on 1990 estimates (van der Merwe, 1994). South Africa also recently became one of 155 signatories to the United Nations Framework Convention on Climate Change by which the Council for Scientific and Industrial Research (CSIR) has undertaken to prepare a South African inventory of greenhouse gas emissions in line with the Intergovernmental Panel on Climate Change (IPCC) guidelines. A national report entitled *Building the foundation for sustainable development in South Africa* (1992) was presented to the United Nations Conference on Environment and Development, held in Rio de Janeiro during June 1992.

Ethically, both South Africa and the world conservation strategies are similarly based on a utilitarianism rationale by which the aim of environmental conservation is to produce the greatest amount of good for humankind (Fuggle, 1992). The shortcoming of this approach is that it allows for the exploitation of the natural environment to meet the needs of humans. It does not recognize the right of nature to exist for its own sake, making stringent environmental control difficult to justify. How South Africa manages its atmospheric environment within this ethical framework forms much of the following discussion on characteristics of South African air pollution and its control.

1.2.2 Characteristics of South African air pollution and its control

In the background to a study of atmospheric pollution in Pietermaritzburg, it is necessary to review the characteristics of air pollution and its control in South Africa as a whole. Pietermaritzburg is a case study that reveals many climatological, economic, social and legal issues that are pertinent to the national situation and *vice versa*. The analysis to be presented in Chapters Three, Four and Five must be viewed in this broader context.

1.2.2.1 Major sources of air pollution

With the exception of pollution generated by vehicles, the combustion of fossil fuel produces the bulk of air pollution in South Africa. Coal is the country's primary energy source and is likely to be used well into the next century, while oil is ranked second as shown in Table 1.

Dependence on coal is based on South Africa's extensive coal reserves, with 122 million tons being consumed domestically in 1988. Of this, 94 percent is used by three industries alone - Eskom (electricity), Iscor (steel) and Sasol (synthetic fuels). Eskom is the single largest user of coal, consuming 67.5 million tons at 18 power stations during 1989 (Eskom, 1989). The net electrical output of 28 233 MW represents half of the total electricity generated in Africa, but as a consequence of such vast coal consumption, there is concern over the environmental impact of Eskom's activities.

Table 1: Contributions of various energy forms to South Africa's primary energy demand (after Petrie, Burns & Bray, 1992).

Energy form	Percentage
Coal	82.3
Oil	10.4
Biomass	6.1
Nuclear	1.0
Hydro	0.2

Concern is greatest in the Eastern Transvaal Highveld (ETH) because it is both a major agricultural and forestry area, yet home to ten of Eskom's coal fired power stations and Sasol petrochemical plants II and III. High industrial density and pollution generation combined with poor dispersion climatology have made this area the focus of several recent studies.

Atmospheric pollution and its implications in the Eastern Transvaal Highveld (Tyson, Kruger & Louw, 1988) is the most definitive. The report was prepared under the auspices of the National Programme for Weather, Climate and Atmosphere Research of the CSIR, and provides a yardstick by which the full extent of fossil fuel generated air pollution in South Africa can be measured. In brief, the findings are as follows (compiled from Louw, 1988 & Tyson, Kruger & Louw, 1988):

- the Eastern Transvaal Highveld atmosphere is highly unfavourable for the dispersion of atmospheric pollutants;
- substantial amounts of pollutants are released into the atmosphere in this region (Table 2);
- ambient atmospheric levels of pollutants generally comply with local ambient air quality standards although high concentrations of SO_2 may be experienced during certain types of air flow;

- pollutants emitted by tall stacks accumulate in the upper layers of the atmosphere (above the surface inversion) and are recirculated resulting in acidic deposition;
- the atmospheric pollution problem has, for practical reasons, not as yet been fully addressed.

Table 2: Atmospheric pollution - Eastern Transvaal Highveld and national figures (after Els, 1990).

Source	**Emissions (tons y^{-1}) 1987**			
	Particulates	**SO_2**	**NO_X**	**CO**
Power stations	355 843	1 110 585	371 791	43 538
Total in ETH	427 264	1 217 728	407 011	371 888
Total nationally	1 059 000	3 305 000	1 106 500	

The relationship between atmospheric pollution and environmental degradation is better quantified using ambient concentrations than absolute pollutant amounts, as dilution and dispersion mechanisms are then taken into account. When ambient SO_2 concentrations from the Eastern Transvaal Highveld are compared with those of residential areas such as Soweto, they are found to be much lower as shown in Fig. 2 (p.6). Similarly, particulate (smoke) levels over the ETH are much lower than those monitored in urban areas such as Soweto and the Vaal Triangle as shown in Fig. 3 (p.7). In Soweto, United States Environmental Protection Agency (EPA) guidelines for particulates are regularly exceeded (Rorich, 1988).

Diffuse ground level emissions from domestic coal consumption in residential areas thus still constitutes a major pollution problem in South Africa. It is a result of existing energy consumption practices and environmental degradation will continue until alternatives to solid fuel are found. Eskom argues that electrification will alleviate the problem, but there is still much debate as to the net effect because of increased pollutant generation from more power stations.

It is not the purpose of the thesis to solve the above debate, but the significance of the ETH region to South Africa and in turn Pietermaritzburg must be noted. First, it is clear that the need for industrial development will preclude the option of full atmospheric pollution control, and secondly, the development of air management policies for the whole country will depend largely on what actions are taken to alleviate the environmental pressure in the ETH region, and when.

Analysis of air pollution from crude oil refining processes is difficult because information on such commodities is protected by government legislation. Petrie *et al.* (1992) nevertheless managed to calculate that the total contribution from oil refining to complete SO_2 emission amounts to only 1.5 percent of that from coal in South Africa. However, the bulk of sulphur present in crude oil is retained by petroleum products, which will result in significant diffuse emissions of SO_2 through combustion within the transport sector.

1.2.2.2 National research and monitoring

International incidents such as the London fog of 1952 and the recognition of photochemical smog in Los Angeles in 1953 initiated concern for South Africa's atmospheric environment. In 1955, a conference on air pollution was organized by the CSIR where it was announced that a National Committee on Air Pollution was to be formed (Halliday, 1981). This marked the beginning of government action and wide public interest.

The CSIR's Air Pollution Research Group was established in 1961 with funding from the industrial sector and from then on it grew rapidly in numbers and in the diversity of its activities. This culminated in 1980 with the formation of the present Atmospheric Sciences Division of the CSIR.

Considerable research over the past three decades by the Atmospheric Sciences Division (and its predecessor) has been devoted to the type and concentration of pollutants, the physics of dispersion processes and the effect of meteorological changes. Such work has made it possible to assess the extent to which poor atmospheric ventilation produces undesirable concentrations of pollutants in certain areas, enabling town planners to determine which areas will be suitable for industrial and residential use. These models have been applied to Richards Bay, Saldanha Bay, Sishen, Nelspruit, Pretoria, Cape Town and Durban with varying degrees of success.

Monitoring of ambient levels of selected atmospheric pollutants has also been conducted by the CSIR for many years. Early studies in Pretoria, Johannesburg and Durban showed that concentrations of carbon monoxide, hydrocarbons, ozone and particulates were not such as to warrant legislative action to control automobile emissions. As a contribution to global monitoring, the CSIR is measuring carbon monoxide, CFCs, ozone, carbon dioxide and methane at Cape Point.

More importantly for the current research, the CSIR was involved in the establishment of the National Air Pollution Monitoring Programme that now involves 41 local authorities. Approximately 200 stations throughout the country monitor the levels of SO_2 and particulate matter in the air; 150 monitor smoke, while 114 monitor SO_2 (Petrie *et al.*, 1992). A mobile laboratory is also used to make comparative measurements in towns and cities participating in the survey. Pietermaritzburg's involvement in this programme will be considered in Chapter Two.

Apart from the CSIR, industries such as AECI, Sasol and Eskom have their own monitoring stations and conduct valuable research into air pollution in South Africa. Eskom is particularly strong in this regard and some of its recent research initiatives are listed below (compiled from Lennon and Turner, 1992):

- a joint project with Forestek (CSIR) on forestry impacts on the escarpment;
- a cooperative project with the Medical Research Council, Department of Health and various other industries on health affects and air quality in the Vaal Triangle region;

- a joint project with Ematek (CSIR) on optimising national rain quality monitoring for the Department of Health;
- a long-term project on atmospheric chemistry in partnership with the Foundation for Research and Development;
- a joint project with Ematek to evaluate air recirculation and pollutant accumulation above the ETH.

Universities are also involved in much of the above mentioned research. In addition, the University of Natal has completed projects measuring the thermal stability of the boundary layer and ozone trends over Southern Africa. The University of Cape Town has undertaken a large scale survey of Greater Cape Town, assessing ventilation potential and specifying expected problem areas, while the Climate Research Group at the University of the Witwatersrand recently completed the Vaal Air Characterisation Study.

One other major organisation which plays a largely collaborative role in air pollution research in South Africa is the National Association for Clean Air (NACA). The objectives of the organization can be summarized as: promoting the cause of air quality, contributing to the prevention of air pollution, accumulating and disseminating information on air pollution and its control, and representing South African clean air interests both nationally and internationally.

Of particular value is NACA's organization of International and National Conferences that provide an opportunity for those involved in air pollution and its control in South Africa to gather and share expertise. A review of such conference proceedings over the past four years is a good indicator of where emphasis is being placed in current research. Papers at recent conferences have covered research on: air pollution in Soweto (Sithole, 1990), Eskom's strategy on air quality management (Gore, 1990), respiratory illnesses in the Vaal Triangle (Terblanche *et al.*, 1993), particulate matter in Johannesburg (Rama, 1993), the Cape Town brown haze (de Villiers and Dutkiewicz, 1993), and air quality assessment for the city of Port Elizabeth (Janse van

Rensburg, 1993). The complete absence of papers on research based in Natal is noticeable and was one of the motivating factors behind the Pietermaritzburg study.

1.2.2.3 Legislation and economic considerations

South African legislation has comprehensively addressed the problem of air pollution only since the mid-sixties. An official investigation was conducted into the desirability of air pollution control in 1955, but it took until April 1965 for the final promulgation of the Atmospheric Pollution Prevention Act.

The Act is administered by the Department of National Health and Population Development and consists of six parts as follows.

- Part I: Administration
- Part II: Control of Noxious or Offensive Gases
- Part III: Smoke Control
- Part IV: Dust Control
- Part V: Control of Emissions from Vehicles
- Part VI: Penalties

(Department of National Health and Population Development, 1994 after Act 45 of 1965)

It is claimed by the Department that the levels of air pollution in some places in South Africa have dropped over the past 25 years. Lennon and Turner (1992) verify this based on CSIR statistics, finding that SO_2 and smoke levels in the major cities have decreased by an average of 1.5 percent per annum over the past 20 years. However, several causes of continued concern have been identified to receive priority in the future. These include: residential areas without electricity, power station emissions, wood processing plants, lead in petrol, smoke from smaller industries and motor vehicle emissions. With the exception of power station emissions, all of these pollution sources are significant in Pietermaritzburg, highlighting the contemporary relevance of the present study. The role played by small installations in cities, such as coal stoves and boilers in factories, hospitals and blocks of flats should not be underrated as their emissions are usually at low levels in (or adjacent to) residential areas.

Regionally, the PWV area, the ETH, the greater Durban area and the western Cape have been singled out as requiring the most attention (Department of National Health and Population Development, 1994).

The establishment of a National Air Pollution Advisory Committee (NAPAC) is provided for by legislation. NAPAC consists of seven to 11 members appointed by the Minister of National Health and Population Development. Its functions are to advise the Minister on air pollution matters and generally promote interest in the problem of air pollution, but part-time membership and infrequent meetings prevent the committee from being truly effective. The Atmospheric Pollution Prevention Act also provides for the appointment of the chief officer and inspectors who must be persons technically and academically qualified with practical experience in industry. To this end, the country's first Chief Air Pollution Control Officer was appointed in 1968 (Department of Health and Welfare, 1984).

Control of noxious and offensive gases is the direct responsibility of the chief officer as stipulated in Part II of the Act. The objectives of control outlined by the department are: the efficient control of industries, the limiting of SO_2 and NO_X levels in the ETH to acceptable levels, the limiting of volatile hydrocarbon levels to acceptable levels, the elimination of visible particle emissions from industries, the limitation of specific noxious emissions from specialised industries, the monitoring of all emission sources as far as possible and the monitoring of environmental pollution levels by industries as part of the national monitoring programme (Department of National Health and Population Development, 1994).

In order to achieve these objectives, a system of scheduled processes has been implemented since 1968. The Department of National Health and Population Development (1994) recognizes 96 industrial processes that are subjected to control by registration as defined in schedules to the Act, with more than 1600 factories having applied. No one may carry on a scheduled process without holding a current registration certificate. Such certificates are issued once the company has satisfied the Chief Air Pollution Control Officer that the best practicable means are being adopted for preventing or reducing to a minimum the escape into the atmosphere of noxious or offensive gases produced by the scheduled process.

'Best practicable means', as defined by the Act, is the basis of all air pollution legislation in South Africa. The definition is summarized by Petrie *et al.* (1992) as *'the adoption of measures which are technically feasible and economically possible, bearing in mind the well-being of the people in the area of the plant'*. The advantage of this method of control is that it is very flexible and can be quickly adapted to changing circumstances, making it easily applicable in a developing country such as South Africa. No ambient air quality standards are set and the degree of air pollution tolerated depends upon the discretion of the chief officer.

Adoption of the 'best practicable means' approach to air pollution control is based on the principle that while a safe and healthy environment is essential, air pollution control is very costly. The requirement of high levels of control can therefore harm industries and retard economic growth that is desperately needed to redress poverty. A delicate balance must be maintained between what is essential for a healthy environment and what can be afforded. The achievement of this balance relies upon the full cooperation of industry and the authorities.

The pros and cons of this approach, which is largely an issue of environmental economics (grounded in the utilitarian environmental ethic), will be addressed in more detail in Chapter Five. Its success as a control rationale in Pietermaritzburg can be better assessed once the factual data have been presented. Alternative approaches will also be discussed.

Returning to the issue of a provisional registration certificate, the chief officer must be satisfied that the scheduled process in question may reasonably be permitted to be carried on in the area concerned, having regard to the nature of the process and the character of the locality in question. The latter raises some important questions about scheduled processes in Pietermaritzburg and will be examined in subsequent chapters.

It is an offence to carry on a scheduled process in the absence of a registration certificate which may be cancelled or suspended if the holder fails to comply with the conditions. However, if the penalty for an air pollution offence is to be effective as a deterrent, the probability of detection must be high and the sanction must be severe enough so as not to be regarded merely as a cost of doing business (Petrie *et al.*, 1992). Unfortunately, this is often the case in South Africa as the maximum penalty for contravention of the Act is only R 500 for a first offence or R 2000 for a second. When compared with the cost of abatement technology, it is clear that the Act favours the industrialist.

Part III of the Act places responsibility for the control of smoke pollution in the hands of local authorities whose areas of jurisdiction have been declared as smoke control zones. The first such zone was declared in 1966 and there are now over 220 (Boegman, 1994). Objectives of smoke control are: residential areas must be declared as smoke control zones, smoke levels in all residential areas must be reduced to acceptable levels, smoke from all non-scheduled industries must be limited to a minimum and all local authorities must participate in a national monitoring programme (Department of National Health and Population Development, 1994).

To achieve these objectives, a local authority may make regulations prohibiting the emission of dark smoke of a specified colour and density (according to the chart set out in the Act) and to authorize the inspection of fuel-burning appliances. In the event of contravention of these regulations, the local authority can serve a notice upon the owner or occupier of the premises requiring them to abate the nuisance within a specified period. Failure to comply with a notice constitutes an offence for which the owner/occupier may be prosecuted and subsequently ordered to take the necessary steps to bring about a cessation of the smoke. Failure to take the prescribed steps within the specified time (usually one month) empowers the local authority to abate the nuisance and to recover costs from the polluter (Act 45, 1965).

In principle, these regulations may sound adequate, but certain concessions make effective smoke control difficult. These relate to the unavoidable emission of dark smoke during the starting up, breakdown or disturbance of the appliance and to the installation of fuel-burning appliances commenced prior to a fixed date. It will be argued in Chapter Five that local industries use these concessions as loopholes to escape prosecution for actual contraventions of the Act. The interpretation of the term nuisance is also very subjective and often denies successful prosecution of offenders.

Part IV of the Act provides for the control of dust pollution from mine dumps and industrial processes not scheduled in Part II. Only the latter is of concern in Pietermaritzburg and is controlled by the local authority. Any person in a dust control area who carries on an industrial process which creates dust or is liable to cause a nuisance to residents in the vicinity must take the prescribed steps or, where no steps have been prescribed, must adopt the best practicable means to abate the nuisance. Penalties are similar to those relating to the emission of noxious or offensive gases and again there is debate as to whether they present a sufficient deterrent.

Vehicle emissions are dealt with in Part V of the Act and also fall under the control of the local authorities. The objectives outlaid by the Department of National Health and Population Development with regard to Part V of the Act are: to minimize visible smoke from vehicles, remove lead from petrol, limit hydrocarbon emissions and implement an efficient monitoring network. If an officer appointed by the local authority has reason to believe that excessive fumes are being emitted by a diesel vehicle, the vehicle owner must be notified to take the necessary steps to reduce the emission to acceptable levels and make the vehicle available for re-examination. Efficient vehicle emission control therefore depends on the vigilance of the local authority in the carrying out of regular inspections.

The emissions of petrol engine vehicles are also a matter of concern, but no standard tests have yet been developed and no regulations have as yet been issued under the Act. The onus thus rests solely on the owner of the vehicle to ensure that the engine is well tuned to prevent hazardous pollution.

Finally, the Department outlines some general objectives for air pollution control in South Africa. Two of these are of particular relevance to this thesis. First, the public must be educated on matters relating to the control, effects and prevention of air pollution, and secondly, research must be carried out on the occurrenec and abatement of air pollution in South Africa. Both of these are also objectives of the current research as pertaining to Pietermaritzburg.

The characteristics of South African air pollution and its control have been established to place the study in broad perspective. Many controversial environmental issues have been identified, but not discussed in any depth, for it is the intention of the research to examine these issues in the local context of Pietermaritzburg and formulate scientifically reasoned judgements based on the data collected. Solutions to current and potential problems can then be sought for the local situation and the methodology, rather than specific proposals, used as a contribution to the formulation of a new national air pollution control policy. *'New legislation..., if properly formulated and enforced, could be the most important step ever taken with regard to the environment in South Africa'* (Boya, 1993).

1.3 PIETERMARITZBURG AS A STUDY LOCATION

1.3.1 Physical environment

Pietermaritzburg is located in the southern Natal Midlands, some 80 kilometres inland of the coastal city of Durban (Fig. 4). The city is situated in a hollow formed by the valleys of the Msunduze River and its tributaries, measuring roughly 8 km x 12 km (Tyson, 1962) as shown in Figs. 5 and 6. Rounded hills and dissected spurs surround the city except in the south-east where a gap allows the Msunduze to flow out of the basin to meet the Mngeni. This topography is typical of the region and many Natal towns are found in similar valleys and basins. A well defined escarpment rises 400 metres above the city on the west and north-west sides where resistant dolerite sills protect underlying sandstone and shale. One resistant sill forms the crown of Swartkop and another that of World's View - two of the highest points in the area. Table Mountain, to the south-east of the city is another prominent topographic feature that represents a remnant outlier of the Natal Group sandstones. Fig. 5 shows the Pietermaritzburg hollow as seen from World's View looking south-east towards Table Mountain.

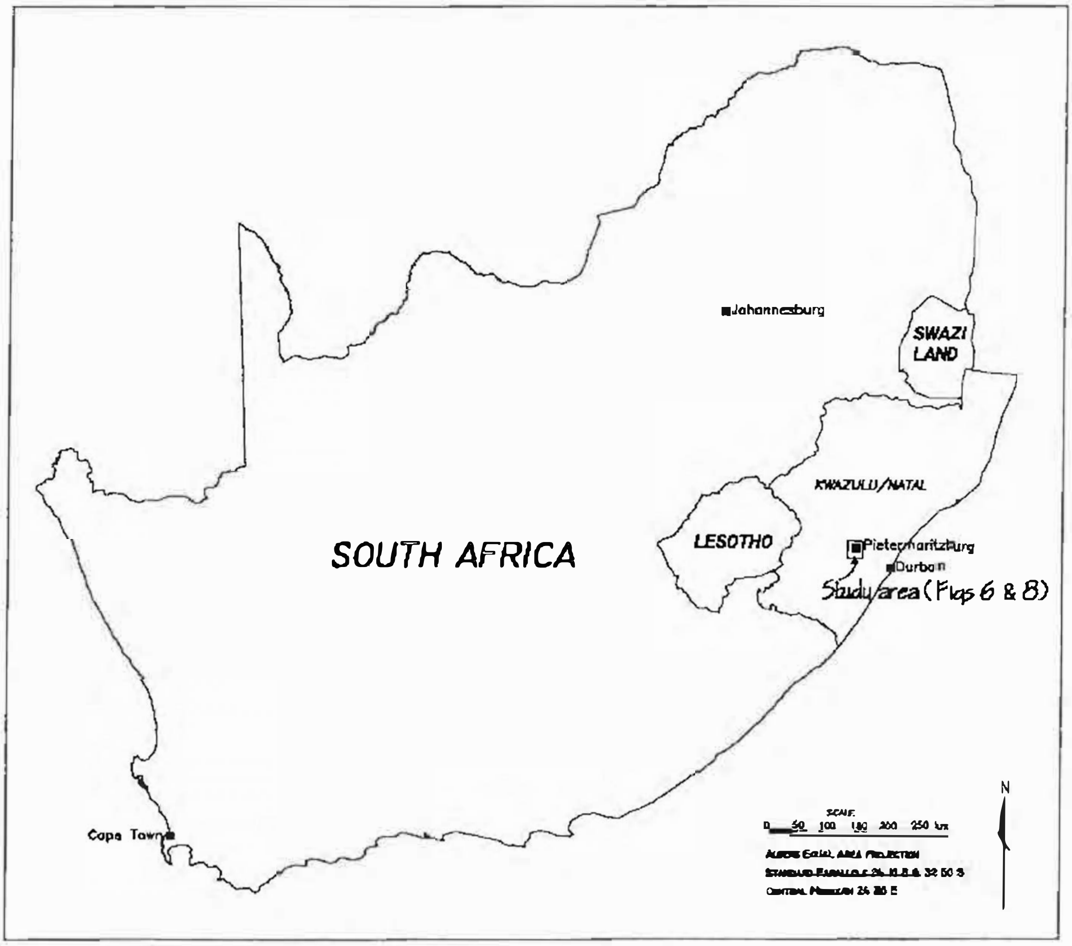


Figure 4: The location of Pietermaritzburg in Southern Africa in relation to three major cities.

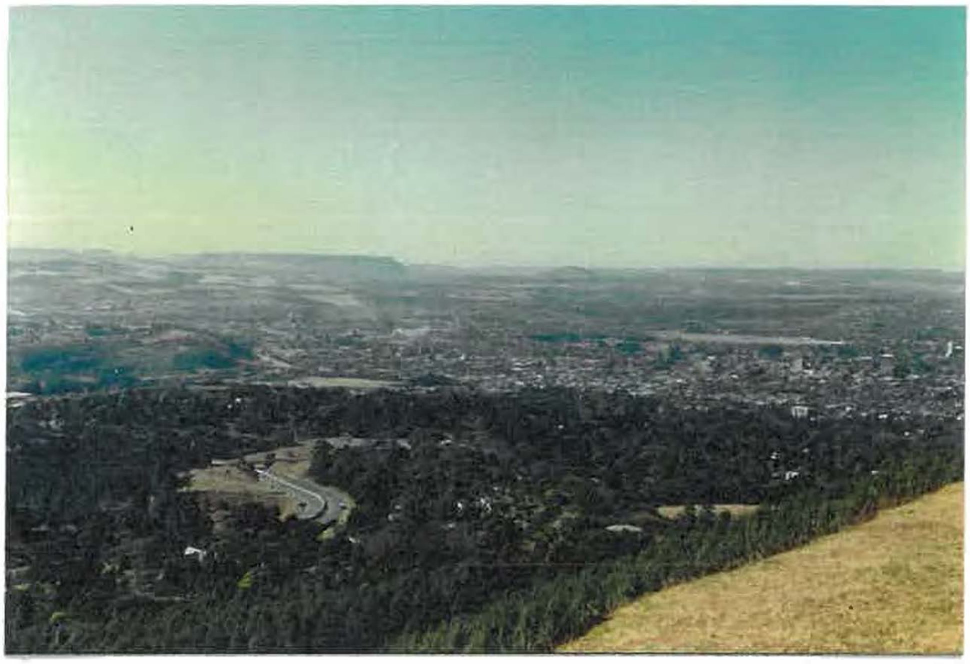


Figure 5: The Pietermaritzburg hollow as seen from World's View looking south-east towards Table Mountain on a clear winter day. The N3 freeway can be seen winding down Town Hill to the city.

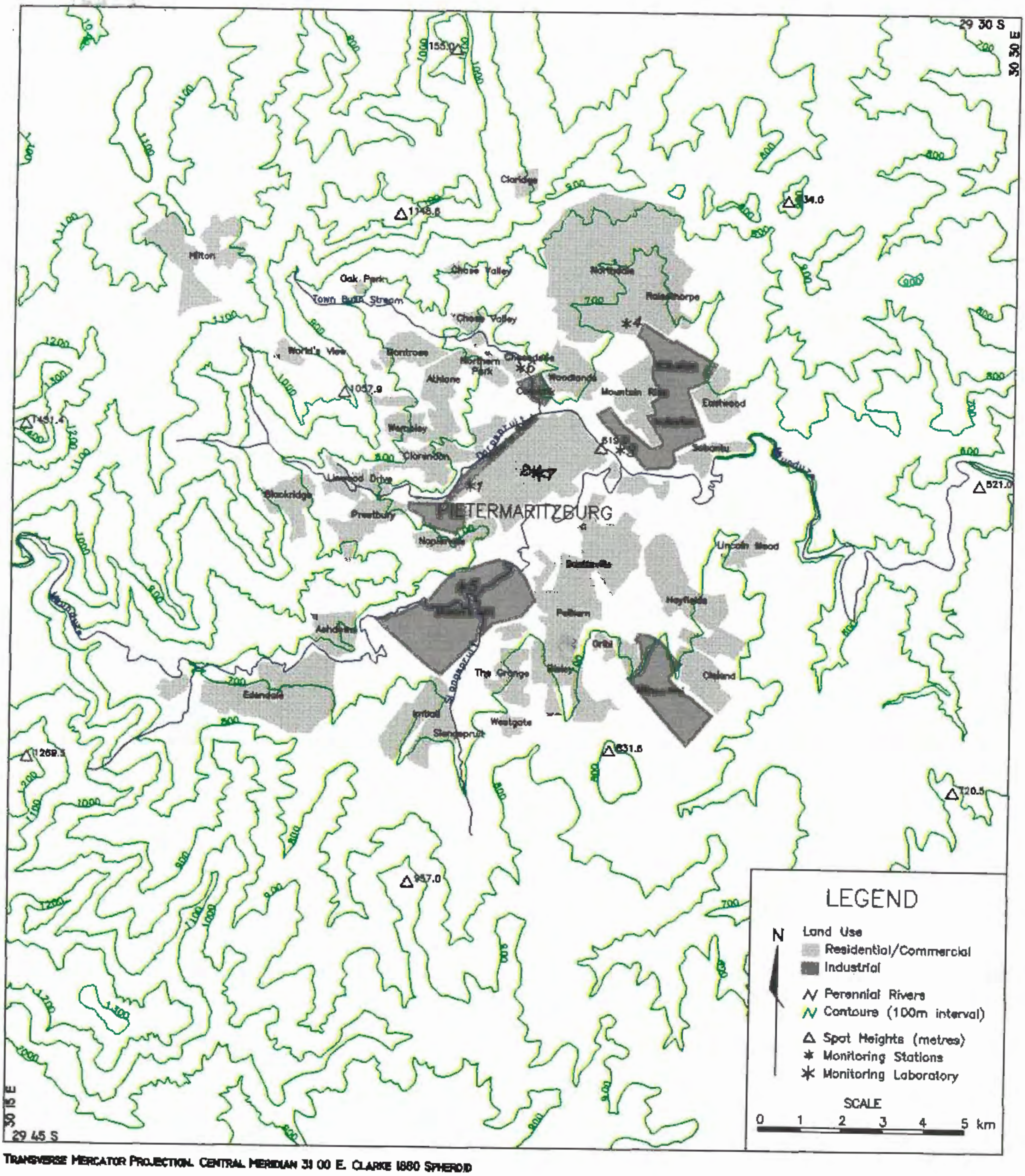


Figure 6: Pietermaritzburg area: drainage and relief (with location of monitoring stations for later reference).

The central business district occupies the relatively flat basin floor (Fig. 7) with the altitude of the City Hall being 658 metres. Growth of the city has radiated outwards from the central business district (CBD) with many of the newer residential suburbs located on the surrounding hillslopes to the north and north-west, while industries have tended to locate on or adjacent to the lowlying floodplains of the Msunduze and Dorpspruit because of the need for level land. However, the largest industrial area, Willowton has now spread up the hillslopes to the north-east of the city because of proximity to a reliable labour source. This locational choice of industries in relation to the local topography is of particular significance to atmospheric pollution as discussed in Chapters Two and Three.

Figure 7: The central business district taken from World's View with a 200 mm zoom lens. The clock tower of the City Hall can be seen in the foreground, while Scottsville racecourse is clearly visible in the background. Note how the topography rises out of the basin.

1.3.2 History and development

After defeating the Zulus in 1838 the Voortrekkers selected farms and settled in Natal. To serve as capital of their republic they founded the town named Pietermaritzburg after their leaders, Piet Retief and Gert Maritz. The site was chosen because of the fertile soils and availability of water from the Msunduze, air pollution not being a consideration at the time!

Pietermaritzburg today is the provincial capital of KwaZulu-Natal, although it is currently contesting this title with Ulundi under the new political dispensation. The town which grew to a city has greatly benefitted from its capital status over the past 150 years and has become an important educational, agricultural and industrial centre, apart from its administrative function. A large manufacturing sector has emerged over the past 50 years with the city benefitting from government decentralization grants during the 1980s. Employment opportunities thereby created have attracted people of all races to the city and the population of the functional area[1] has grown rapidly to a total of 452 255 (Population Census, 1991).

The city is well served by road and rail networks and the N3 highway that forms the vital link between the PWV and Durban passes through the city (Fig. 8). Because it is one of the busiest freeways in South Africa and a link to major markets, industries locate close by to maximise transport benefits. The same applies to the railway lines running through the city, but unfortunately, in both cases these linear features tend to follow the valleys as far as possible. The net result is (again) that industries are located in the least suitable locations as far as atmospheric dispersion is concerned. Conflicting needs between development and the environment are scarcely more evident than in Pietermaritzburg.

1.3.3 Current socio-economic situation

Pietermaritzburg, like all other South African cities, needs to find a balance between development and environmental protection. Faced with rapid urbanisation, high population growth rates and large numbers of poor, rapid economic growth is wanted. But economic growth in the form of industrial expansion can cause great environmental problems, which in turn can impede economic development. So one of the principal tasks in formulating a policy

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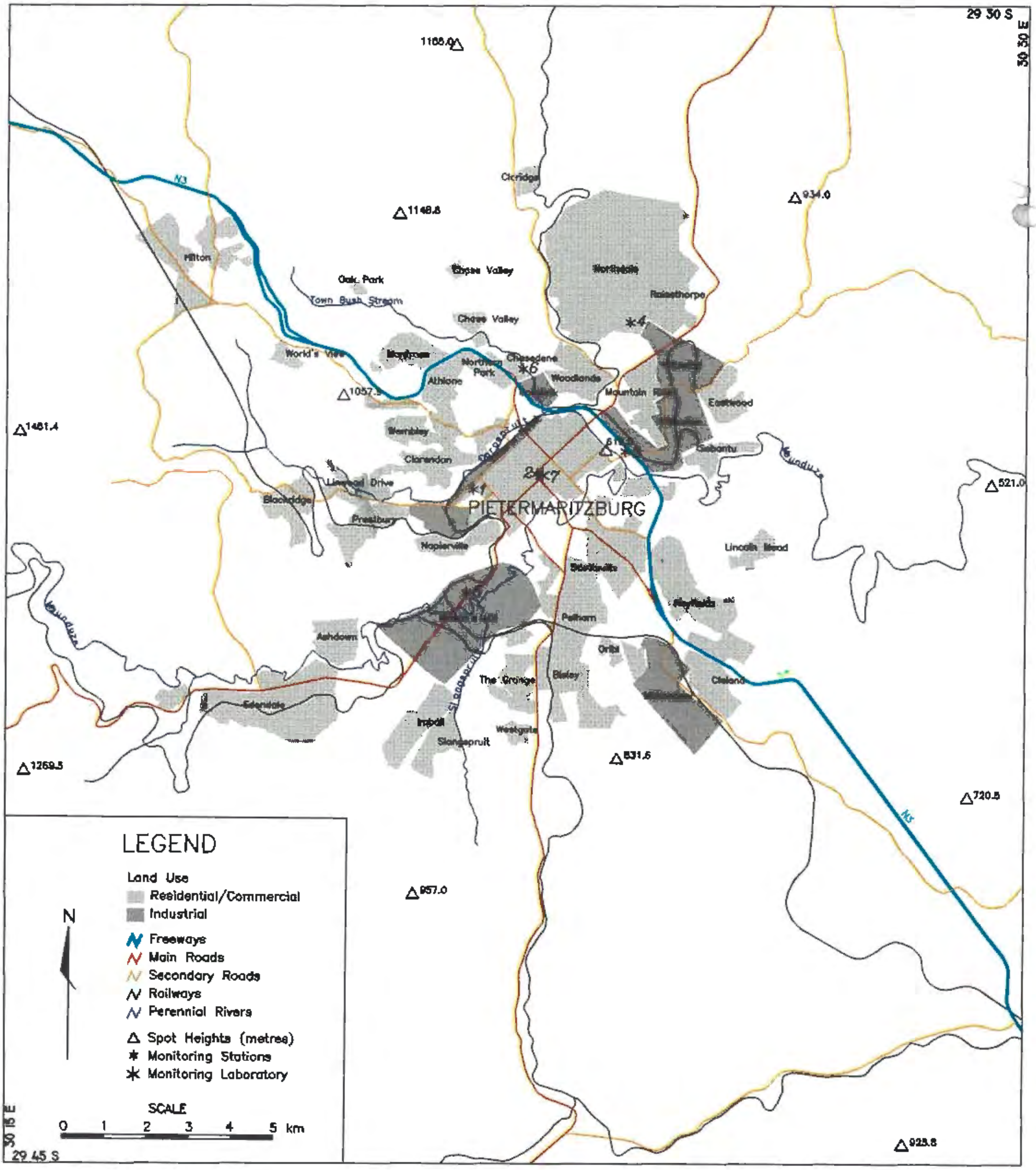
[1] The functional area of Pietermaritzburg includes the former KwaZulu district of Vulindlela, consisting largely of Edendale and Imbali where the majority of the city's black labour force resides.



TRANSVERSE MERCATOR PROJECTION. CENTRAL MERIDIAN 31 00 E. CLARKE 1880 SPHEROID

Figure 8: Pietermaritzburg area: land-use and transport infrastructure (with location of monitoring stations for later reference).

of economic development is to find ways to foster strong economic growth without causing significant environmental damage from pollution.

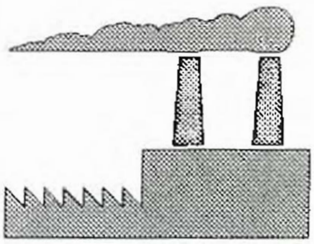
The local situation is further complicated by the current demand for jobs in the wake of the country's first democratic elections. Meeting the aspirations of a recently liberated population is placing more pressure on the environment than ever before by making economic growth an absolute necessity rather than just a priority. The local government must compete with other cities in a relatively stagnant economy to attract business and it does not want to deter industrialists by the enforcement of strict environmental regulations.

However, Pietermaritzburg cannot afford to ignore the consequences of unrestricted atmospheric pollution because its local topography and consequent air circulation make the city particularly prone to air quality problems.

* * *

Now that the current research has been placed in the broader context of air pollution in South Africa, succeeding chapters are devoted to details of air pollution monitoring and its findings in Pietermaritzburg.

Chapter Two



Air Pollution Monitoring in Pietermaritzburg

2. AIR POLLUTION MONITORING IN PIETERMARITZBURG

2.1 THE NEED TO MONITOR

It is evident that many interrelated factors play a role in the monitoring and control of air pollution wherever it occurs. In Pietermaritzburg the situation has become extremely complex as a result of the high visibility of the problem and a long history of concern for the local air quality from various sectors of society.

Public concern for the atmospheric environment is not surprising given that everybody is obliged to breathe the same air. A socio-economic survey conducted recently by the Geography Department at the University of Natal revealed that 28.5 percent of residents in a section of the central district identified air pollution as a major problem (Paul, 1992). This was rated above other major issues in the area such as racial tensions, security, dirty streets and overcrowding.

A large proportion of residential Pietermaritzburg is located on the hillslopes surrounding the city, particularly to the north and west of the central district (Fig. 6, p. 22). While these residents enjoy scenic views over the valley on clear days (Fig. 5, p. 21), the city is barely visible beneath a blanket of smog on most winter mornings (Fig. 9). This is also the sight that greets visitors when driving down Town Hill to the city on the N3 freeway, giving Pietermaritzburg the reputation of a smoky hollow which does little to attract either tourists or investment.

A profusion of letters and articles in the local newspaper each winter is the most common manifestation of this public concern, and such letters are often very critical of the City Health Division. Criticism of monitoring programmes has been rife and was allowed to continue through a lack of communication on behalf of the authorities. It was felt unnecessary to actively inform the public about air pollution levels and trends when data collected over the years suggested that pollution concentrations are well within South African guidelines.

Figure 9: Cause for concern - pollution filling the Pietermaritzburg hollow on a typical winter morning. Contrast this picture with Fig. 5 (p. 21) taken shortly after a passing cold front had cleared the air.

However, threshold standards and so-called acceptable levels are not the final word in air pollution. Many residents claim their respiratory ailments are exacerbated or even caused by Pietermaritzburg's polluted environment and such claims cannot simply be disregarded. Indeed, a paper by a local medical doctor states that asthma was as prevalent in the city as in the heavily industrialised Vereeninging and Vanderbiljpark region in 1990. Sales of asthma medication to the private sector in Pietermaritzburg amounted to R 1.5 million in that year (Kirkby, 1992).

Although claims that such health problems are a direct result of anthropogenic air pollutants are highly controversial, they still highlight the need to find an economic and environmental balance through effective monitoring and control of ambient air quality. It is equally critical that the public be kept informed as part of this process, by establishing regular communication between the citizens of Pietermaritzburg and the health authorities if they are to be supported in the choices they make (Simpson, 1994a).

As part of the current project, a bi-weekly pollution graph and report was compiled and published in *The Natal Witness* for the winter months of 1994 (Simpson and Sherry, 1994; Simpson, 1994b; Simpson 1994c). These short articles proved very popular with the public who were pleased to be informed of the levels of various pollutants in Pietermaritzburg compared to the South African guideline concentrations. Feedback indicated that people were generally surprised that the levels were ~~not higher~~, confirming that the general perception is that Pietermaritzburg's air is dirty.

Subsequent chapters will examine whether this perception is scientifically valid based on climatological and pollution data collected ~~over~~ the past year, but first, the development of air pollution monitoring in Pietermaritzburg is discussed as it became an essential part of the current research and the first step towards solving the problem.

2.2 PREVIOUS RESEARCH ON ATMOSPHERIC POLLUTION

Local air circulations over Pietermaritzburg were first studied in detail by Tyson in 1962. The aim of the study was to describe the local climate in the context of macroclimate and topography, and to examine the dispersal of pollutants within this climatic framework (Tyson, 1962). Using relatively simple instrumentation, meteorological and pollution data were collected during 1961 and 1962 at several sites. These data were then rigorously analysed in terms of the macroclimate and relevant climatological and meteorological theory available at the time.

In summary, it was found that Pietermaritzburg's local climate is strongly influenced by the topographic environment. On clear winter nights, katabatic flow occurs as cool air drains into the valleys. The sinking of cool air below warm upper air induces temperature inversions to occur in the Pietermaritzburg basin. As a result of these stable inversion conditions, pollutants are trapped, giving rise to a blanket of visible smoke, fog and other invisible pollutants over the city. During the late morning, dynamic and thermal fumigation occurs as the inversion begins to dissipate with uniform heating and the development of turbulence. This air movement causes thorough mixing of the pollutants in the stable layer below the elevated inversion such that high ground level concentrations result. Only when the inversion has dissipated does the air eventually clear.

A large proportion of Tyson's research was devoted to katabatic flow as its occurrence is the fundamental cause of Pietermaritzburg's air pollution problem. The study thus established a detailed climatic framework for the city and it was recognized that future industrial expansion would be problematic if no cognizance was given to the atmospheric environment. However, these timeous warnings went largely unheeded for many years. Even the publication of a journal article on the findings (Tyson, 1964) did little to attract the attention of the local authorities - perhaps a reflection of the times when environmental issues were low on the agendas of planners and politicians. The result of this ignorance is that thirty years on, the hollow is still shrouded with smog on most winter mornings.

Tyson's work remains the most definitive on atmospheric pollution dispersion over Pietermaritzburg to date, although rising public concern in recent years has prompted more research into the subject as well as a profusion of letters in *The Natal Witness* each winter. The CSIR conducted a ventilation study over the area in 1976 which concluded that, *'all industries subject to smoke control should be situated at least 100 meters above the floor of the Pietermaritzburg Basin...'* (Langenberg, 1976). Eleven years later a pilot study of pollution in Pietermaritzburg was conducted by the University of Natal (Kleyn, 1987), and most recently, ambient air quality data for a ten-year period were analyzed in a previous report by the writer (Simpson, 1992).

However, no previous research has answered the question as to how much pollution the winter smog really contains and how much of it is merely valley mist. There is also concern as to the invisible components present and their concentrations at various times. It is such questions that have caused the Pietermaritzburg City Health Division to become actively involved in monitoring and control of air pollution. The initiation and development of their monitoring programme is the subject of the next section.

2.2.1 Ambient air quality monitoring programme

From the results obtained by Tyson it became apparent that the air quality over the city was a cause for concern. It was further advocated that, *'it is necessary to undertake microclimatic surveys before industrial development is envisaged'* (Tyson, 1962). To this end, the City Health Division set up four monitoring stations in July 1972 with the assistance of the then Air Pollution Research Group of the CSIR (Kleyn, 1987 and Walters, 1988). Initially, all four stations monitored long term trends of particulate matter, while two also monitored sulphur dioxide. An additional health inspector was appointed to administer smoke control areas under Part III of the Atmospheric Pollution Prevention Act, and so began the ambient air quality monitoring programme in Pietermaritzburg.

Since this beginning the City Health Division has added two additional smokeless zones and four further monitoring stations, adding sulphur dioxide monitoring to all the stations. The monitoring network contributes to the National Air Pollution Monitoring Programme conducted by the CSIR, where the results are ratified and information collated to provide a picture of long term trends of air pollution in South African cities.

Methods of measurement are those recommended by Kemeny and Halliday (1968) as derived from The Department of Scientific and Industrial Research in Great Britain. The basis of the method for the determination of smoke and soot is described below.

A measured volume of air is drawn through a white filter paper of which the light transmission has been measured. Smoke and other particulate matter suspended in air drawn through the filter paper collect to form a stain of varying darkness. At the end of the sampling period, the light transmission of the filter paper with the deposit on it is again measured. From the two light transmissions the Soiling Figure 'S' is calculated which is the measure of the soiling potential of the air sampled. The concentration of particulates is obtained by dividing the Soiling Figure 'S' by the volume of air which was drawn through the filter paper and expressed by an optical unit called Soiling Index (S/m^3). Its definition is as follows (Kemeny, 1966):

> The Soiling Index (S/m^3) is the darkening potential of smoke and soot, suspended in one cubic metre of atmospheric air and collected on a circular area, 32 mm in diameter, of Whatman No. 42 filter paper.

Soiling Index values may be converted into the metric unit micrograms per cubic metre if multiplied by a conversion factor. A factor of five can be used for Pietermaritzburg (Boegman, 1993, pers comm.).

The apparatus for the measurement of smoke and soot consists of standard filter units which are located at the monitoring sites (Fig. 10), and a densitometer for measurement of light transmission in the laboratory (Fig. 11). A filter unit without the items required for sulphur dioxide measurements was located adjacent to the monitoring laboratory (described later) to record 24-hour average smoke concentrations for the winter of 1994 (Fig. 12).

Sampling periods are either 48 or 72 hours with filter papers being renewed on Monday, Wednesday and Friday of each week. Air volumes must be 1.4 to 1.7 cubic metres during a 48-hour sampling period and 2.1 to 2.5 cubic metres during a 72-hour sampling period. Sampling periods exceeding 72 hours are not recommended because they obscure important peak values. However, even 24-hour measurements do not sufficiently monitor peak values in Pietermaritzburg as will be shown later in the text.

The standard method used for the measurement of sulphur dioxide concentrations in combination with particulate matter is also described by Kemeny and Halliday (1964). The principle of the method is as follows.

A measured volume of air is drawn through a gas washing bottle containing a dilute solution of hydrogen peroxide (Fig. 10). The sulphur dioxide in the air is absorbed and oxidized to sulphuric acid. The resultant increase in acidity of the solution is determined by titration using a pH meter and the sulphur dioxide concentration in the air is calculated from the amount of titrant used. The method is not specific because it measures the acid radical and not only sulphur dioxide. However, it is recognized as the most suitable method for measuring sulphur

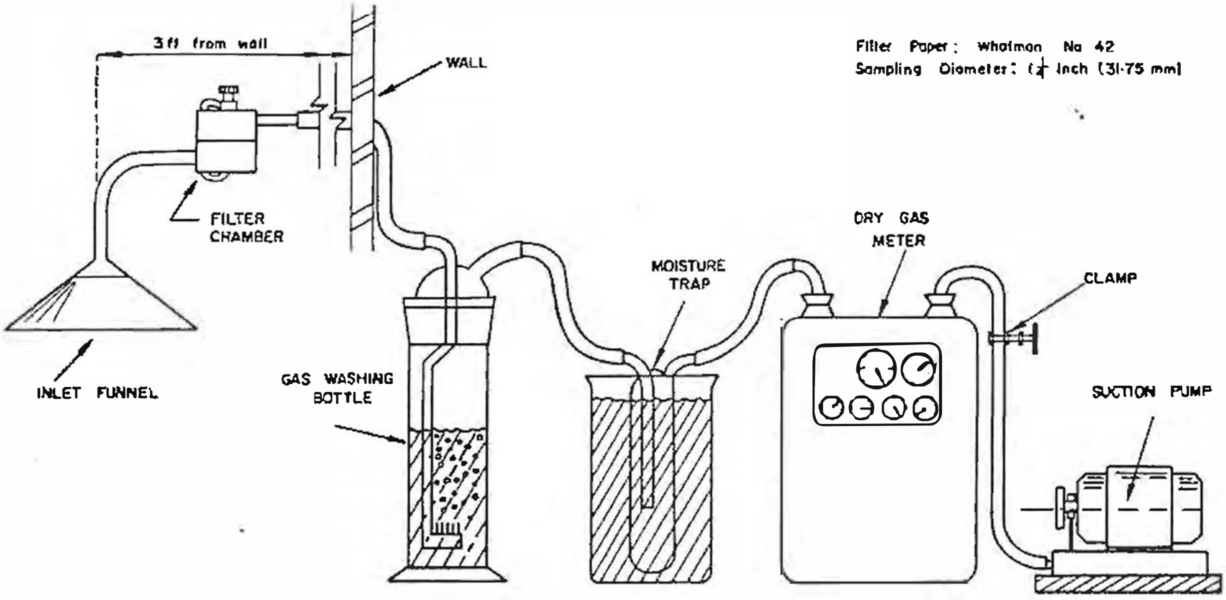


Figure 10: Standard filter unit used for the measurement of smoke and sulphur dioxide concentrations in the atmosphere in South Africa (after Kemeny and Halliday, 1968).

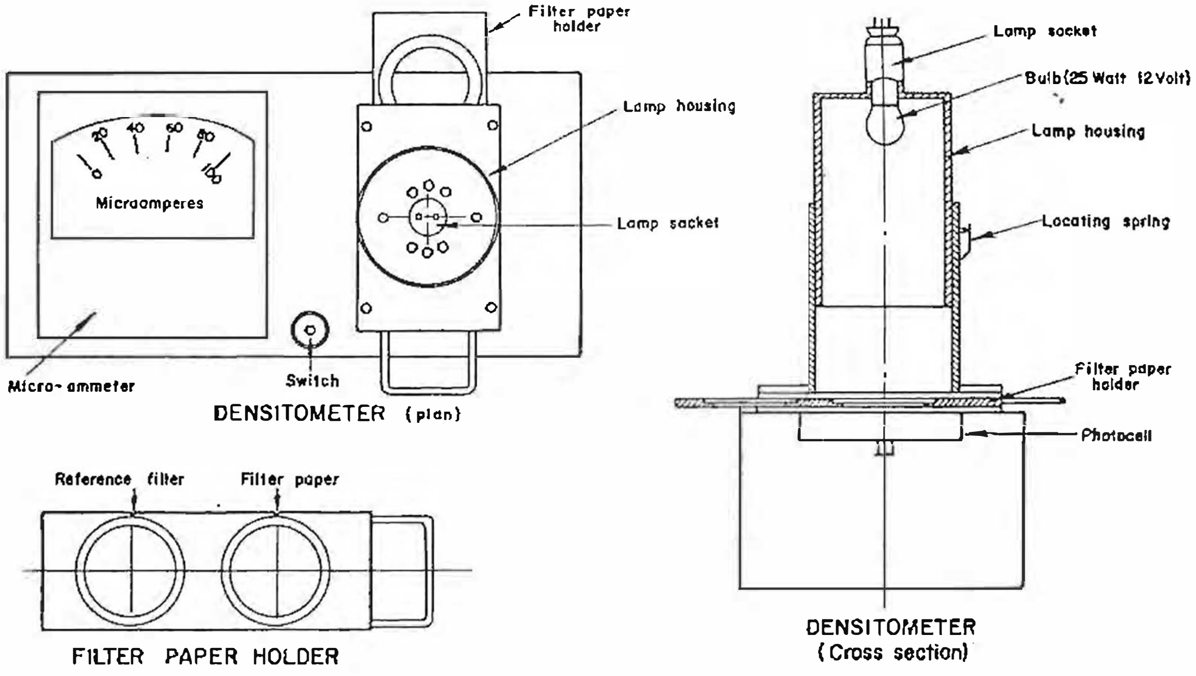


Figure 11: Densitometer for the measurement of light transmission (after Kemeny and Halliday, 1968).

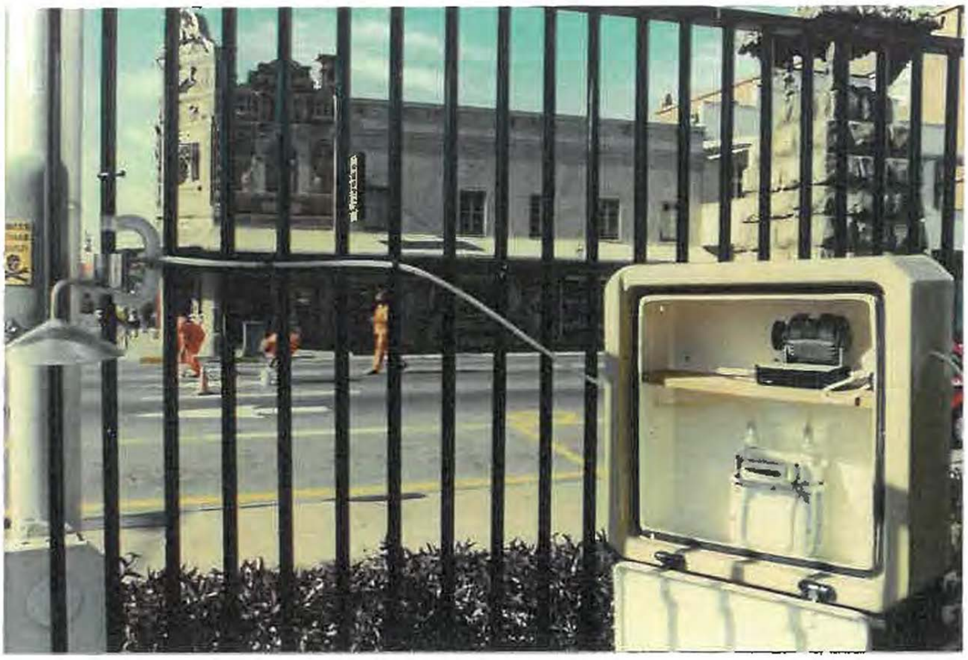


Figure 12: Filter unit and housing adjacent to monitoring laboratory. Inlet funnel, gas meter and suction pump are visible while gas washing bottles are absent as only smoke is being measured. Longmarket Street is in the background.

dioxide in the air on a continuous basis because of its simplicity. The concentrations of interfering substances in urban environments are generally much smaller than those of sulphur dioxide and may be ignored (Harrison, 1983).

Sulphur dioxide concentrations are generally expressed as micrograms per cubic metre of air sampled. The sampling periods and air volumes are the same as for smoke measurement, with the hydrogen peroxide solution being changed at the same time as the filter papers.

The six stations currently in operation are sited in areas suspected of having air pollution problems. All stations are located below an altitude of 700 metres, on the basin floor, and are within or adjacent to industrial areas (Fig. 6, p. 22). Table 3 summarizes each location in the context of air pollution.

Table 3: The site, location and main known pollutants of the present monitoring stations in Pietermaritzburg. The station numbers refer to those on Fig. 6 (p. 22) and Fig. 8 (p. 25)(modified from Simpson, 1992).

Station	Site	Location	Known Pollutants
1	Joliffe Swimming Pool	Near railway marshalling yards and light industry	Smoke
2	City Hall	Commercial centre	Vehicle emissions
3	Old Beer Hall (Echo Road)	Near Willowton industrial area and National Road (N3)	General industrial emissions
4	Northdale (Bombay Road)	Near Willowton industrial area	General industrial emissions
5	Mason's Mill (Somta Tools)	Main road to Edendale township and industrial area	Domestic smoke Industrial emissions
6	Chasedene (Open Door Church)	Adjacent to brick factory and National Road (N3)	Industrial dust and smoke Vehicle emissions

These six stations have provided valuable data on smoke and sulphur dioxide pollution in Pietermaritzburg for over ten years. Long-term trends and levels were analysed in a previous report by the writer (Simpson, 1992) as mentioned earlier and recent data will be used in Chapter Four for comparison with those obtained from the more advanced instruments. The value of these standard monitoring techniques is that they are relatively inexpensive and simple, allowing a local authority to operate several stations on a continuous basis. They are thus ideal for assessing long-term trends at a variety of locations within an urban area. However, this method of measurement and the way in which the data have been analysed and presented by the City Health Division has been strongly criticized over the past decade.

In a report on pollution in Pietermaritzburg by the University of Natal (Kleyn, 1987), it was argued that the calculation of the city's overall pollution levels by averaging averages of all six monitoring stations was completely unacceptable since essential information is lost. It was further recommended that smoke and sulphur dioxide measurements should be taken every 24 hours during June and July to detect pollution peaks as two- and three-day averages are not adequate to assess health effects. Investigation into the use of real-time monitoring equipment for pollutants and meteorological parameters was also suggested to record maximum levels on a daily basis.

2.3 REAL-TIME MONITORING

Increased public concern and the publication of newspaper articles claiming *'City's potential pollution dangers not measured'* (Anon, 1987a) and *'Fault in analysis of pollution measures'* (Anon, 1987b) in the wake of the University report prompted a review of air pollution in Pietermaritzburg by the Health Department in which it was stated *'The department is acutely aware of the need to introduce more effective control measures in Pietermaritzburg...'* (Walters, 1988). In response to the criticism of standard monitoring techniques and in anticipation of Part II of the Atmospheric Pollution Prevention Act's being delegated to local authorities, the purchase of a real-time monitoring caravan was proposed.

After much debate by the city council, the CSIR was approached to supply and assemble a fully equipped (see Section 2.3.3) monitoring caravan to the Pietermaritzburg City Health Division at a cost of approximately R 200 000. A caravan was originally requested so that the monitoring laboratory could easily be moved to different locations in the municipal area. However, for reasons of security and data integrity, a fibreglass hut was eventually delivered in 1990 and installed in the grounds of the Supreme Court, adjacent to Church Street. It was equipped to monitor four meteorological parameters (wind speed, wind direction, temperature and relative humidity) and seven pollutants (particulates, sulphur dioxide, ozone, nitric oxide, nitrogen dioxide, methane and non-methane hydrocarbons) and record these by computer on an hourly basis. Whether it was intended that this unit should still be moved around is unknown, but the names 'Mobile Monitoring Laboratory' and 'Monitoring Caravan' became fixed and well-known by the public of Pietermaritzburg.

2.3.1 Progress and problems

The CSIR's Division of Earth, Marine and Atmospheric Science and Technology was originally contracted by the City Health Division to calibrate and maintain the laboratory. A report of the air quality data was to be produced on a monthly basis and presented to the Medical Officer of Health. Reports were produced for the months of December 1990 and January, February, May, June and August 1991 (De Jager *et al.*, 1991a, b, c; Lisowski, 1991a, b, c). These reports reveal that from the very outset the monitoring laboratory was plagued by problems (Table 4).

The initial perception that the equipment was largely automated and needed little attention proved to be far from the truth, as it soon became evident that maintenance of such instruments is both time-consuming and expensive. This is in part due to the specialized nature of the gas analyzers (which are imported from the United States), but is exacerbated by agents and technicians being remotely located in the Transvaal (Simpson, 1994a). CSIR technicians, based in Pretoria, would visit only on a monthly basis because of the cost. If an instrument broke down half way through a month, the fault would not even be recognized until the month end, and then could often not be fixed until the next month because spare parts would have to be brought from the PWV or even ordered from the United States, in which case the instrument would be out of operation for a few months.

While valuable information was gathered during the CSIR's contract period, the cost of the programme became prohibitively expensive. Ratepayers began to question why such vast sums of money were required by the air pollution monitoring programme which did not appear to be producing any results. The weak link was in the communication of pollution levels and trends to the public and explanation of how real-time monitoring would benefit the city. Thus, in late 1991, when nearly all the analyzers had developed faults and required costly repair and calibration, and with the economy deep in recession, it was decided not to renew the contract with the CSIR. The equipment was left in a state of disrepair and with no-one at the municipality either qualified, or with enough time to attend to the problems, the monitoring laboratory became a very expensive white elephant.

Table 4: Technical faults logged at the Pietermaritzburg Air Pollution Monitoring Laboratory from December 1990 to August 1991 (compiled from De Jager *et al.*, 1991a, b, c; Lisowski, 1991a, b, c).

Month	**Faults**
December 1990	Relative humidity probe discrepancy
January 1991	Data lost for 11 days (246 hours) through power failure SO_2 analyzer faulty Temperatures inside hut beyond instrument operating requirements (>30°C and high fluctuation recorded)
February 1991	SO_2 analyzer faulty Temperature inside hut beyond instrument operating requirements (>30°C and high fluctuation recorded)[2]
May 1991	Frequent power failures causing lost data O_3 analyzer faulty NO/NO_2 analyzer faulty Non-methane hydrocarbons analyzer faulty
June 1991	Two power failures causing lost data NO/NO_2 analyzer faulty Nephelometer faulty
August 1991	Two power failures causing lost data NO/NO_2 analyzer faulty Non-methane hydrocarbons analyzer faulty Nephelometer faulty

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[2] This problem was eventually solved by double insulating the walls and roof of the hut and fitting an air conditioner.

2.3.2 University involvement

Use of services and expertise offered by the local campus of the University of Natal would seem to be the obvious answer to many of the problems experienced in the air pollution monitoring programme, but for various reasons these amenities have not been optimised until recently. The problem in the past was largely a lack of communication between the local government departments and the university. When there was communication, it tended to be confrontational, ending in the two parties retreating to their own spheres of influence and achieving little real progress together. The university tended to view the local authority as an inefficient bureaucracy while the local authority viewed the university as being out of touch with the real problems experienced on the ground.

As an example, in 1987 the city council commissioned the University of Natal to produce a report on pollution in the city, as previously mentioned (Kleyn, 1987). However, the report was strongly critical of the Health Department which provoked the Medical Officer of Health and the City Engineer to become defensive and dispute some of the findings of the report. Hence, the interaction between the two institutions was not very constructive, only serving to fuel public criticism of the monitoring programme.

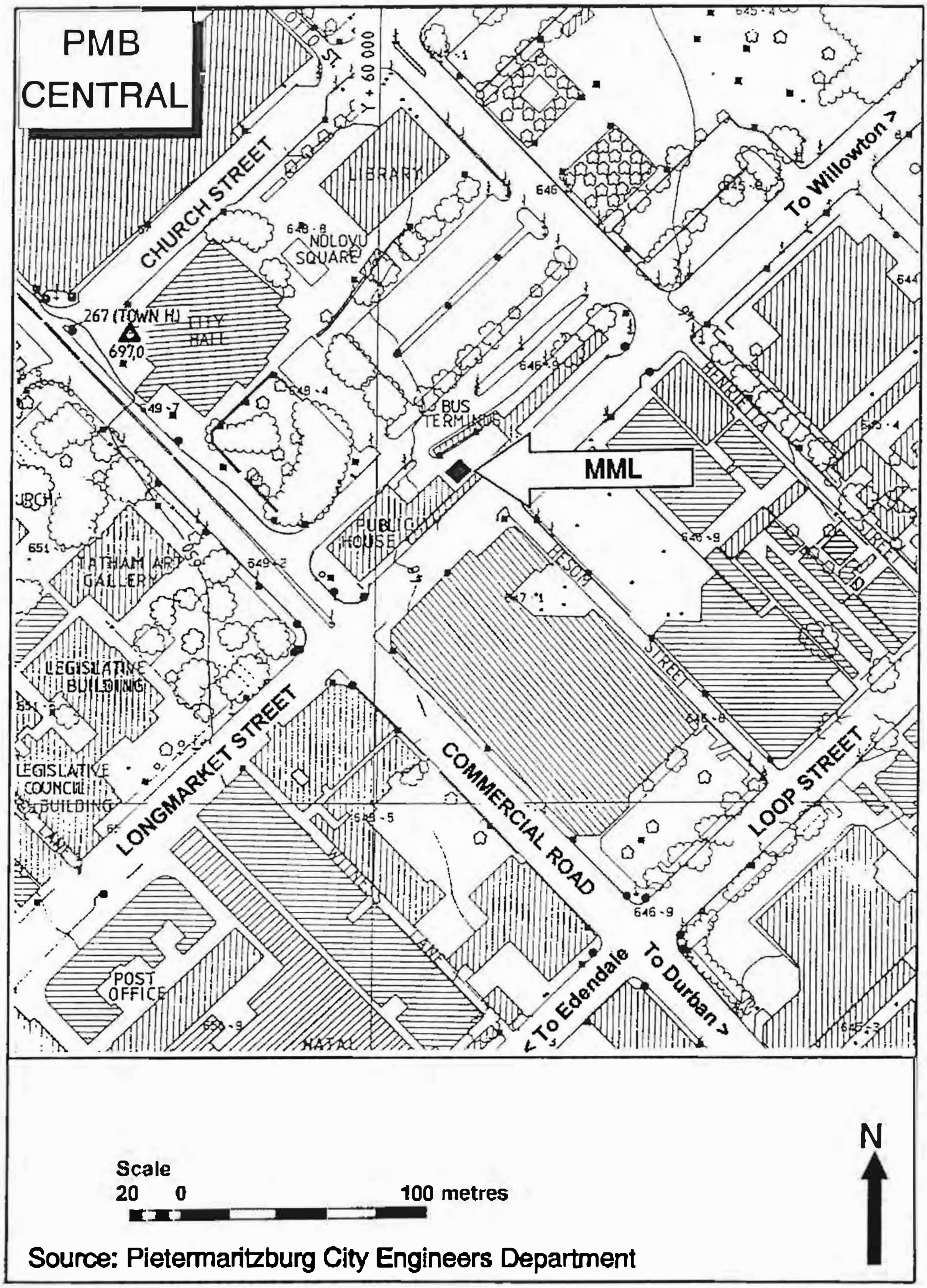
In July 1992, the writer approached Mr Sherry, the Senior Smoke Control Officer at the Pietermaritzburg Health Department, for the purposes of an Honours' level research project based on the ambient air quality monitoring programme. Much enthusiasm was shown and data made available, enabling the successful completion of the project (Simpson, 1992). During this time, the writer became aware of the monitoring laboratory and its potential for beneficial further research. Unfortunately, the unit was not operational at the time, owing to the problems described.

Nevertheless, there were plans under way to recommission the station using the technical services of S I Analytics, a Johannesburg based company. It was planned that the station would be fully operational by January 1993 and that data would be made available if desired. This vast potential data source combined with the need to justify the expenditure on the equipment presented an ideal opportunity for both parties. The challenge lay in getting the laboratory up and running to do the job it should have been doing since 1989.

In January 1993 the first setback came when it was made known that the monitoring station would have to be moved from its site outside the Supreme Court to allow for extensions to that building. Upon making further enquiries to the City Health Division, it was revealed that no definite date could be given about when the station would be functional and no guarantee could be given that the monitoring programme would continue at all. Such uncertainty placed the future of the research in jeopardy, so the city council was contacted to arrange for the case to be presented to the Pietermaritzburg Environmental Council meeting on 26 February 1993.

The address was successful in obtaining official permission from the Medical Officer of Health to use the required facilities. It then took a further two months to choose a suitable and acceptable site to which the station could be moved. The final site chosen was behind Publicity House, next to Longmarket Street and close to the intersection with Commercial Road (Fig. 13). Many factors, both related and completely unrelated to the climatology of air pollution had to be considered in settling on this final location.

It then took another month for the City Engineer's Department to move the structure and supply electricity. Once in place, the instruments were serviced and calibrated by technicians from S I Analytics. Only ten hours after the technicians had returned to Johannesburg, it was found that the logging computer was freezing all parameters at seemingly random times for several hours. After reinstalling the software, replacing the analogue-to-digital board, damping the vibration from the sample pumps and rewiring much of the equipment with no success, assistance was requested from the municipal Electricity Department and the Electronics Workshop at the University of Natal. The cause was eventually found to be fluctuations in the electrical power supply to the monitoring station causing the computer to lock-up. A surge protector, power regulator and uninterrupted backup system were then installed to rectify the problem.



Source: Pietermaritzburg City Engineers Department

Figure 13: The location of the 'mobile' monitoring laboratory (MML). See also station 7 on Fig. 6 (p. 22) and Fig. 8 (p. 25).

The close involvement of the writer from the initiation of the renewed monitoring programme has been essential for the research and beneficial to the City Health Division. Data collection, analysis and interpretation are handled by the writer and monthly reports are produced in cooperation with Mr Sherry for submission to the city council. A closer relationship between the municipality and the technical services offered by the university has also been fostered through the current research with the use of local skills and facilities reducing downtime for the monitoring station and saving ratepayers' money. The Department of Chemistry at the University of Natal are particularly helpful in repairing frequent breakdowns, completely free of charge. This is possible because of the mutually beneficial relationship that now exists whereby the University of Natal gets recognition for serving the local community (which is one of its official aims) in return for prompt technical service.

2.3.3 Instruments used for the investigation

In situ continuous monitoring systems for meteorological parameters and air pollutants are highly specialized, being manufactured largely in California where stringent environmental regulations demand detailed monitoring of pollutants. The equipment used for the current study was obtained from various manufacturers in the United States and installed by the CSIR as described.

The siting of these instruments is crucial. Rorich (1993) demonstrates the need for knowledge of all possible pollution sources in the area of concern, as well as the local meteorological conditions by using results from an air quality monitoring project undertaken by Eskom. Fortunately, Tyson (1962) and Langenberg (1976) had already described the local air circulations and ventilation potential of the atmosphere over Pietermaritzburg to such an extent that suitable sites for the station were not difficult to find in that respect. However, factors such as adequate electrical supply, accessibility and security forced some compromise in the final site selection. Fig. 14 shows the monitoring station on the car park adjacent to Publicity House.

Figure 14: The air pollution monitoring laboratory sited in the car park adjacent to Publicity House (right) in the central business district. The meteorological mast is clearly visible with the various instruments attached. Security was a major concern as indicated by the fence.

Meteorological instruments are attached to a ten metre mast with the anemometer and wind vane at the top, and the temperature and humidity probes at four metres above ground level. Two sample intakes protrude from the roof of the hut, both slightly above head height to measure respirable pollutant concentrations. One intake is for the gaseous pollutant analyzers and one for high-volume particulate sampling. The air pollution monitoring instruments are housed inside the laboratory (Fig. 15) and are described individually below.

ORIGINAL PHOTO MISSING

Figure 15: Inside the laboratory the various components making up the real-time monitoring system can be seen. In the foreground are two of the Dasibi analyzers and the sample intake for all of the gaseous pollutant monitors. In the background (from left to right) are the Byron hydrocarbon analyzer the nephelometer, logging computer and modem. A simple maximum-minimum mercury thermometer is used to check that the temperature inside the hut does not exceed the operating range of the instruments.

2.3.3.1 Integrating nephelometer

Particulates are measured by the integrating nephelometer (Fig. 16) which determines the scattering extinction coefficient, a parameter related to visual range and aerosol particle mass per volume air (Belfort Instrument Company, 1989). The 1597 series nephelometer used in the laboratory measures the scattering of green light centred on 530 nm which allows measurement of visual range in ambient air from that of the particle free atmosphere to as low as 3.84 km in polluted conditions. For measurement of visual range using the Koschimieder relation:

$$L_{vd} = 3.9/b_{scat}$$

where L_{vd} is the visual range and b_{scat} is the sum of Rayleigh gas (b_{RG}) and particle scattering (b_{sp}) extinction coefficients. b_{sp} can be related to fine particle mass loading (FPM - mass of dry particle of diameter less than 2.5 μm per m^3 of air) by:

$$FPM = b_{sp}/(3.3m^2.g^{-1})$$

if b_{RG} is taken to be 7.56 x 10^{-6} m^{-1}. A typical value of $b_{sp} = 10^{-4}$ m^{-1} therefore gives a visual range of 38.4 km and an estimated fine particle mass loading of 30 $\mu g/m^3$. Thus a conversion factor of 30 is used to convert the readings obtained from the instrument (in units of 10^{-4} m^{-1}) to the more commonly used gravimetric measure of particulate matter (units of $\mu g/m^3$) such that full scale on the instrument represents a fine particle mass loading of 300 $\mu g/m^3$.

It is essential to explain these relationships if comparisons between the data obtained from the standard filter paper method and those recorded by the nephelometer are to be meaningful. The significant difference is that the standard filter method measures smoke concentrations where smoke is defined as suspended particulate air pollutants less than 15 μm as measured by determining the staining capacity of the air (Harrison, 1983), whereas the nephelometer measures fine particle mass loading defined as dry particles of diameter less than 2.5 μm determined by the scattering of light from a sample of ambient air (Belfort Instrument Company, 1989). The filter paper technique thus monitors a much broader range of particulates and more closely approaches the true definition of total suspended particulates.

An accessory heating tube is fitted around the intake duct of the nephelometer to heat the incoming sample air stream and reduce relative humidity. Condensation of nuclei from vapour in the air stream being pumped through the instrument can lead to the growth of droplets which are then registered as pollutants because of their light scattering effect. This process was found to occur during the summer months, affecting the accuracy of the instrument as discussed in Chapter Four.

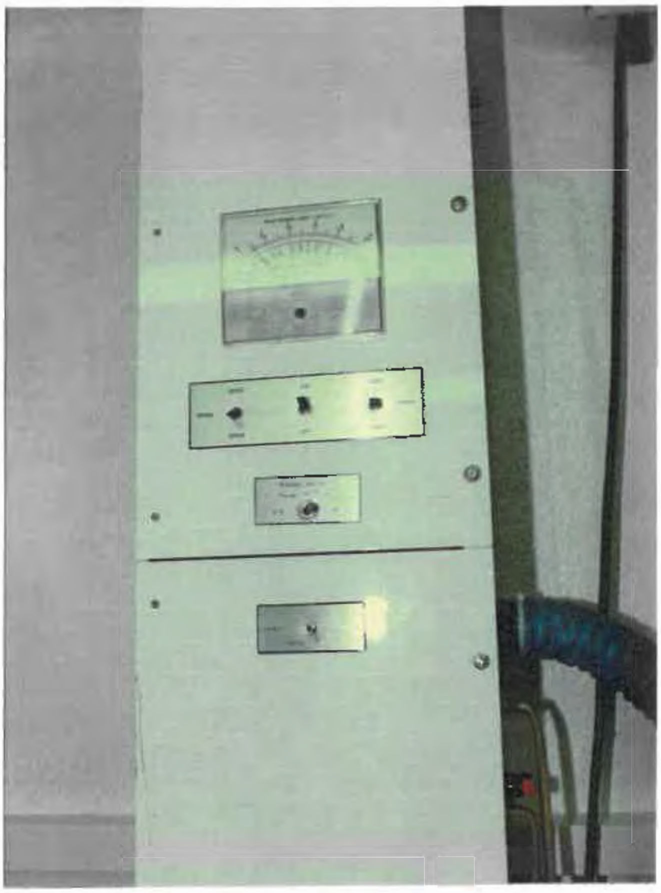


Figure 16: Model 1597 integrating nephelometer.

2.3.3.2 UV fluorescence sulphur dioxide analyzer

Sulphur dioxide concentrations are measured using a Dasibi Model 4108 ultra-violet fluorescence SO_2 analyzer with a total range of 0 - 2000 parts per billion (ppb) and a precision of 1 percent (Dasibi Environmental Corporation, 1989a). Its operation is diagrammatically represented in Fig. 17.

Optically filtered pure monochromatic light from a zinc lamp is focused into a gas sampling chamber. This invisible UV light beam enters the reaction chamber as the excitation/primary beam and its intensity is measured by a light detector. The excitation beam is also viewed at right angles by a photomultiplier detector which is only sensitive to radiation in a discrete portion of the visible spectrum. SO_2 molecules, introduced through the sampled air stream, intercept the primary beam and are UV energized by primary beam light absorption. These excited molecules then release energy by re-emitting light at a higher wavelength. The re-emitted light is given off in all directions and a portion of it, the secondary beam, is viewed by the photomultiplier detector. Non-pulsed UV radiation is used to increase the signal-to-noise ratio and hence improve accuracy. A microprocessor-controlled shutter system then enables the instrument to correct for photomultiplier dark currents (zero offset) instead of the usual light pulsing.

The SO_2 concentration is proportional to the intensity of the secondary beam and is obtained by microprocessor computation that also takes account of lamp intensity, detector dark currents and scattered light contributions. The technique is highly accurate and specific to sulphur dioxide (Harrison, 1983), unlike the standard titration method described earlier.

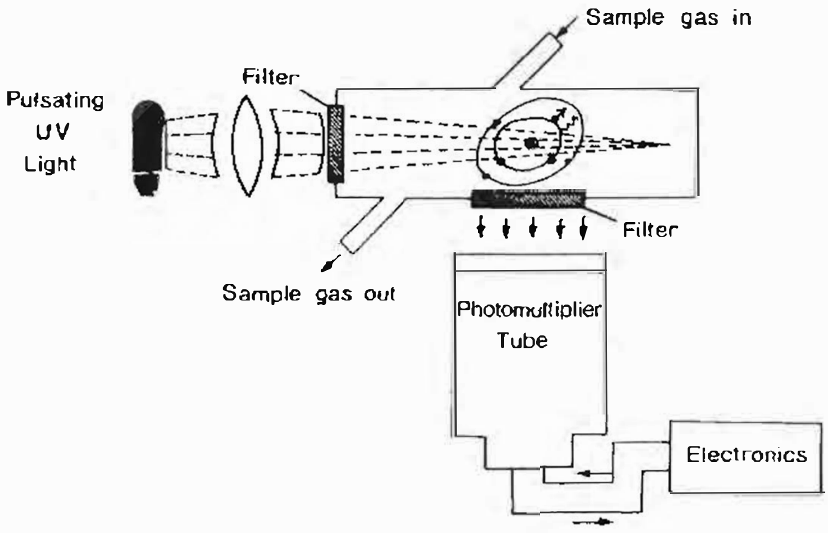


Figure 17: Diagrammatic representation of SO_2 UV fluorescence analyzer (modified from Harrison, 1983).

2.3.3.3 Chemiluminescent nitrogen oxides analyzer

Oxides of nitrogen (NO_X) are monitored by a Dasibi Model 2108 chemiluminescent nitrogen oxides analyzer with a total range of 0 - 4000 ppb and a precision of 1 percent (Dasibi Environmental Corporation, 1989b). The apparatus is illustrated in Figs. 18 and 19.

The analyzer utilizes photometric detection of the chemiluminescence resulting from the gas phase reaction of nitric oxide (NO) and ozone (O_3) to give electronically excited nitrogen dioxide (NO_2) which emits light in the 600 nm to 2400 nm spectral region with a maximum intensity at about 1200 nm. In the presence of excess ozone, the light emission varies linearly with the concentration of nitric oxide over the whole range of the instrument.

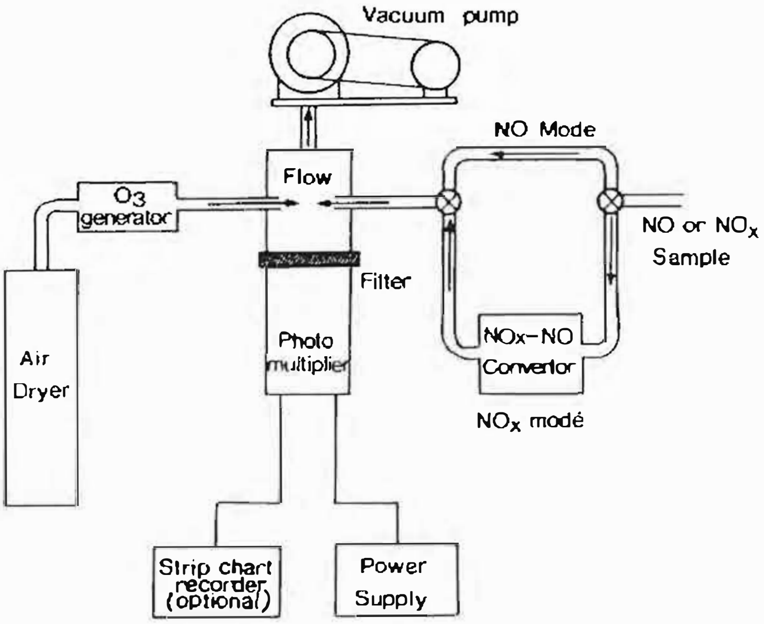


Figure 18: Diagrammatic representation of chemiluminescence NO_X analyzer (Harrison, 1983).

Figure 19: Dasibi Model 2108 chemiluminescence NO_X analyzer. The outer appearance is very similar for all three Dasibi analyzers with the instantaneous concentration and diagnostics display top centre.

Similar measurements of NO_2 are made indirectly by first reducing the NO_2 to NO, then reacting the resultant NO with ozone and measuring the light intensity from the reaction. In practice, the NO_2 in a sample of air is first reduced to NO by means of a converter. Any NO which is already present passes through the converter unchanged, causing a resultant total NO_X concentration equal to NO + NO_2. A separate portion of the air sample is also reacted with ozone without having passed through the converter, yielding the NO concentration. The latter NO measurement is then subtracted from the NO_X measurement to give the final NO_2 measurement.

2.3.3.4 UV photometric ozone analyzer

Ozone is measured by a third Dasibi instrument - a Model 1108 UV photometric ozone analyzer with a total range of 0 - 2000 ppb and a precision of 1 ppb (Dasibi Environmental Corporation, 1989c).

The analyzer uses photometric detection of ozone based on the absorption of UV radiation at 245 nm by ozone molecules present in the sample gas. The ozone concentration is obtained by measuring the intensity of transmitted UV light through the sample gas during each sample cycle, relative to a similar measurement made for the sample gas from which the ozone has been scrubbed during each alternate reference cycle. A microprocessor then calculates the final ozone concentration in ppb for the relative UV light intensities obtained during the sample and reference cycles. Although truly continuous measurement of ozone levels is not possible, response is fast and readings may be taken at intervals of 30 seconds or less.

2.3.3.5 Methane and non-methane hydrocarbons analyzer

Hydrocarbons can also be monitored in the station, using the Byron Model 301 Analyzer (Fig. 20). It is basically a gas chromatograph in which a capillary column packed with activated charcoal is used to separate methane and non-methane hydrocarbons in the ambient air sample. Detection of the compounds is by flame ionisation, yielding accurate readings that are not significantly affected by water vapour, carbon monoxide and carbon dioxide.

Figure 20: Byron Model 301 methane and non-methane hydrocarbons analyzer.

Unfortunately, this instrument gave continual problems throughout the course of the research. No valid readings could be obtained in spite of considerable effort. However, with the technical workshop of the Department of Chemistry now assisting, it is hoped to have the instrument operating for future research.

All instruments, including the meteorological sensors on the mast, are connected to a logging computer. They output electrical signals in the range of 0 - 2 volts either continuously or several times a minute (depending on the instrument), which are received by a 15 channel analogue-to-digital converter installed in the personal computer. Software is used to interpret and record these signals and a report is saved to the hard drive of the hourly average reading for each of the parameters. These reports are archived in a flat file ASCII format and can be extracted and imported into commercially available software for statistical analysis (Chapters Three and Four).

Each parameter has to be calibrated for the computer to calculate the reading in the chosen units from the electrical signal in volts (Appendix 1). This calibration is separate from the external and internal calibrations of the air pollution analyzers and was carried out in cooperation with the Electronics Workshop at the University of Natal. External calibration of the gaseous pollutant monitors is performed using calibration gases with known concentrations of the appropriate chemicals and was undertaken by S I Analytics in July 1993. However, the company would not issue calibration certificates as they are the officially appointed agents for a different brand of monitors. While this was not ideal, it was the only option, as the official agents for Dasibi Environmental Corporation and Byron Instruments in South Africa had proved to be extremely unreliable in the past.

2.4 STATISTICAL TREATMENT OF DATA

2.4.1 Data collection and validation

Owing to the many logistical and technical problems experienced in the early stages of the research, monitoring only began in mid-July 1993. The data collection period for the current research thus began on 1 August 1993 and continued through a complete year to 31 July 1994. It allows for observation of seasonal trends of pollutants and most importantly the transition from winter to summer and summer to winter.

Technical problems persisted throughout the duration of the research with the main culprit being the power supply which caused the computer to freeze periodically in spite of all possible protection devices being fitted. Lightning during summer storms proved to be the most common cause of data loss.

Overall, a good rate of data collection was achieved for most parameters as shown in Table 5. Statistically valid monthly means could be obtained for all the given parameters throughout the sample period with the notable exception of NO and NO_2. The Dasibi NO_X analyzer suffered from a faulty chemical converter which the appointed agents took over three months to repair. When the instrument was eventually returned, the vacuum pressure was found to be too high. These problems mean that statistically valid data for NO_X could only be collected for three of a possible 12 months or 27 percent of all possible hours. However, sufficient readings were obtained to enable analysis of diurnal NO and NO_2 trends in Pietermaritzburg.

2.4.2 Data analysis

Arithmetic means are not the most suitable parameters with which to describe the characteristics of air pollution data as they are not normally distributed (Taylor *et al.*, 1986). This also applies to meteorological data when being related to air pollution. It is therefore not coincidental that most of the criticism levelled at the City Health Division's air pollution monitoring in past years has been that concentrations are expressed as averages over periods of days or even months and therefore do not reveal potentially dangerous pollution peaks. The purchase of the real-time monitoring laboratory was a direct response to this criticism and one of the aims of this research is to identify and quantify such peaks to more accurately describe air quality in Pietermaritzburg.

Frequency distributions and extreme values are used in the statistical analysis to address this

Table 5: Data collection statistics for the monitoring laboratory during the 12 month study period. The criteria for representative monthly means is a <u>minimum</u> of 548 hourly averages (De Jager, *et al.*, 1991).

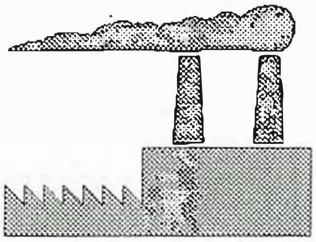
Month	**Wind speed**		**Wind direction**		**Temperature**		**Relative humidity**		**Fine particulate mass**		**Nitric oxide**		**Nitrogen dioxide**		**Sulphur dioxide**		**Ozone**	
	Hours	**%**	**Hours**	**%**	**Hours**	**%**	**Hours**	**%**	**Hours**	**%**	**Hours**	**%**	**Hours**	**%**	**Hours**	**%**	**Hours**	**%**
August	681	92	681	92	681	92	0	0	681	92	345	46	345	46	542	73	681	92
September	696	97	696	97	696	97	0	0	696	97	696	97	696	97	696	97	624	87
October	741	100	741	100	741	100	0	0	741	100	717	96	717	96	741	100	0	0
November	715	99	715	99	715	99	609	85	715	99	0	0	0	0	715	99	399	55
December	660	89	660	89	660	89	660	89	604	81	0	0	0	0	660	89	507	68
January	606	81	606	81	606	81	606	81	606	81	0	0	0	0	606	81	390	52
February	671	100	671	100	671	100	671	100	671	100	0	0	0	0	671	100	456	68
March	557	75	557	75	557	75	557	75	557	75	0	0	0	0	557	75	557	75
April	720	100	720	100	720	100	720	100	720	100	0	0	0	0	697	97	720	100
May	674	91	674	91	674	91	674	91	674	91	640	86	640	86	674	91	674	91
June	717	100	717	100	717	100	717	100	717	100	0	0	0	0	717	100	717	100
July	668	90	668	90	668	90	668	90	668	90	0	0	0	0	534	72	668	90
TOTAL	8106	93	8106	93	8106	93	5882	67	8050	92	2398	27	2398	27	7810	89	6393	73

Total hourly readings collected = 57 249 criticism, while arithmetic means are still used to describe trends which are important to model air pollution on a daily and seasonal basis. Ambient air quality standards are also largely based on arithmetic means as is much existing data and research.

* * *

Having described the monitoring programme that developed as an integral part of the current research, it is now necessary to consider the data that were collected.

Chapter Three



Local Climatology and Dispersion

3. LOCAL CLIMATOLOGY AND DISPERSION

Once pollution has been released into the atmosphere, its accumulation and dispersion is dependent upon the complex nature of local climate. The boundary layer characteristics of stability and turbulence regimes and the nature of the low-level windfield are of the greatest importance (Tyson *et al.*, 1988). Information relating to the nature of diurnal and seasonal variation of the boundary layer and the influence of the local terrain must also be considered.

Section 3.1 reviews the macroscale circulation of the atmosphere over Southern Africa, mesoscale circulations within the boundary layer and local effects in the context of air pollution dispersion climatology. Section 3.2 then relates this existing knowledge to the data collected over the past year to describe the conditions prevailing specifically over Pietermaritzburg.

3.1 GENERAL CONSIDERATIONS

3.1.1 Macroscale synoptic conditions

Macroscale synoptic conditions are a vast subject, so only the main elements and processes influencing the local air pollution dispersion climatology are discussed.

Southern Africa is well placed to experience a high frequency of occurrence of anticyclonic weather conditions. The mean atmospheric circulation over the sub-continent is anticyclonic throughout the year as illustrated by Jackson (1952) and Taljaard (1953). Such airflow is associated with strong subsidence throughout a deep layer, adiabatic warming, increasing atmospheric stability, suppression of precipitation and conditions highly conducive for the formation of surface and elevated inversions (Preston-Whyte and Tyson, 1988 and Tyson *et al.*, 1988). Subsidenec and examples of summer and winter continental anticyclones over Southern Africa are shown in Figs. 21 and 22 respectively.

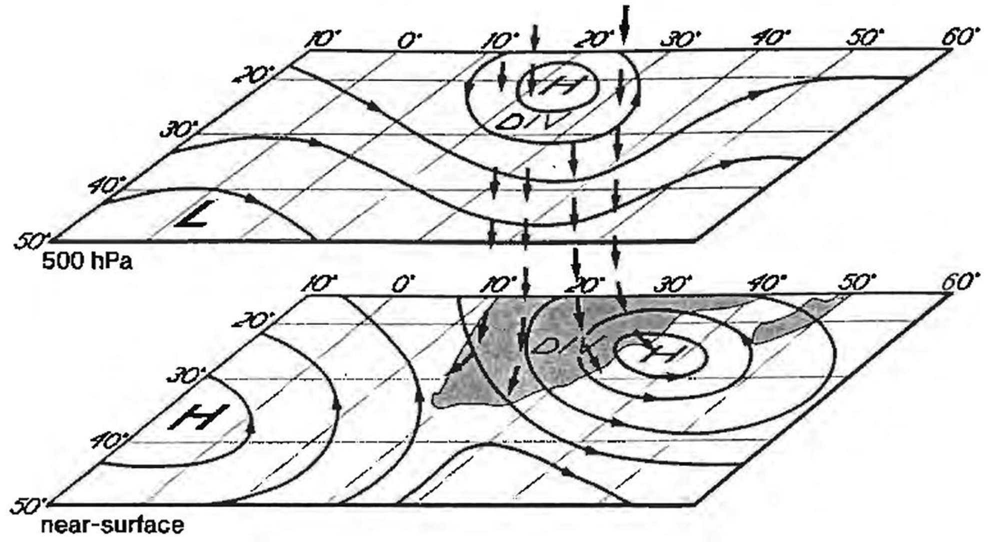


Figure 21: A schematic representation of the near surface and 500 hPa fine-weather circulation associated with high pressure systems over Southern Africa (after Preston-Whyte and Tyson, 1988).

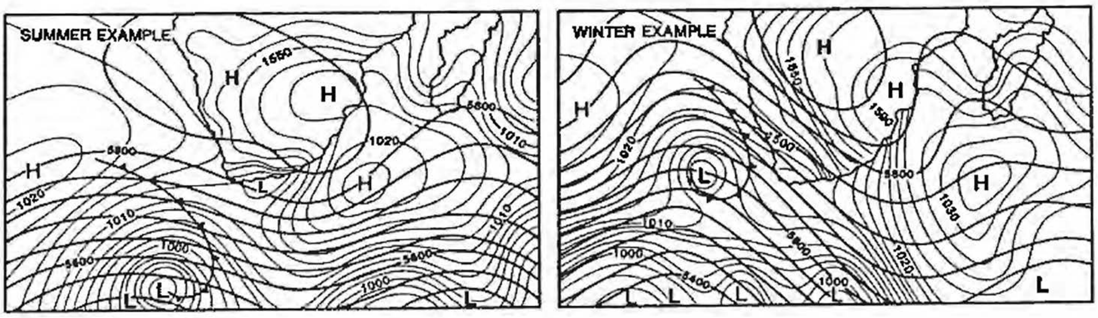


Figure 22: Examples of fine-weather continental high pressure types prevailing in summer and winter. Light lines show isobars at mean sea-level (hPa) over the oceans and contours of the 850 hPa surface over the land; heavy lines show contours of the 500 hPa surface (after Preston-Whyte and Tyson, 1988).

The frequency of anticyclonic conditions reaches a maximum over the interior plateau in June and July (79 percent) with a minimum during December (11 percent) (Vowinckel, 1956). Such high frequencies of winter subsidence mean that averaged over the year as a whole, vertical motion is downward. Localized upward motion obviously does dominate at times, otherwise there would be no chance for precipitation. Mid-latitude westerly disturbances increase in spring and autumn while tropically induced easterly disturbances peak in summer.

Clear, dry air and light winds associated with anticyclonic circulation of the atmosphere over Southern Africa are ideal conditions for the general development of nocturnal surface inversions, particularly in winter (Fig. 23). In winter the maximum depth of the inversion varies from less than 300 metres to more than 500 metres over the plateau at around sunrise, when the average strength within the inversion layer is about 5 - 6 °C (Fig. 24). In summer the surface inversion is about the same depth as that occurring on average in winter but has a strength of less than 2 °C. Inversions over Pietermaritzburg tend to exceed these figures because of the boundary layer modification by the valley topography which intensifies the flat-ground inversion as described later.

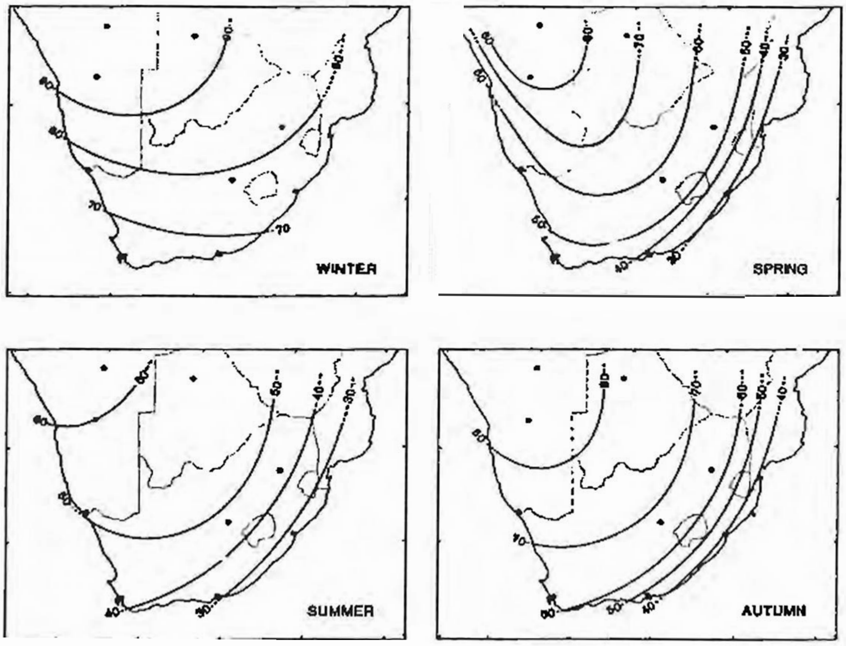


Figure 23: Seasonal percentage frequencies of midnight inversions over Southern Africa (after Tyson, *et al.*, 1976).

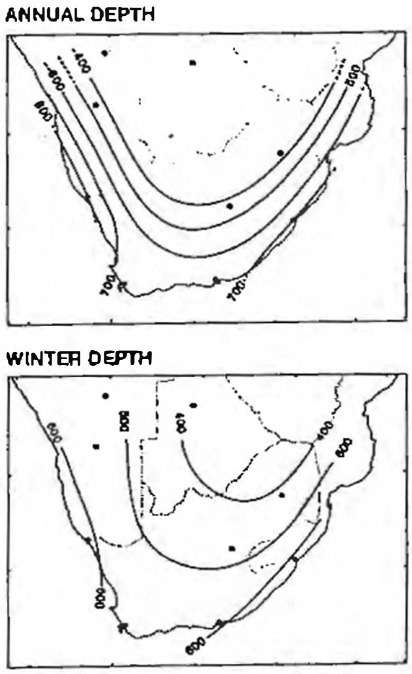


Figure 24: Early morning (07h00) inversion depth (metres) and strength (°C) over Southern Africa (after Tyson, *et al.*, 1976).

As the stable boundary layer is eroded from below by convective heating and turbulence during the day, a mixing layer develops which will most often completely dissipate the surface inversion (Fig. 25). Mixing depths show a strong seasonal and diurnal variation, particularly over the interior part of Southern Africa. They are generally deepest during the day and in summer, usually being zero for most night hours (Diab, 1975).

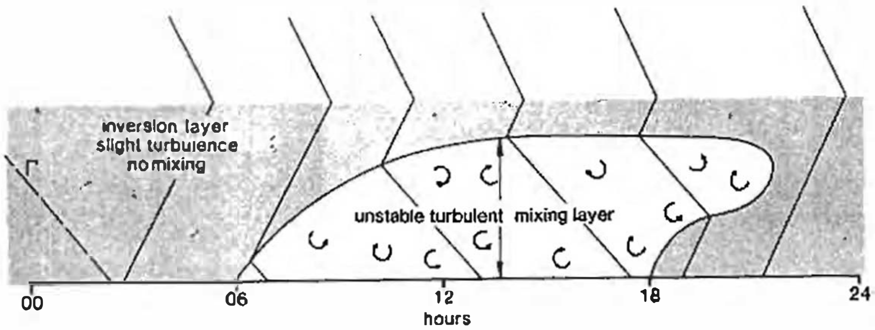


Figure 25: The daytime development of a turbulent mixing layer (adapted after Diab, 1975).

3.1.2 Mesoscale seasonal and diurnal variation

Annual variation of atmospheric pollution in and around South African cities shows a marked seasonal variation with a pronounced maximum in winter and minimum in summer. This is partly a result of the macroscale dispersion climatology described above but more specifically related to the boundary layer conditions, that are accentuated by the effect of topography as described by Tyson (1963).

Diurnal pollution curves tend to show the same basic form throughout the year even though summer variations are much less pronounced than those in winter. Over flat ground peaks are usually experienced at about sunrise and sunset with day and night concentrations being fairly low while in hilly terrain, pollution tends to accumulate from sunset onwards with a pronounced maximum just after sunrise.

These seasonal and diurnal trends have been explained as a product of atmospheric stability. Over flat ground the atmospheric stability shows a simple diurnal variation with a maximum just before sunrise in the inversion period and a minimum at noon in the lapse period. However, in valleys such as the Pietermaritzburg hollow, stability shows a rapid increase just after sunrise to a maximum about 09h00 followed uniform decrease throughout the day with a minimum just before sunset (Fig. 26). The rapid increase after sunrise is caused by differential heating of the ridge tops and valley floors while the sun is at a low angle - the initial effect of heating on the ridge tops is to increase the intensity of the inversion between ridge and valley; once the sun is high enough to heat the ridges and valleys uniformly, stability decreases rapidly. After sunset a rapid increase in stability occurs as cold air drains by katabatic flow off the slopes into the valleys to form intense inversions. As the hollow fills with cold air, further inflow is checked and so the stability becomes more constant.

Tyson (1962) found a strong correlation between stability and smoke pollution. When smoke, expressed as optical density (OD) was plotted against stability given in terms of lapse rate of temperature (dT/dz) for August 1961, the result was linear (Fig. 27). Correlation coefficients of 0.63 for a station located on the valley floor and 0.82 for a station located 58.5 metres

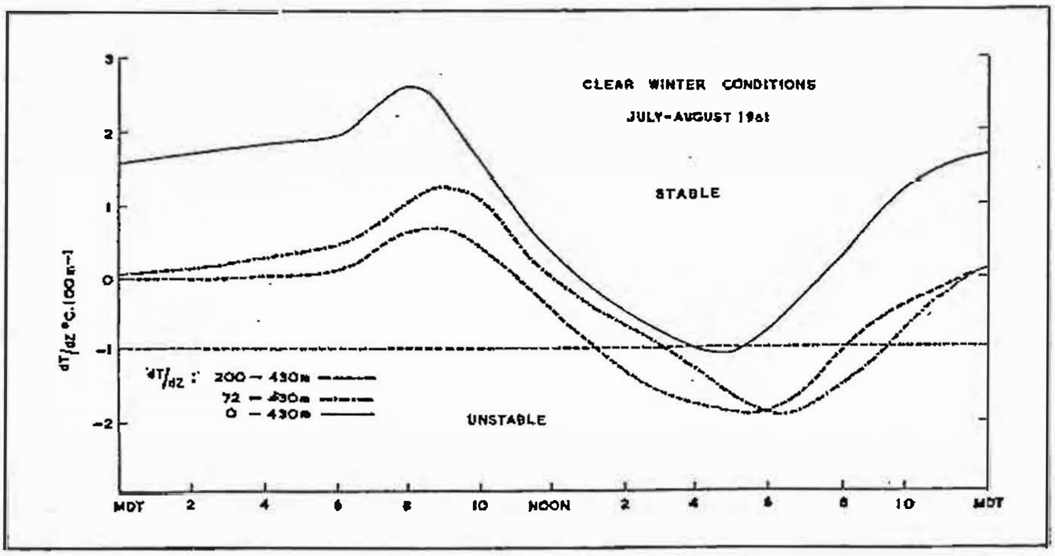


Figure 26: Mean diurnal variation of atmospheric stability in the Pietermaritzburg hollow (after Tyson, 1962).

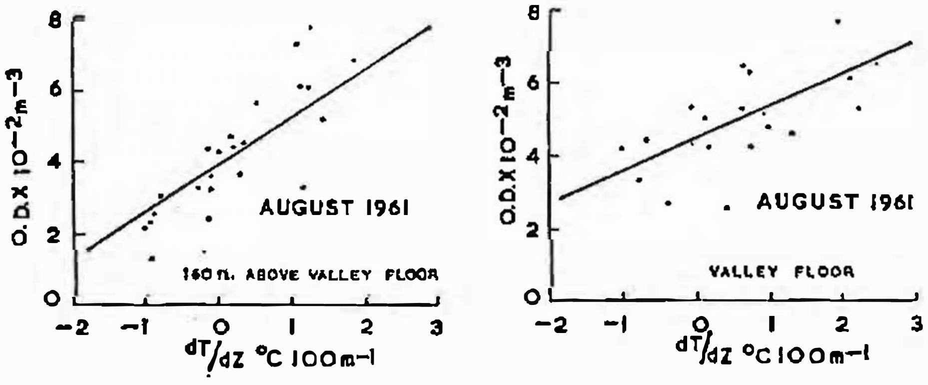


Figure 27: Scatter diagrams showing linear regression line for optical density (OD) vs lapse rate (dT/dz) for August 1961 (after Tyson, 1962).

above the valley floor were calculated.

Thus, Tyson (1963) concluded that '...*pollution in the Pietermaritzburg hollow increases directly with atmospheric stability, which is directly proportional to the degree of valley inversion obtaining and hence to the amount of katabatic flow in the hollow.*' It was also noted that on the valley floor the source of pollution is quasi-constant and meteorological conditions affect only the dispersal of pollutants, while higher up on the slopes of the hollow, above the main sources of pollution, they affect both concentrations and dispersal of pollutants; hence the higher correlations above the valley floor.

No such correlation for specific day-to-day and hourly variations exists between pollution and stability over flat ground, highlighting the important effect of topographic control over local climates and hence pollution. In the hollow the normal evening peak in the pollution curve is absent because at sunset stability is at a minimum and turbulence is still active. On flat, open ground, pollutants settle during the night, resulting in night minima of pollution, while in valleys and hollows drainage of cold air and smoke off slopes results in a stagnant pool of pollution increasing in density towards morning. High morning concentrations are commonly observed as late as noon as will be shown by the current data.

It is also necessary to review the variation of pollution with height under specific boundary layer conditions as discussed by Tyson (1963). Pollution decreases with height under normal lapse conditions, but under inversion conditions high concentrations of pollution tend to occur at the top of the inversion. This phenomenon is noticeable in Pietermaritzburg, where the cold stable air and pollution drain katabatically into the hollow, the pollution remaining at the height at which it was emitted, showing little tendency to mix and remaining in clearly defined plumes which drift undiluted for kilometres in the stable conditions (Figs. 28, 29 and 30). With the rapid decrease in stability once the hollow receives uniform heating and with the onset of turbulence, the high pollution concentrations are rapidly brought to the ground, resulting in fumigations (Tyson, 1963 after Hewson, 1951).

Figure 28: Smoke from a continuous point source gathering at the top of the valley inversion over Pietermaritzburg at 07h30 during July 1993. It is relatively clear both above and below the pollution band which is held in the calm temperature-stratified air.

Figure 29: The same smoke band viewed from close by on the slopes of the valley in Northern Park. Again, it is remarkably clear both above and below the pollution band.

Figure 30: Plumes from continuous point sources drifting undiluted for many kilometres in the stable early morning conditions during June 1994.

Regional topographically induced circulations of a mountain-plain and plain-mountain variety also occur in Southern Africa. Mountain-plain winds produce large scale regional airflow between cooler mountains and warmer plains by night while plain-mountain winds produce an opposite flow between cooler plains and warmer mountains by day. In Natal, the sequence of flow from the Drakensberg towards the coast by night and in a reversed direction by day is particularly well developed and has been described in detail by Tyson (1966, 1967, 1968a, 1968b). The diurnal sequence of regional and local topographically-induced wind development over Natal is summarized in Fig. 31.

These local and regional winds dominate the near ground airflow (Section 3.2.1) which has important environmental implications. Hollows fill with cold air by katabatic flow, valleys with cold mountain-wind air and the whole region becomes overlain by the cool mountain-plain wind drift resulting in a low-level temperature stratification over most of Natal. Flow is non-turbulent and highly stable allowing inversions to occur in nearly every valley and hollow (Fig. 32). Given their regularity of occurrence in suitable terrain, such flow represents highly

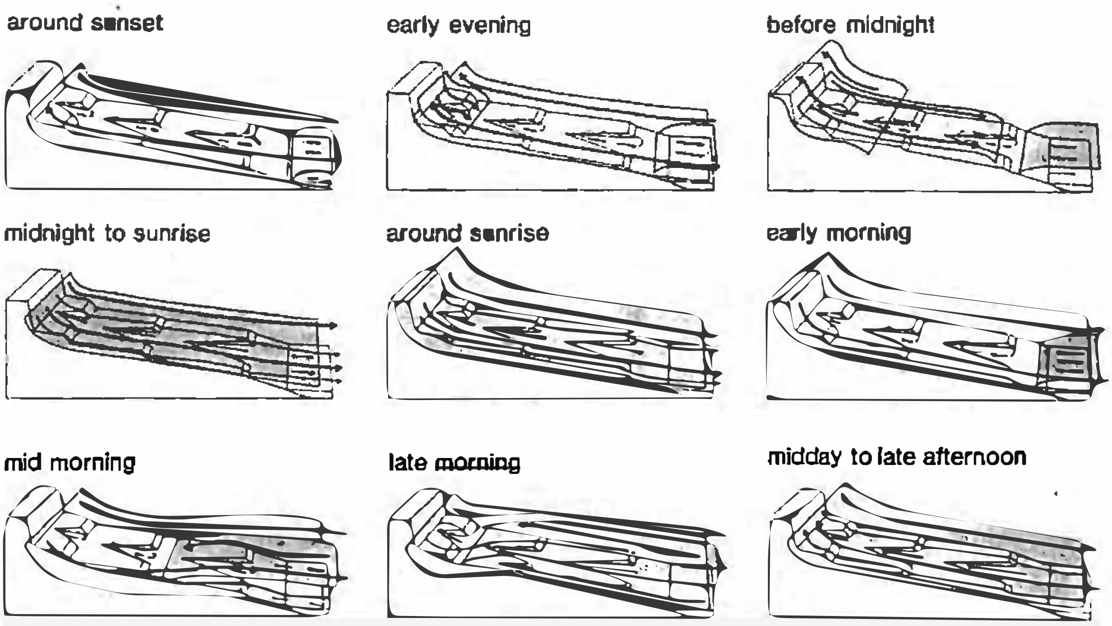


Figure 31: The diurnal variation of regional and local topographically-induced winds between the escarpment and sea over Natal (after Preston-Whyte and Tyson, 1988).

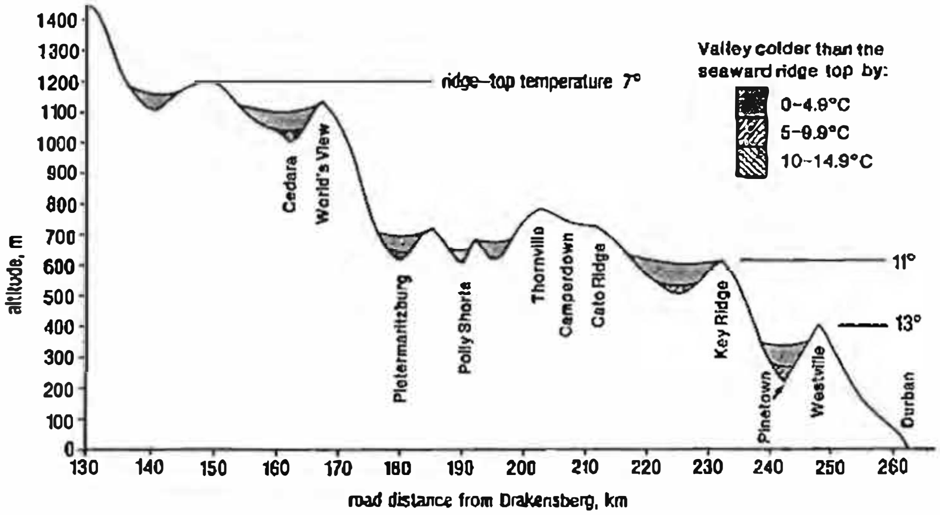


Figure 32: A simplified temperature section across part of Natal from the Natal Midlands to Durban on a clear winter night 00h00 to 06h00, to show the development of valley inversions. The diagram is based on a traverse during June 1987. A similar traverse on a cloudy night showed that no valley inversion formed under such conditions.(Modified after Preston-Whyte and Tyson, 1988)

adverse pollution conditions, particularly when the early morning break-down of the nocturnal local winds results in fumigations as described earlier.

One other boundary layer phenomenon that influences the dispersion of atmospheric pollution is the urban heat island. A lower frequency of surface inversions and higher frequency of low-level elevated inversions than in the surrounding rural areas is one of the main characteristics. Conditions favourable for pollution fumigations are consequently enhanced. The surface urban heat island over Pietermaritzburg is clearly evident from isotherms shown in Fig. 33.

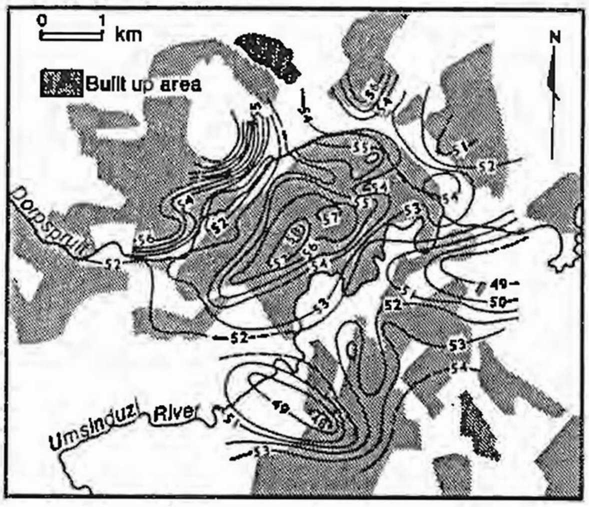


Figure 33: The surface urban heat island over Pietermaritzburg at 22h00 on a winter night (after Wilton, 1971). Temperatures in °F.

3.1.3 Local considerations

The wind field in the boundary layer is further complicated by buildings and other structures which constitute obstacles to airflow. While this has few implications for large-scale transport and diffusion of atmospheric pollution, local flow around obstacles may exert important effects on urban dispersion and the diffusion of plumes from industrial establishments. In the context of the current research, such local considerations must be taken into account for the location of monitoring stations. Analysis of climatological and pollution data from all stations must recognize the effect that nearby structures may have on the climatic framework and hence the readings obtained.

* * *

It has already become evident that Pietermaritzburg suffers from adverse pollution dispersion climatology at all scales, from general macroscale subsidence to local valley inversions. The situation intensifies during winter when the various circulations combine to form a highly stable boundary layer over the city with few disturbances. Climatological data recorded at the monitoring laboratory from August 1993 until July 1994 will now be examined to describe specifically the temporal dispersion potential during the study period.

3.2 TEMPORAL DISPERSION OVER PIETERMARITZBURG

Because data were collected predominantly at only one point in the hollow, it is necessary to describe the climatic framework in a temporal, rather than a synoptic model. Detailed spatial analysis of dispersion potential is beyond the scope of the current study but is derived from existing literature and extrapolated from all available data. Further research would be desirable to formulate a combined temporal and synoptic dispersion model for the Greater Pietermaritzburg area.

A vast amount of data were nevertheless collected (Table 5). All 12 months have been analysed at a general level and August 1993, January 1994 and July 1994 have been analysed in greater detail to provide comparisons of two different winter months and a summer month.

3.2.1 The wind field

Fig. 34 shows the mean, maximum and minimum recorded hourly wind speeds for the 12-month study period. It is immediately apparent that the mean wind speeds for all months are low, in the range of 0.5 to 1 m/s. This is indicative of the overall calm and stable conditions

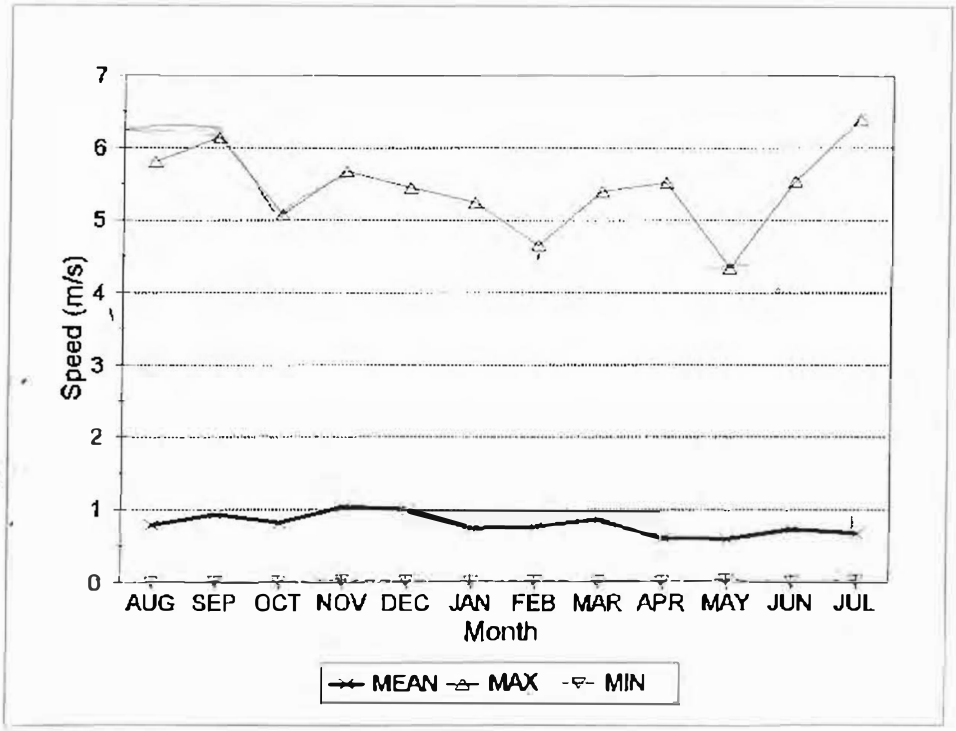


Figure 34: Mean, maximum and minimum hourly wind speeds recorded in central Pietermaritzburg from August 1993 to July 1994.

experienced in the city during most of the year. Higher average wind speeds during the summer months indicate more turbulence owing to the decrease in anticyclonic subsidence at a macroscale level and the related incidence of convectional summer thunderstorms. The lowest mean wind speeds were recorded for the winter months of May, June, July and August highlighting the prevalence of calm, stable atmospheric conditions during these months.

High maximum hourly wind speeds occur during the months of July, August and September, contrasting with the low average and minimum wind speeds for the same months. While gentle local winds are typical at this time of year, occasional passing cold fronts, preceded by Berg wind conditions are responsible for the gusts exceeding 6 m/s. Other high maximum wind speeds are related to summer storms.

Hourly surface wind direction frequencies for all hours of the day during the months of August 1993, January 1994 and July 1994 are shown in Figs. 35(a), (b) and (c) respectively.

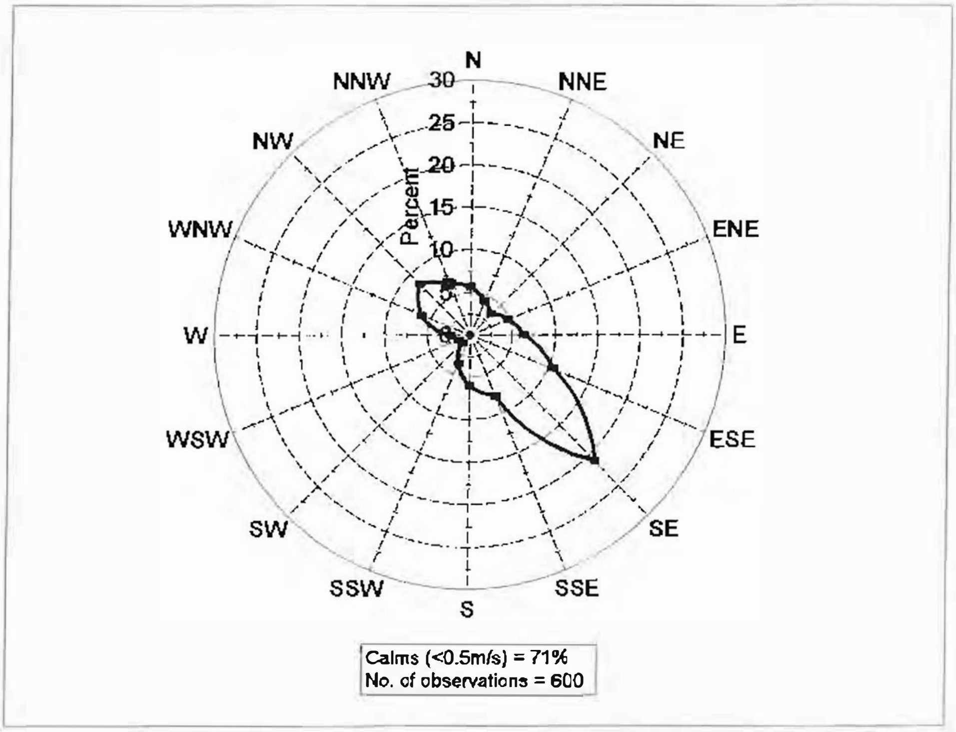


Figure 35(a): Surface wind direction frequencies for all hours of the day during August 1993 in central Pietermaritzburg.

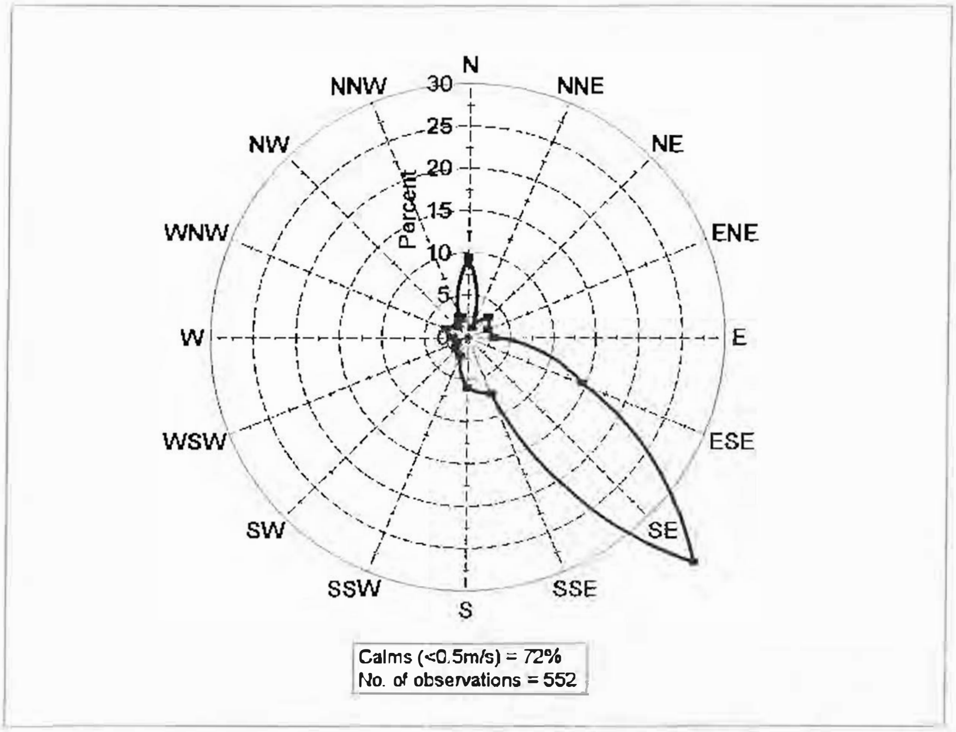


Figure 35(b): Surface wind direction frequencies for all hours of the day during January 1994 in central Pietermaritzburg.

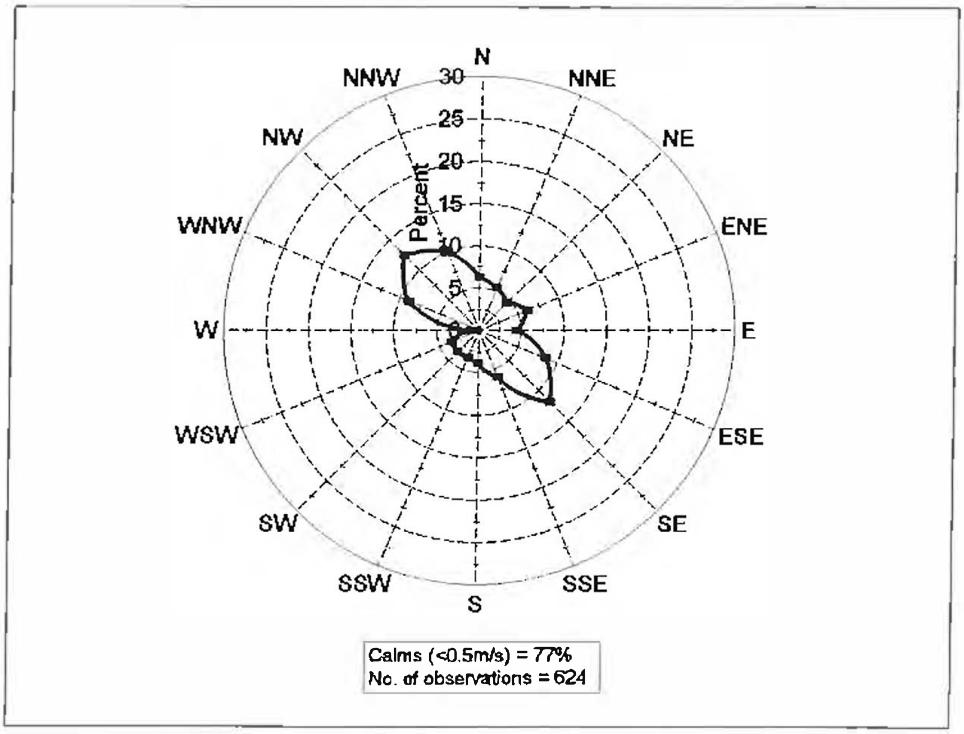


Figure 35(c): Surface wind direction frequencies for all hours of the day during July 1994 in central Pietermaritzburg.

The distinctly linear pattern for August 1993 (Fig. 35(a)) emphasizes the bi-modal wind field during the winter months that is largely controlled by the delineation of the Msunduze River valley. The predominant direction is from the south-east, being the direction of the local scale valley wind and regional scale plain-mountain wind as discussed. This wind blows predominantly during the day while the secondary wind from the north-west is a product of the nocturnal mountain wind (katabatic flow) to be described in more detail in Section 3.2.2.

During January 1994, the south-easterly wind direction becomes clearly dominant (Fig. 35(b)). Winds from the north-west are now insignificant, illustrating the absence of katabatic flow during the summer months. The only other notable wind is that from the north, which occasionally circulates inland from the coast.

Wind direction frequencies for July 1994 (Fig. 35(c)) show a sightly different distribution to those of August 1993 (Fig. 35(a)), with the north-westerly component being more prevalent. The prevalence of the north-westerly wind over the south-easterly is attributed to a more severe winter with more frequent occurrence of katabatic flow. Lower mean, maximum and minimum hourly temperatures were recorded for July 1994 than for August 1993 (Fig. 36). There was also a greater percentage of calm conditions, with 77 percent of wind speeds recorded in July 1994 classified as calm as opposed to 71 percent in August 1993.

However, it must be noted that over 70 percent calm conditions prevailed for each of the three months. This is in concordance with the predominant south-easterly and north-westerly wind systems that are both entirely fine weather phenomenon. Neither of these winds bears any significant relationship to pressure gradients of the general circulation according to Tyson (1968) and neither is conducive to air pollution dispersion.

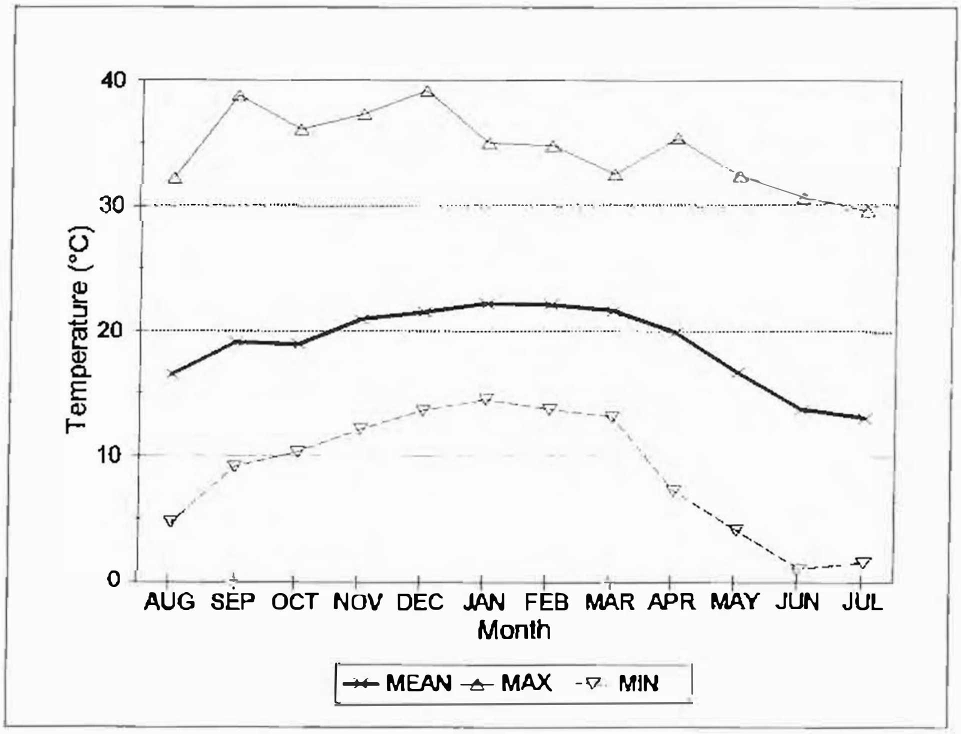


Figure 36: Mean, maximum and minimum hourly temperature recorded in central Pietermaritzburg from August 1993 to July 1994.

3.2.2 Katabatic and anabatic flow

Katabatic winds have been identified by Tyson (1962, 1964) as fundamental to the air pollution problem over Pietermaritzburg. Such light winds actually increase contamination of the air under stable conditions where there is a source of pollution. The real-time data have been carefully analysed to enhance existing knowledge about the katabatic and anabatic wind flow system over the Pietermaritzburg hollow.

The wind roses for the months of August 1993, January 1994 and July 1994 (Fig. 35) are divided into eight-hour components to analyse three distinct phases of the day; inversion, fumigation and dissipation (Fig. 37(a), (b) and (c)). Prevailing wind fields are discussed for each component, followed by a more detailed discussion of the fumigation period in Section 3.2.3, because of its special significance to air pollution concentrations.

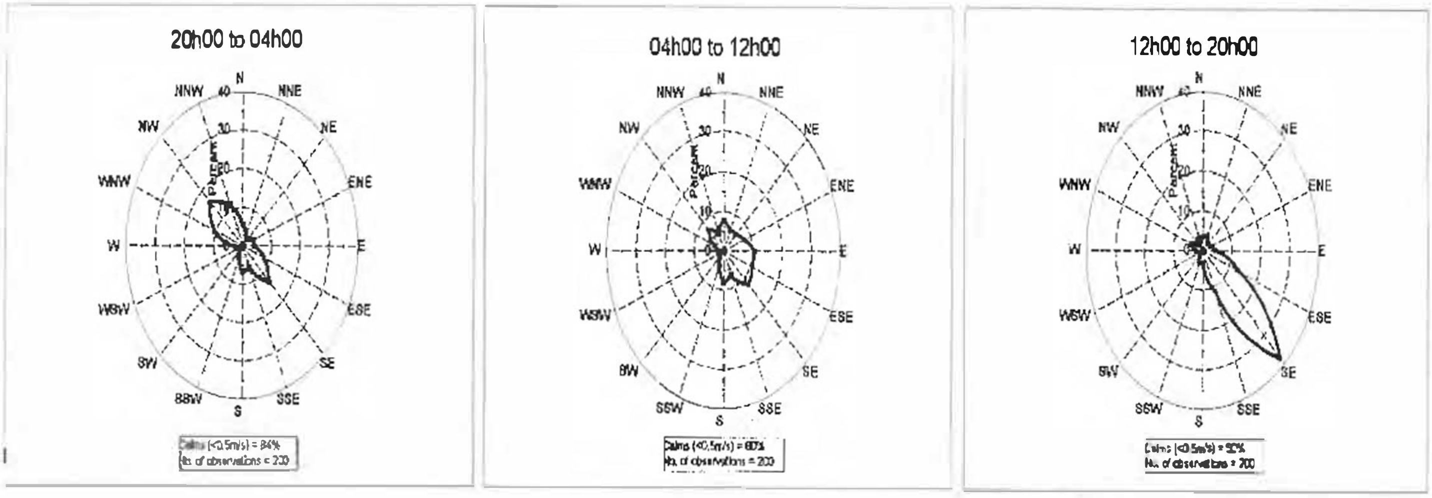
On clear, calm evenings, the ground surface cools rapidly after sunset and cold air begins to drain off the slopes into the valleys, initiating katabatic flow into the Pietermaritzburg hollow. The actual direction of flow varies according the orientation of the valley (Fig. 38), with the most dominant delineation being that of the Msunduze River valley. For the period 20h00 to 04h00, the modal wind direction is from the north-west during both winter months. The general north-westerly direction is totally dominant during July 1994 with no significant secondary trend, while south-easterly winds do occur during the nocturnal period of August 1993, probably as a result of the persistence of anabatic flow in the early evening, owing to the relatively warmer conditions (Fig. 36).

In contrast, the north-westerly flow is totally absent during the summer nights (Fig. 37(b)), demonstrating the lack of katabatic flow under a warmer, cloudier, more turbulent and less stable atmosphere. The south-easterly wind is most common at this time of year, even during the night.

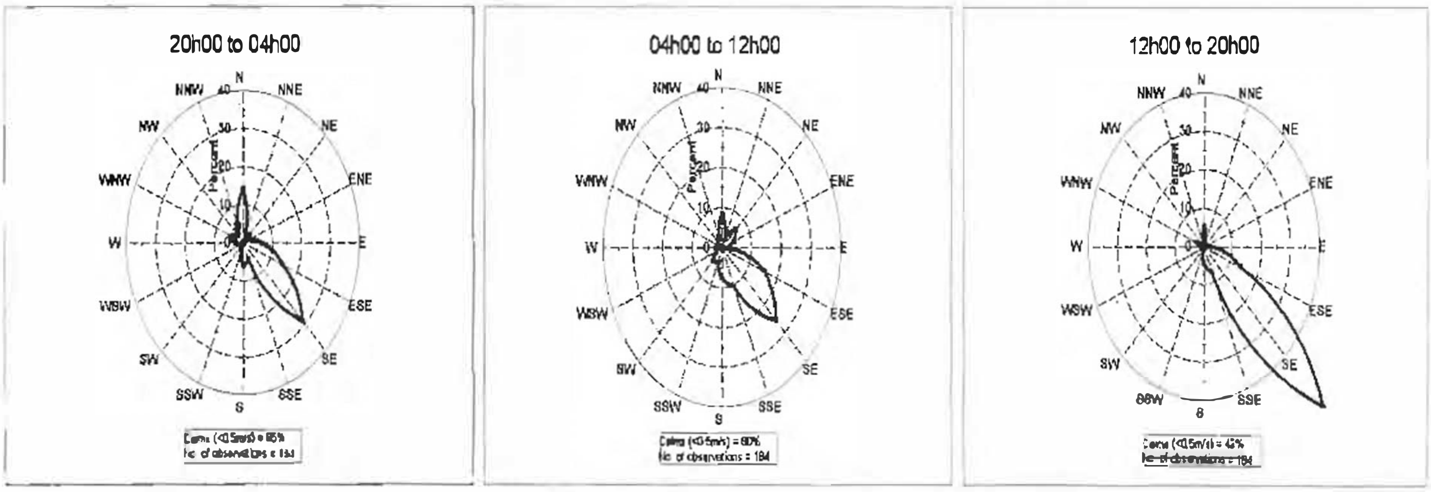
During this nocturnal period, there is a very high percentage of calms throughout the year with more than 80 percent of the wind speeds recorded for each of the three months being lower than 0.5 m/s.

REDUCED TO FIT FROM ORIGINAL LARGER THAN A4

a) AUGUST 1993



b) JANUARY 1994



c) JULY 1994

Figure 37: Diurnal variation of surface winds in central Pietermaritzburg.

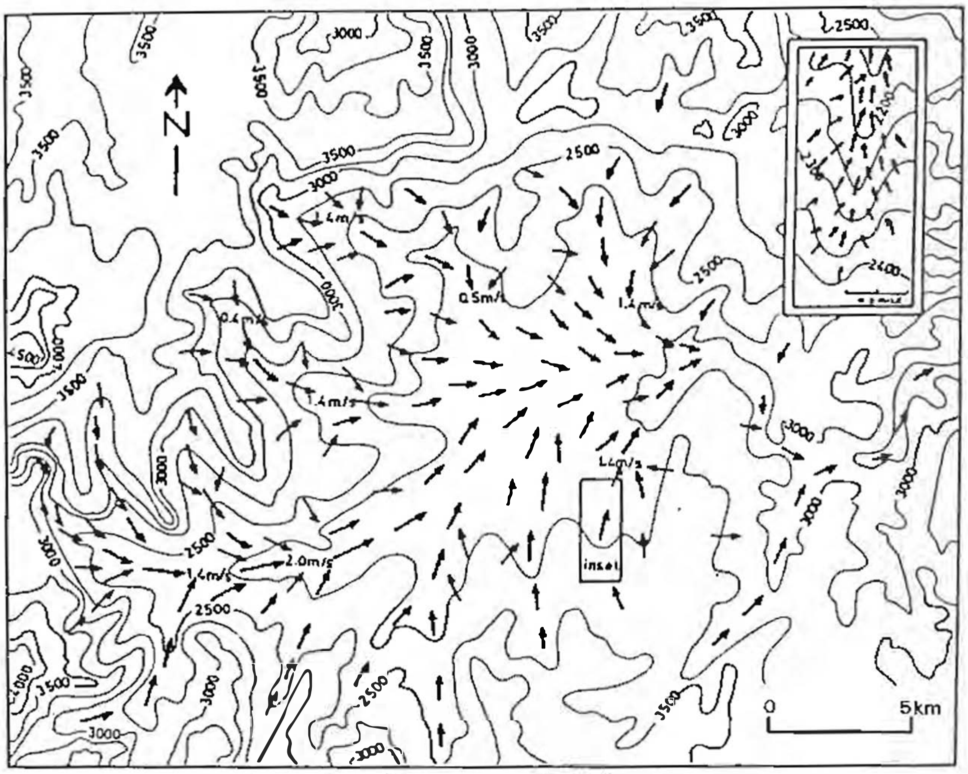


Figure 38: Katabatic flow on 13 July 1961 between 18h00 and 22h00 (after Tyson, 1962).

Katabatic flow from the north-west continues through the night, feeding cold air into the basin to strengthen and deepen the inversion. With sunrise, the ground begins to warm the lower layers of air, invoking turbulence that erodes the inversion layer from the bottom up. The wind rose for the period 04h00 to 12h00 during August 1993 shows no marked directional trend, although the north-west south-east lineation is still evident. The same is true for the fumigation period during July 1994. Fumigation occurs during a transitional period in the flow field that represents the change from katabatic down-valley flow to anabatic up-valley flow.

Again, the wind direction frequency for summer (Fig. 37 (b)) is different to the winter trends for the eight-hour time period. The south-easterly wind prevails, although with a reduced frequency compared to the other times of day. It is expected that a turbulent fumigation will not occur during the summer season because there is no dramatic change of wind direction from night to day.

The percentage of calms is still high during the fumigation as the air is more turbulent, but shows no uni-directional flow that is usually associated with high wind speeds. The fumigation is characterized by stable but turbulent air within a restricted inversion layer.

The third period of the day, between 12h00 and 20h00 is referred to as dissipation. It is immediately evident that with warming of the valley floor through the morning, air movement has become strongly up-valley. South-east is clearly the dominant wind flow direction during the afternoon for each of the three months analysed. The differences in the directional frequencies correspond with the climatological variations for the months already described.

In January 1994, nearly 60 percent of all winds between 12h00 and 20h00 came from the south-east, proving the occurrence of well-developed anabatic flow, enhanced by the south-westerly regional wind. It is also during this time that the lowest percentage of calm conditions is recorded (42 percent), when the atmosphere is most unstable and consequently best able to disperse pollutants.

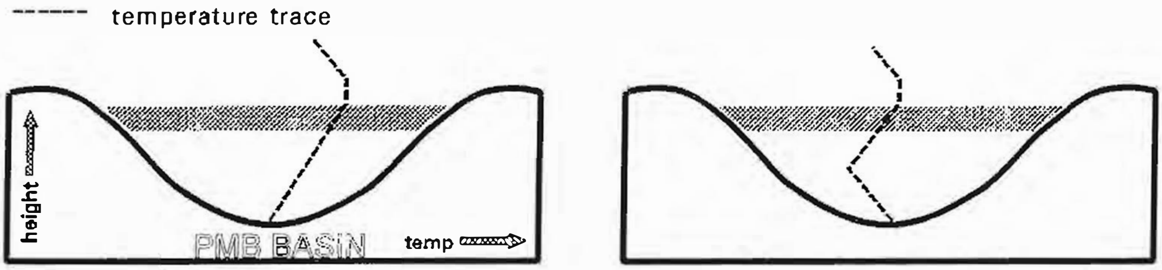
Conversely, in July 1994, the dominance of the south-westerly is at its least for the time of day and a much higher percentage of calms is recorded (57 percent) than for January. A west-north-west component is even evident, suggesting the early onset of katabatic flow during the evening.

Overall, the afternoon period presents the best wind field conditions for the dissipation of stability and dispersion of air pollution throughout the year, although only partial clearance occurs during the winter months and is responsible for the gradual accumulation of pollutants from May to August, broken only by the passage of cold fronts (Section 3.2.4).

3.2.3 Fumigation

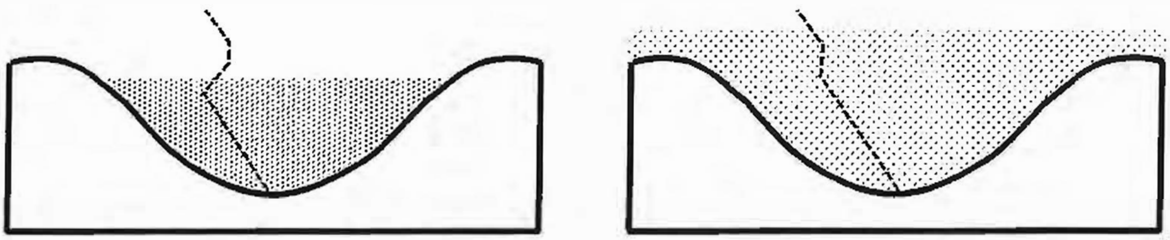
While fumigation has been discussed in terms of the wind field, it is necessary to view the process holistically, by incorporating the vertical temperature profile into the model. Unfortunately, no new vertical temperature profiles were obtained during the current study, but all previous research and the new climatological and pollution data that were obtained have been used to develop the following model.

Fig. 39 presents a schematic summary of the existing theory and observations made during the current study. The fumigation sequence is also photographically illustrated in Fig. 40 (a), (b) and (c). Times given for various stages of fumigation in Fig. 39 are approximate and those given for Fig. 40 relate to a specific day. The actual times vary depending on a range of climatic factors which are in turn dependent upon the season.



A) 07h00 *EARLY INVERSION*
Strong inversion, upper and lower pollution boundaries evident. Pollutants released unable to disperse vertically owing to stable stratification, or laterally as a result of topography.

B) 08h00 *LATE INVERSION*
Strong inversion still present but being eroded from the ground up by surface heating. Pollution continues to accumulate near top of inversinn.



C) 09h00 *FUMIGATION*
Normal lapse conditions reach pollution layer while elevated inversion still constrains circulation to within basin. Peak pollution concentrations experienced at ground level.

D) 10h00 *DISSIPATION*
Inversion dissipated, normal lapse conditions prevail and partial dispersal of pollution occurs.

Figure 39: Diagrammatic representation of the fumigation sequence as it occurs over Pietermaritzburg during winter.

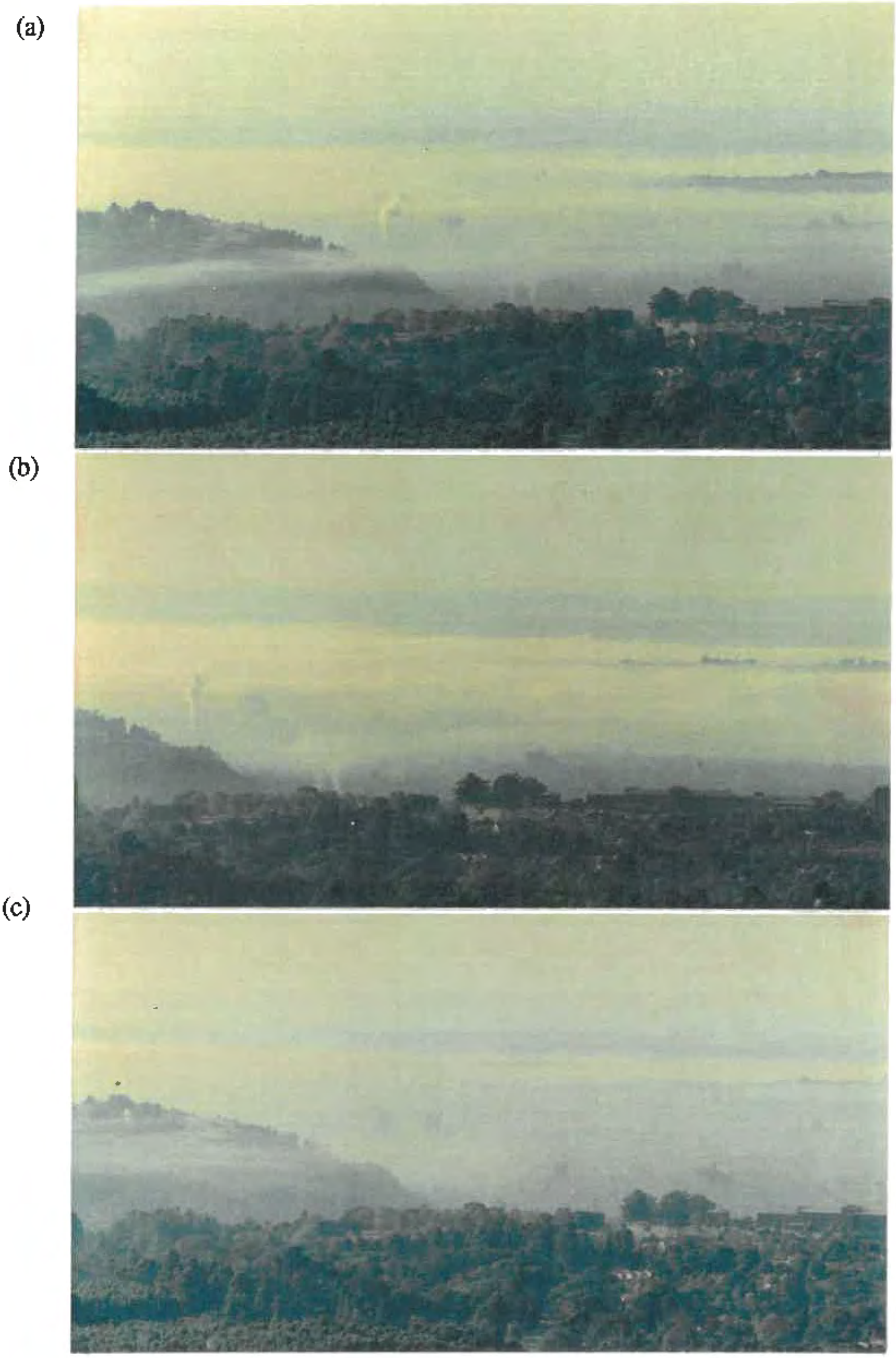


Figure 40: Series of photographs taken during the early morning of 26 June 1994 from Ferncliffe Nature Reserve looking south-east over Pietermaritzburg. See discussion in text.

The typical winter fumigation event captured in the photographs can be described as follows. Prior to fumigation, the trapped pollution is restricted to a band at the top of the inversion layer with upper and lower boundaries evident (Fig. 40(a)). The pollution plumes in the centre of the photograph are unable to break through the top of the inversion layer and spread laterally across the stratified temperature 'ceiling'. Approximately half an hour later, lapse conditions reach the elevated pollution band, causing the pollutants to mix to ground-level (Fig. 40(b)). Vertical confinement by the elevated inversion (note that plumes have still not broken through the inversion), and lateral confinement by the valley topography result in peak primary pollutant concentrations between 08h00 and 09h00 in the central district. By 09h30, the inversion is dissipating, as evidenced by the plumes finally breaking through the top of the inversion, and pollution can disperse out of the hollow (Fig. 40(c)). Much of the pollution also drains out through the Msunduze valley to the east-south-east although this drainage is soon checked by the onset of anabatic flow. Thus, pollution often disperses only partially, with a haze remaining over the city for most winter days.

Average hourly readings of temperature, wind speed, fine particulate mass, sulphur dioxide and ozone have been analyzed for the months of August 1993, January 1994 and July 1994 (Fig. 41(a), (b) and (c) respectively) to show how the fumigation is reflected in diurnal pollution trends recorded at the monitoring laboratory.

Fig. 41(a) depicts typical climatological and pollution trends for a winter day over Pietermaritzburg. During the early morning, katabatic flow down the Msunduze valley causes a gentle wind to flow from the north-west with an average speed of 0.5 m/s as described earlier. Gaseous and particulate pollution concentrations are low close to ground level and calm inversion conditions predominate, corresponding with Figs. 39(a) and 40(a).

Shortly after sunrise, the maximum atmospheric stability and minimum temperature are reached at approximately 08h00. Concentrations of sulphur dioxide and particulates begin to increase as soon as erosion of the inversion begins, corresponding with Fig. 39(b).

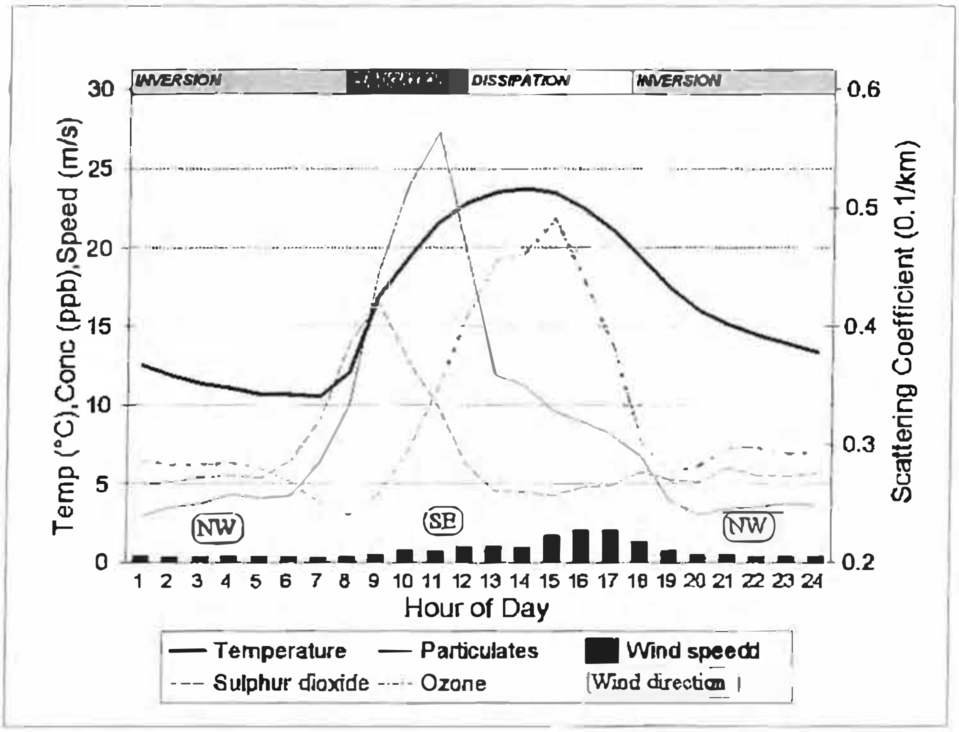


Figure 41(a): Mean diurnal variation of temperature, wind speed, fine particulates, sulphur dioxide and ozone - August 1993. Predominant wind direction also shown.

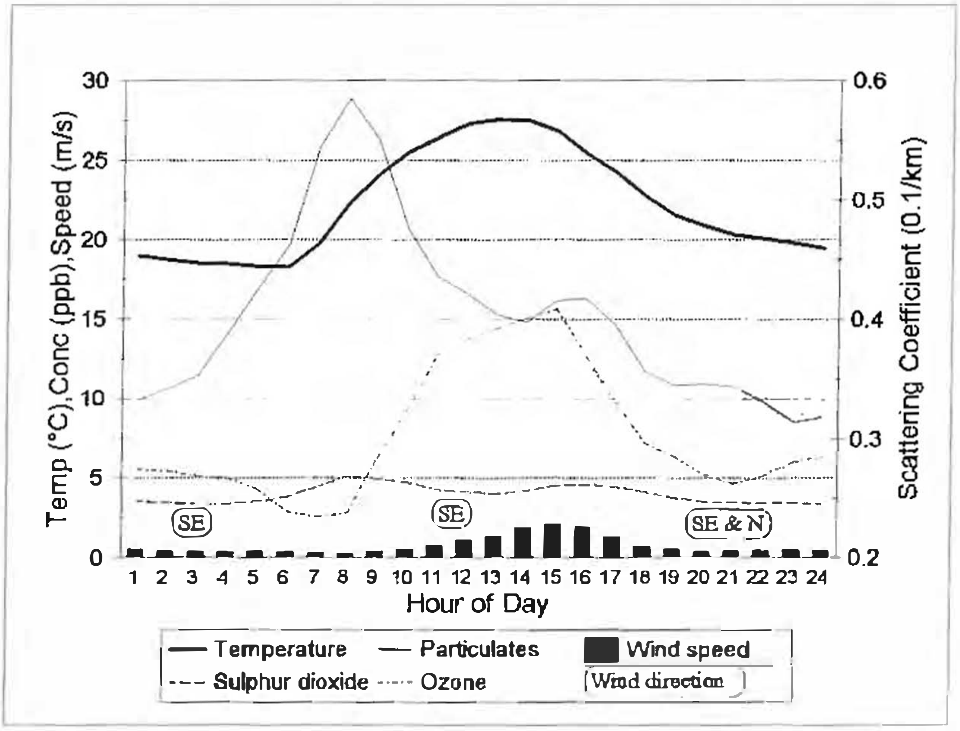


Figure 41(b): Mean diurnal variation of temperature, wind speed, fine particulates, sulphur dioxide and ozone - January 1994. Predominant wind direction also shown.

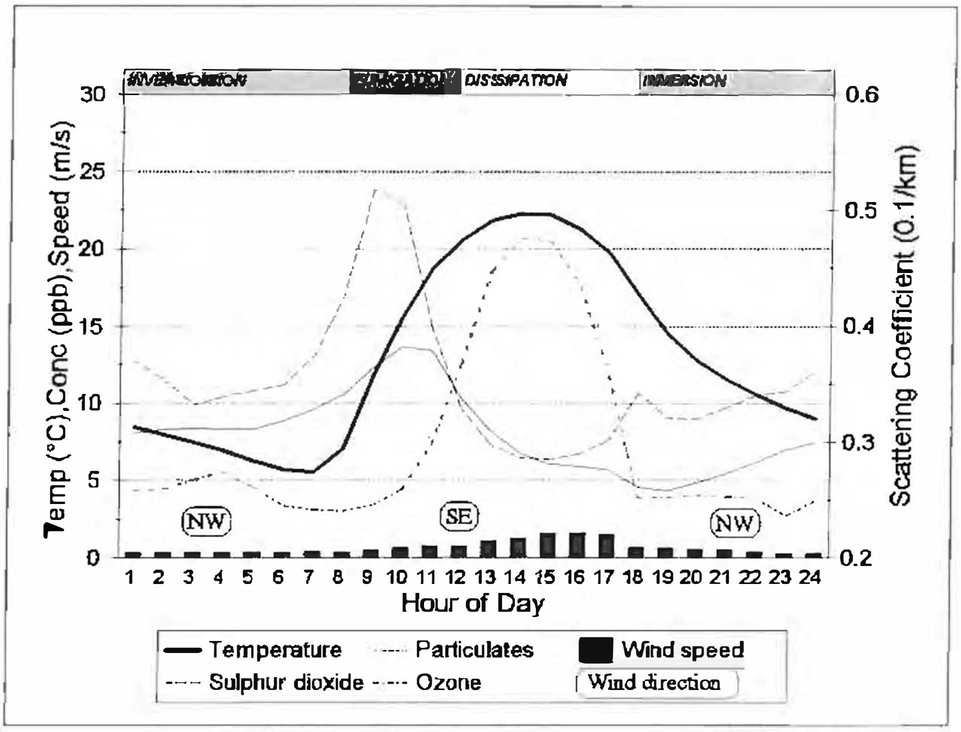


Figure 41(c): Mean diurnal variation of temperature, wind speed, fine particulates, sulphur dioxide and ozone - July 1994. Predominant wind direction also shown.

By 09h00, air temperature is increasing rapidly as are sulphur dioxide and fine particulate concentrations. When the mixing layer reaches the pollution trapped near the top of the inversion, turbulence in the confined air mass brings high concentrations rapidly to ground in the actual fumigation event (Figs. 39(c) and 40(b)). The peak average concentrations of sulphur dioxide and particulates for August 1993 occur between 08h00 and 11h00. These are average hourly concentrations for the whole month. Maximum hourly levels for individual days can be significantly higher with the maximum sulphur dioxide concentration recorded being 45 parts per billion (ppb) between 08h00 and 09h00 on 2 August. The highest daily average was recorded on the same date at a mere 13 ppb - less than one third of the hourly maximum.

At midday, the wind speed has increased to an average of over 1 m/s, with the direction having changed to south-east. Concentrations of fine particulates and sulphur dioxide decline rapidly with decreased atmospheric stability and increased turbulence. Conversely, ozone increases at the expense of many of the primary pollutants. As a secondary pollutant, its presence is dependent upon the availability of primary pollutants and the intensity of sunlight (ultra-violet radiation) which control the rate of formation, rather than stability. Peak ozone concentrations thus occur almost simultaneously with maximum temperature between 13h00 and 15h00 (Fig. 41(a)). The maximum recorded hourly ozone concentration for the month was 53 ppb between 14h00 and 15h00 on 13 August while the highest daily average was 20 ppb on 3 August.

As the sun sets, between 17h00 and 18h00, the wind speed drops dramatically and its direction changes back towards the north-west as katabatic flow is reestablished by the rapidly cooling ground surface . Pollution concentrations are all low at this time of day. During the night an inversion is again formed and any pollutants emitted accumulate in the pool of cold air to fuel the next day's fumigation.

Fig. 41(b) shows the diurnal cycle during summer. Higher average temperatures throughout the day and a reduced temperature range are immediately evident. The other striking feature of the graph is the continuously low and quasi-constant sulphur dioxide trace that barely exceeds 5 ppb. Low levels are also reflected in maximum hourly and daily concentrations recorded for the month, at 11 ppb and 6 ppb respectively. Such levels are indicative of a significant reduction in the frequency and strength of surface inversions and an increase in atmospheric turbulence during the summer, consistent with the findings of Tyson *et al.* (1976).

Ozone trends and levels in January (Fig. 41(b)) are similar to those of August (Fig. 41(a)). While there is an increase in sunlight intensity during summer, that would tend to create more ozone, there is also an increase in cloud cover that reduces the incident radiation. Further, there is a reduction in the abundance of primary pollutants as reactants because of the more effective dispersion climatology at this time of year.

Wind speed also shows a similar trend to that of winter, except greater speeds are reached during the afternoon at around 15h00. Prevailing wind directions differ from the winter as discussed, largely because the local topographic influence is overwhelmed by larger scale circulations.

Generally, the atmosphere is far less stable in the summer resulting in more effective dispersal of pollutants. However, an anomaly is present in the scattering coefficient trace for fine particulates, with a well defined peak occurring at 08h00. Several explanations can be offered for this occurrence (which does not fit into the general model being proposed), but these will be expounded in Chapter Four where it is more appropriate.

Finally, Fig. 41(c) shows the diurnal variation of parameters for July 1994 as a second winter period. Trends and levels are similar to those of August 1993, with a few exceptions. Sulphur dioxide has a higher peak than for the previous winter. Higher hourly and daily maxima were also recorded in 1994 - 72 ppb between 09h00 and 10h00 on 8 July and 23 ppb for 14 July respectively. In contrast, fine particulates display a lower peak than for August 1993.

Comparing the climatic records for the two months, it is found that 1994 was a more severe winter than 1993 as mentioned earlier, and shown by the lower average morning temperatures and greater temperature range (Figs. 36, 41(a) and 41(c)). This caused stronger inversions and more dramatic fumigations, explaining the higher sulphur dioxide concentrations. The lower fumigation peak for fine particulates in July 1994 corresponds with lower daily smoke levels obtained from the standard filter paper method and can be ascribed to the passage of many cold fronts during July 1994, which had a scrubbing effect on the atmosphere, reducing average particulate concentrations for the month. The effect of cold fronts on the local dispersion climatology will now be examined.

3.2.4 Berg winds and cold fronts

The accumulation of air pollution over Pietermaritzburg during the winter months is periodically broken by the sequential passage of Berg winds, coastal lows and westerly wave cold fronts. They occur most frequently in late winter and early spring when the amplitude of westerly moving disturbances is greatest. While all other winter circulations over the city are detrimental to the dispersion potential of the atmosphere, the climatic sequence that will now be described brings a visible clearance to the air, as verified by data collected during the 1994 winter.

Two examples are given for the synoptic sequence over Pietermaritzburg; one from 26 June 1994 to 2 July 1994, that resulted in the dramatic clearance shown in Figs. 5 and 9, and one from 20 July to 26 July 1994, that is related to the 24-hour particulate levels recorded for the same period.

Temperature, relative humidity and wind speed are given for the first sequence in Fig. 42, and the wind frequencies are divided into three distinct phases in Fig. 43(a), (b) and (c).

On the morning of 26 June 1994, Berg wind conditions developed in Pietermaritzburg as a cold front moved over the Cape. A positive temperature departure of 9°C was recorded for the midday high while the relative humidity plummeted below 10 percent (Fig. 42). The warm, dry subsiding air came from the north-north-west (Fig. 43(a)) with higher than average wind speeds. Berg wind conditions persisted through the night with the minimum temperature only dropping to 14°C. During most of 27 June, conditions were very unpleasant with a maximum temperature of 31°C recorded and the air remaining very dry and dusty. The wind continued to blow strongly from the north-north-west. Finally, relief came at approximately 21h00 on 27 June when the cold front reached the city, causing a rapid drop in temperature and increase in relative humidity (Fig. 42). The front was accompanied by low stratiform clouds and drizzle which remained throughout 28 June. Temperature dropped almost continuously for a full 39 hours, reaching a minimum of 1°C at 05h00 on 29 June, with the normal diurnal temperature trend being obliterated by cold, moist polar air being fed far inland from the south to south-east (Fig. 43(b)). Midday temperature on 28 June was only 9°C. Wind was gusty and relative humidity high during the post-frontal stage as the front brought widespread precipitation. Heavy snowfalls were experienced on the Drakensberg, and light snowfalls occurred even on Swartkop, close to Pietermaritzburg. Partial clearance began on 29 June resulting in a more normal temperature pattern, but still with relatively low daily maximum temperatures. From 30 June to 2 July, the wind speeds dropped and the direction returned to the north north-west (Fig. 43(c)), although the air remained moist and temperatures below 20°C, indicative of the extent the cold moist air behind the front.

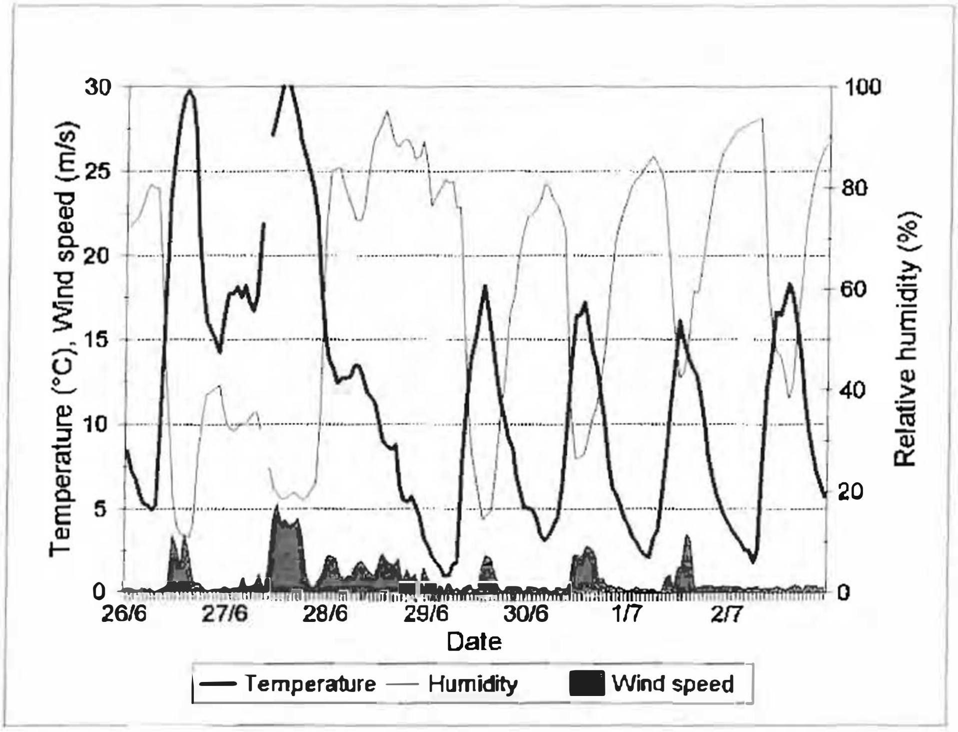


Figure 42: Climatic record for central Pietermaritzburg - 26 June 1994 to 2 July 1994.

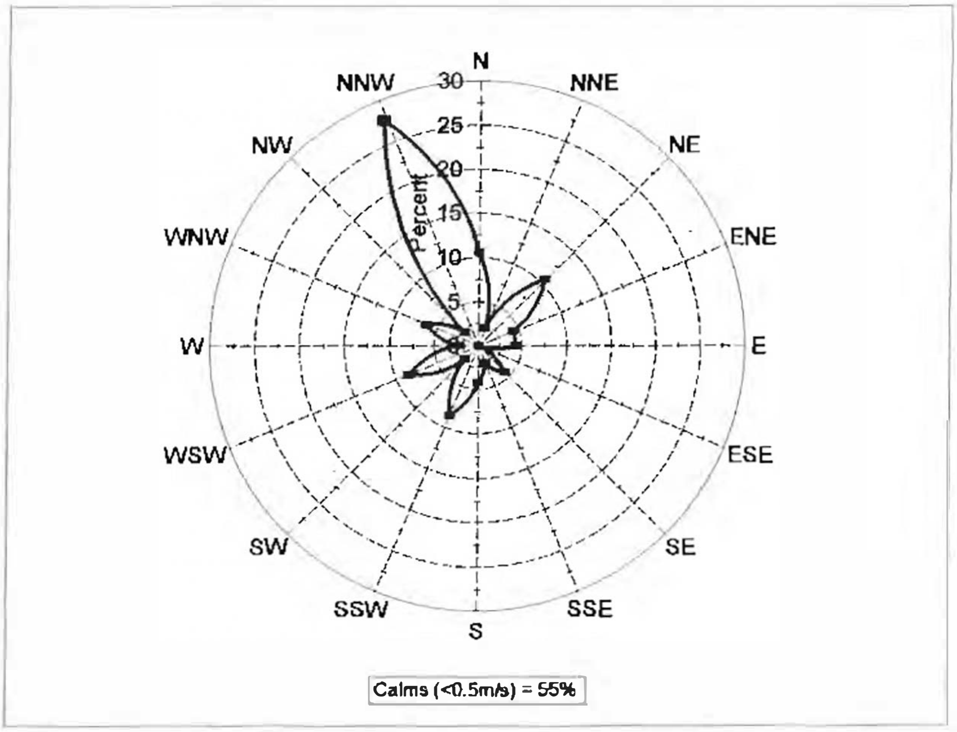


Figure 43(a): Surface wind direction frequencies - 26 June 1994 to 27 June 1994. Berg wind conditions.

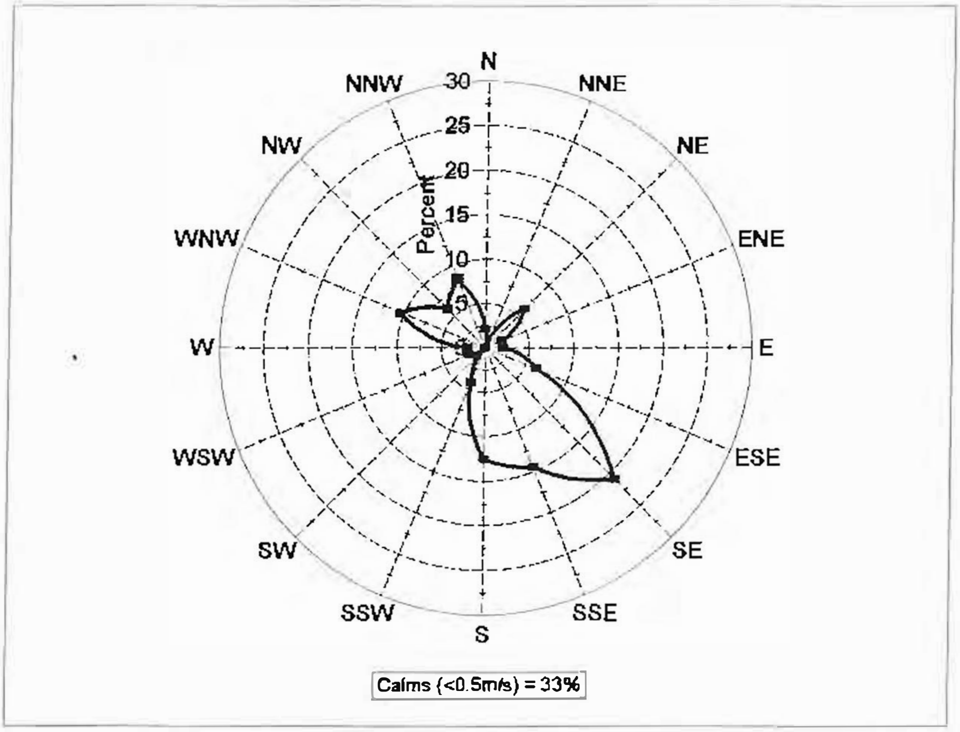


Figure 43(b): Surface wind frequencies - 28 June 1994 to 29 June 1994. Frontal and early post-frontal conditions.

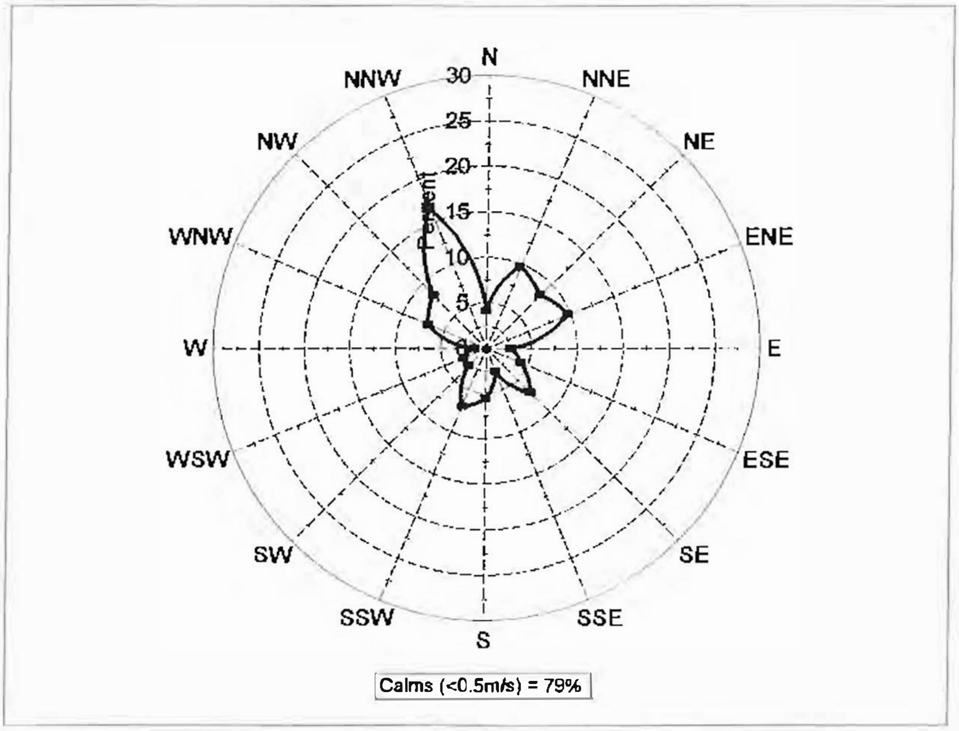


Figure 43(c): Surface wind frequencies - 30 June 1944 to 2 July 1994. Late post-frontal conditions and dissipation.

The surface climatic contrasts between pre-frontal Berg wind conditions and the post-frontal conditions were most pronounced during the described event, as was the decrease of air pollution illustrated in Figs. 5 and 9. The strong, gusty winds and precipitation cause an almost complete clearance of the atmosphere as is now shown by actual smoke levels obtained during the second example.

Climatic data for the period 20 July 1994 to 26 July 1994 are presented in Fig. 44 and Fig. 45(a), (b) and (c). Daily average ambient particulate levels derived from the standard filter soiling technique for 4 July through to 17 August are given in Fig. 46. All data were collected at the monitoring laboratory and filter papers were changed every 24 hours to achieve the best practical resolution. Noon was chosen as the best changeover time, because it ensured that each potential fumigation event was captured on one filter paper. However, the date given for the filter paper therefore refers to the day of insertion, whereas the majority of soiling would more likely occur during the following morning.

On the night of the 20 July 1994, atmospheric conditions were very calm and stable with well developed katabatic flow into the hollow from the north-west (Fig. 45(a)). Under such conditions, pollution accumulated in the inversion layer as described earlier. With the rise of the sun on the morning of 21 July under clear conditions, there was a rapid increase in temperature (Fig. 44), resulting in a severe fumigation. A smoke level of 140 $\mu g/m^3$ was measured for the 24-hour period from noon the previous day, reaching 56 percent of the South African guideline concentration. Visibility was consequently down to 3 kilometres and less. Conditions remained largely unchanged until 23 July when Berg winds started to blow from the north-north-west (Fig. 45(b)), raising temperatures to 29°C and lowering relative humidity considerably (Fig. 44). The warm wind continued through 24 July, until the onset of a coastal low was heralded by a southerly wind at 23h00. This was soon followed by the passage of the cold front that kept the maximum temperature down to 18°C on 25 July. Winds became strong and gusty, bringing precipitation, mainly from the west south-west (Fig. 45(c)). Pollution concentrations dropped, and the filter paper for the 25 July to 26 July showed zero soiling (Fig. 46).

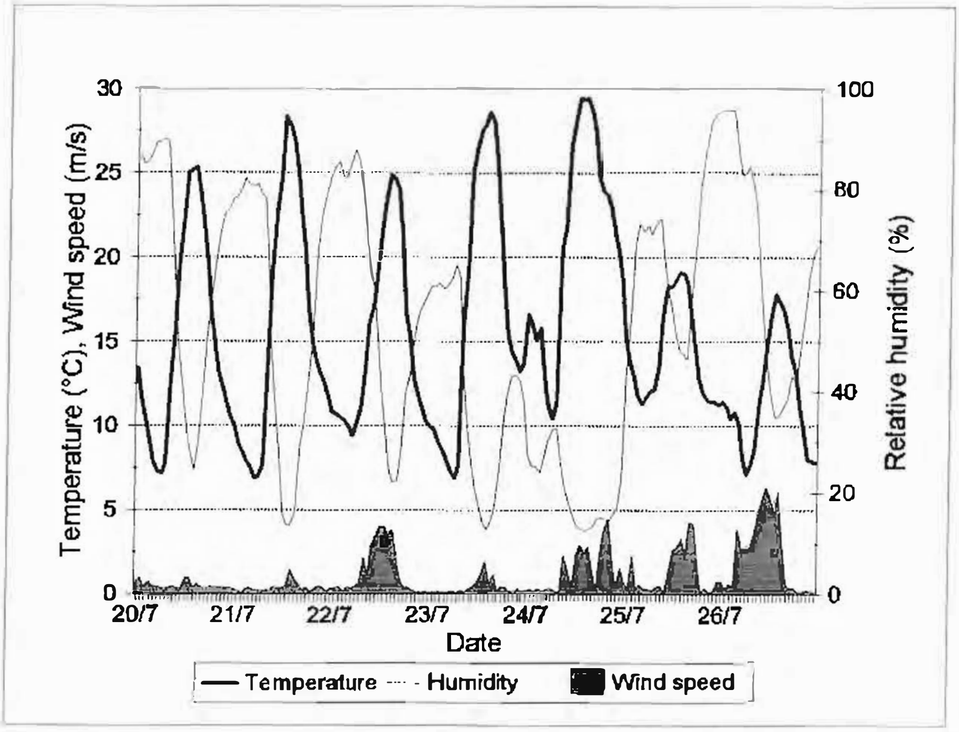


Figure 44: Climatic record for central Pietermaritzburg - 20 July 1994 to 26 July 1994.

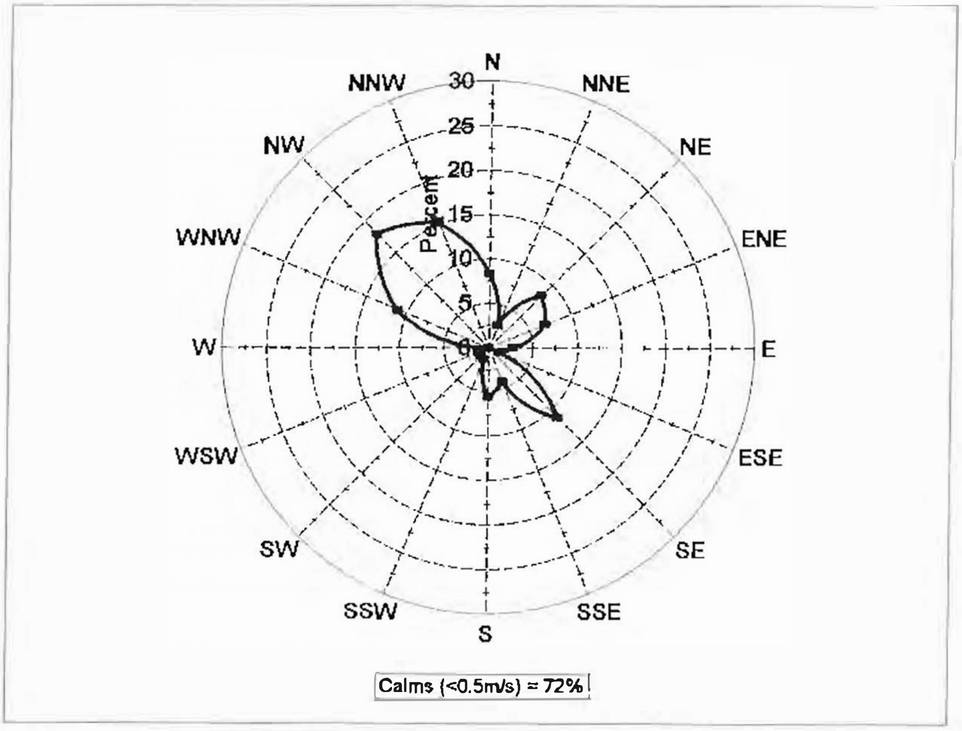


Figure 45(a): Surface wind frequencies - 20 July 1994 to 22 July 1994. Typical clear, calm winter conditions prior to onset of Berg wind.

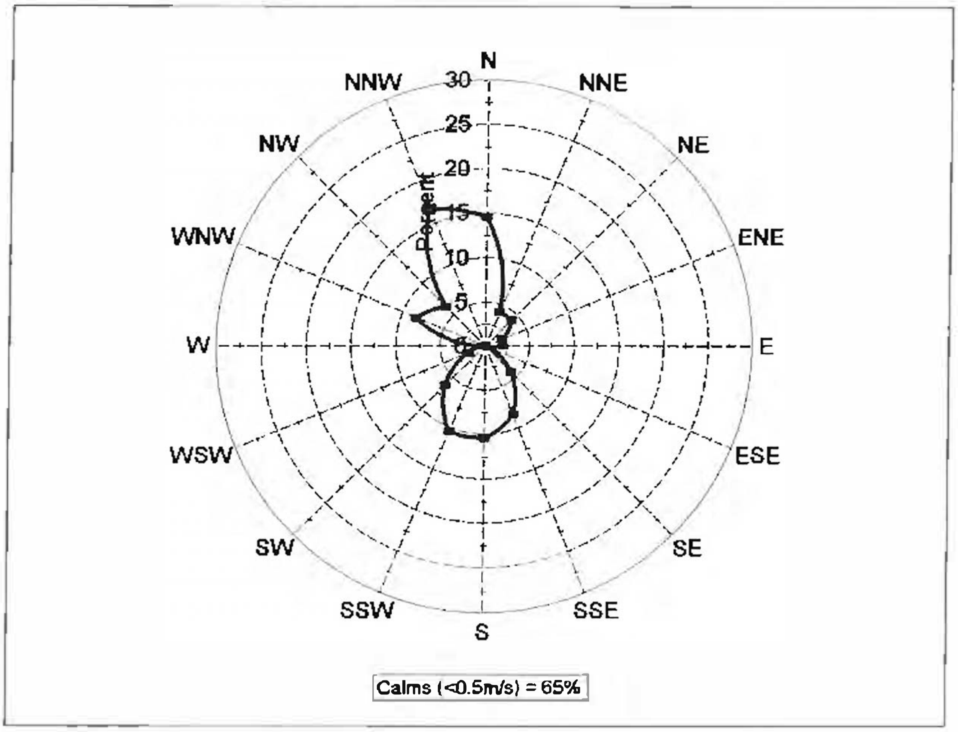


Figure 45(b): Surface wind frequencies - 23 July 1994 to 24 July 1994. Northerly mode constituting Berg wind conditions and southerly mode showing approach of coastal low.

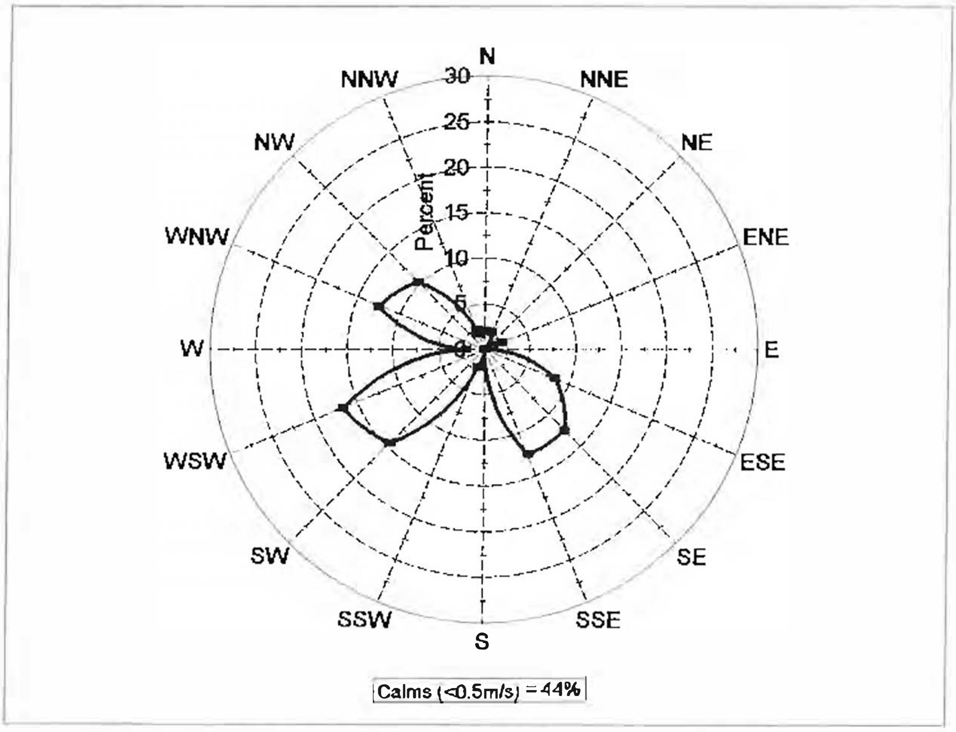


Figure 45(c): Surface wind frequencies - 25 July 1994 to 26 July 1994. Gusty, frontal winds, predominantly from west south-west.

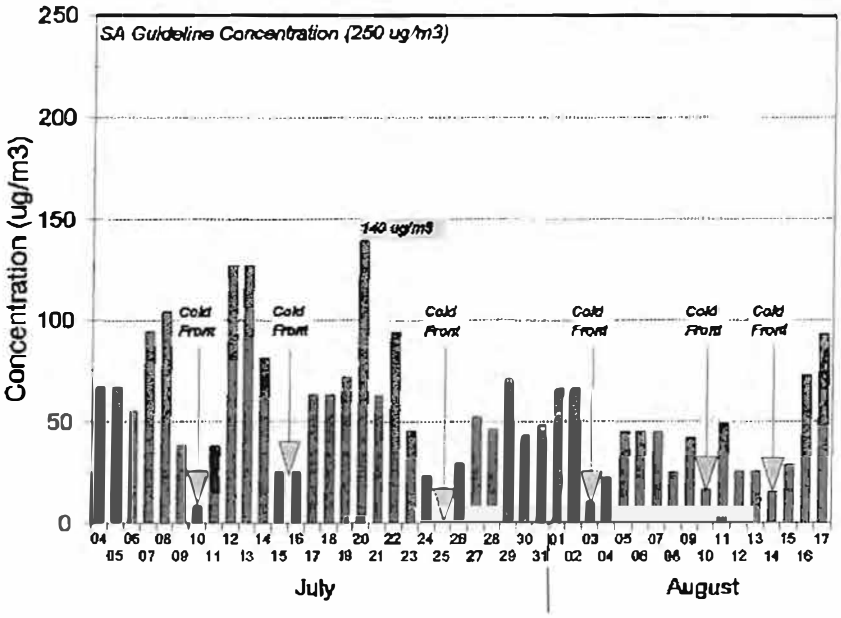


Figure 46: 24-hour average smoke concentrations measured using the standard filter method at the monitoring laboratory site (see Fig. 12, p. 34). Filters were changed manually at noon.

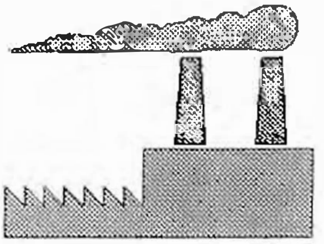
The accumulation and clearance of particulates explained above occurred several times during July and August 1994 (Fig. 46). Highest smoke levels were always obtained between cold fronts and lowest levels immediately after their passage.

In summary, the dispersion climatology of Pietermaritzburg occurs in cycles at three interrelated scales. On the highest level, there is a seasonal increase during winter, largely as a result of the anticyclonic macroscale climatology of Southern Africa. Conditions are exacerbated during winter by the local topographically-controlled climatology on a diurnal basis, and finally alleviated occasionally (every five to ten days during July and August) by passing frontal systems. With further research, this dispersion model for Pietermaritzburg could become more refined, particularly with regard to spatial variation of dispersion potential in the Greater Pietermaritzburg area. However, the model at its current state of development is sufficient to explain many trends observed for both gaseous and particulate pollutants.

* * *

It is now apparent that the dispersion climatology of Pietermaritzburg is critical to the air pollution problem, and explains many of the trends. However, the actual pollutant levels that describe ambient air quality still need to be assessed.

Chapter Four



Atmospheric Pollution in Pietermaritzburg

4. ATMOSPHERIC POLLUTION IN PIETERMARITZBURG

Before assessing atmospheric pollution in Pietermaritzburg, it is worthwhile to consider briefly what the term *air pollution* actually means. *Air* and *atmosphere* are loosely defined terms used to describe the mixture of gases that exist in a relatively thin layer around the earth. Even if the composition of clean, dry air is taken as being pure, with eight major component gases, this does not exist in nature. Gases such as sulphur dioxide (SO_2), hydrogen sulphide (H_2S), and carbon monoxide (CO) are continuously released into the air by natural processes such as volcanic eruptions, biological decay and veld or forest fires. Particles are also taken into the atmosphere by wind and other natural disturbances.

But such natural (background) concentrations of these substances are normally harmless. Air pollution can be defined as the relatively high concentrations (compared with background values) that result from the chemical and biological activities of man. A substance is only really considered a pollutant when it currently or potentially threatens the well-being of man or the environment.

Two questions frequently asked about air pollution are:
(a) which type of source puts the largest amount of pollutant into the air ?; and
(b) which single atmospheric pollutant is present in the largest amount ?
(Stoker and Seager, 1972)

The answer to these questions is not simple. Evaluation of pollutants and sources solely in terms of crude tonnage fails to take into consideration the fact that some pollutants are more harmful and dangerous than others. If weighting factors are applied to each pollutant to compensate for their total effect on man and the environment, it is found that stationary combustion sources become the main culprit. While this ranking is based on a study conducted in the United States some years ago, stationary combustion of low grade fuels has recently been identified as the most important air pollution risk factor in South Africa (Terblanche, 1992, 1993). It is thus apt to begin this section with a review of primary emission sources in Pietermaritzburg.

4.1 PRIMARY EMISSION SOURCES

Primary pollutants (particulates, sulphur dioxide, nitrogen oxide and hydrocarbons) are directly emitted into the atmosphere from sources on the earth's surface. Pietermaritzburg has no major single source of primary pollutants, comparable to the power stations in the Eastern Transvaal Highveld (ETH). Instead, primary pollutants originate from a variety of smaller sources, including industrial emissions, domestic burning, agricultural and veld burning and vehicular emissions. To put this in perspective, Corobrik (a well-known local pollution source), used 20 500 tons of coal in 1988 and cut back to only 3000 tons in 1992 (Sherry, 1993), compared to the 50 000 tons of coal used in one of six boilers per day at one of Eskom's new generation power stations in the ETH (Eskom, 1992).

Industrial emissions occur as point sources from the areas identified in Chapter One, and from the central district (Figs. 6 and 8). Most of these emissions are from coal burning furnaces for boilers or other applications, including 12 scheduled processes operating in the Pietermaritzburg area (Table 6). When the furnaces are run correctly, they do not create a nuisance. However, during incomplete combustion of oil or coal, when there is insufficient oxygen, much carbon monoxide is produced and complex hydrocarbons given off to form a component of smoke, particularly in smaller furnaces. The minor constituents of the coal and oil, sulphur and nitrogen, also form oxides during combustion. For sulphur:

$$S + O_2 \rightarrow SO_2$$

Nitric oxide is also formed during combustion:

$$N_2 + O^* \rightarrow NO + N^*$$
$$N^* + O_2 \rightarrow NO + O$$

(Strauss, 1977)

Table 6: Scheduled processes - Pietermaritzburg.

Industry	Location	Description	Process / source	Main pollutant type
Corobrik Natal	Chase Valley	brickworks, glazing	coal-fired kilns	particulates, SO_2
Natal Rubber Compounders	Willowton	rubber compounders	synthetic rubber manufacture	carbon black (particulates)
PG Bison	Willowton	wood products	drying stack, coal-fired boiler	particulates, formaldehyde
Sutherlands Tannery	Plessislaer	leather tannery	hide curing	odour
Edendale Tannery	Edendale	leather tannery	hide curing	odour
Hulletts Aluminium	Masons Mill ✓	aluminium refining and products	aluminium refining	aluminium oxides, particulates
Natal Foundry	Mkondeni	cast iron products, sand-blasting	cupelo smelter	iron oxide, particulates, SO_2
Bosal Africa	Willowton	sheetmetal products, exhausts	coal-fired furnace, galvanizing	particulates, SO_2, HCl
Slinter Plant	Mkondeni	slintering		SO_2
Anchor Chemicals	Willowton	rubberized compound	bulk chemical processes	
Bohme Chemicals	Willowton	chemical products	bulk chemical processes	
Premix Plant	Copesville	asphalt plant	coal-fired asphalt plant	particulates, carbon black

After being emitted into the atmosphere, the nitric oxide is turned into the dioxide comparatively slowly by a complex series of reactions (Section 4.2). The amount of sulphur oxides produced are largely dependent upon the sulphur in the fuel, whereas the nitrogen oxides depend largely on the method of firing and the resultant temperature.

Smoke, or particulate emission from combustion is a function of the solid incombustible materials in the fuel and of incomplete combustion in the carbon. As stated by Strauss (1977):

> *'Particularly with small industrial, commercial or domestic boilers and furnaces, when these are overloaded, or burning at very low levels, both unburned carbon particles and inorganic matter are emitted. There is generally very little smoke from oil- or gas-fired sources, at optimum rates, and with well-adjusted burners. However, coal-fired units invariably produce some smoke, especially when fired with pulverized fuel, as in modern, large-scale operating practice, and some system of particulate control is essential.'*

Many of the local industries are guilty of operating furnaces inefficiently as evidenced by Figs. 47 and 48. The effect of such emissions is exacerbated by short stacks, not high enough to penetrate the deep inversions described, even with the added updraught velocity of the flume gas. Stacks would have to be at least 100 metres high to reach the top of even moderate inversions over the city.

Other primary emissions are those from domestic burning of coal and wood in the townships surrounding Pietermaritzburg. Domestic combustion is highly inefficient, producing large quantities of respirable level pollution in dense residential areas, especially during the night and winter when the dispersion climatology is at its worst. Little more needs to be said about this type of primary pollution as it is the well-known dilemma of much of the Third World. The Vaal Triangle Air Pollution Health Study documents substantial evidence that particulates are the most likely cause of detrimental health effects in the area (Terblanche, 1993), while a similar rural exposure monitoring project found that the average total suspended particulate exposure for 17 children was 2367 $\mu g/m^3$, compared to the World Health Organization

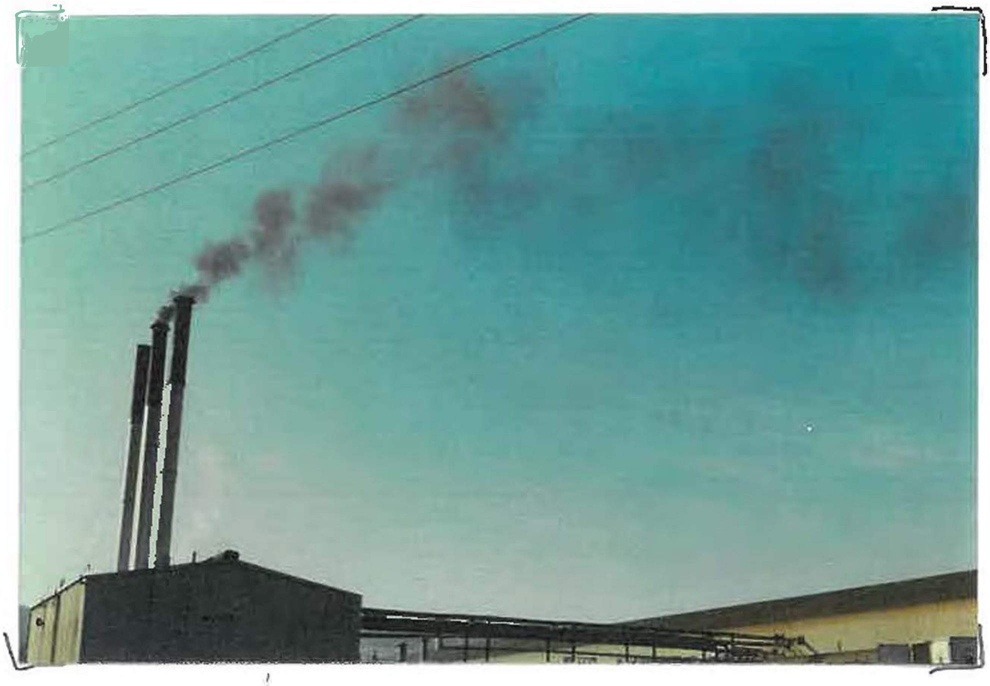


Figure 47: Black smoke being emitted on a clear winter day during 1994 from one of Pietermaritzburg's larger industries. The colour of the smoke is unacceptable if compared to the Ringelmann chart which consists of varying shades of grey squares as used in the Atmospheric Pollution Prevention Act.

Figure 48: Another local industry emitting unacceptably dark smoke on the same day as above. Note how the plume at first loops in a zone of local instability, but then fumigates as it spreads towards the centre of the city during mid morning.

no-effect-exposure limit of 180 $\mu g/m^3$. It is not unlikely that similar readings would be obtained for non-electrified township dwellers around Pietermaritzburg.

Veld fires and agricultural burning also constitute a major source of air pollution in Pietermaritzburg. Carelessness during the dry months leads to many accidental veld fires, causing dense smoke which disperses slowly in the calm winter atmosphere. Cane fires from the many farms on the outskirts of the city send large fly ash particles into the air, which are drawn into the hollow by the katabatic flow field if the fires are at night. Fly ash particles of up to 20 cm in length are not uncommon and provide a source of annoyance to residents, and more importantly break down to form secondary pollution.

Last, but not least, is the contribution of motor vehicles to primary pollution in Pietermaritzburg. The very nature of the internal combustion engine prevents complete combustion of fuels[3] resulting in unburned and incompletely burned combustion products being emitted. Oxides of nitrogen, unburned hydrocarbons, carbon monoxide and lead are the typical pollutants originating from this source, most of which contribute greatly to the formation of secondary pollutants. Pietermaritzburg has a high traffic volume for the size of the town, largely a legacy of apartheid planning, with the majority of the black population resident in the former KwaZulu area of Edendale and Vulindlela to the south-west, while the major employment centres such as Willowton are on the other side of town to the north-east (Fig. 8). Combined with a totally inadequate public transport system, this has forced people to use ever increasing numbers of taxis for daily commuting through the central district. The resulting congestion means that vehicles travel slowly and pollution accumulates.

One of the prime reasons for locating the monitoring laboratory at its current site was because of the high traffic density on Longmarket Street as an arterial route (Fig. 13). Twelve traffic count stations located on the main access routes to the central district recorded an average weekday 24-hour traffic volume of 192 900 vehicles in 1991 (City Engineer's Department,

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[3] Combustion time is limited to a fraction of a second and the cooled cylinder walls prevent complete combustion of the charge. The efficiency of combustion is even less when the engine is cold or incorrectly tuned.

1993) - more than the number of people resident in the metropolitan area.

4.2 SECONDARY POLLUTANTS

Secondary pollutants are created through sunlight-induced chemical reactions between primary pollutants and various atmospheric components, such as moisture (Tyson *et al.*, 1988 and Bridgman, 1990). The most well-known are ozone (O_3) and peroxyacetyl nitrate (PAN), which are the main components of photochemical smog. Even in a small urban atmosphere, such as that of Pietermaritzburg, the wide variety of anthropogenic materials increases the amount of oxidants formed by at least an order of magnitude over background concentrations, creating potentially dangerous pollution situations.

Whilst traffic densities may not be high by world standards, relatively high densities associated with high incident solar radiation and adverse meteorological conditions can cause photochemical smog. The concentration of ozone is often taken as an indicator of photochemical smog (Dutkiewicz, 1990).

The chemistry of ozone formation depends upon the presence of oxides of nitrogen (NO_X), non-methane hydrocarbons (NMHC), catalysts such as carbon monoxide (CO), free radicals such as the hydroxyl radical (OH), and the presence of sunlight. Most of the reactions are reversible, reflecting the continuous process of ozone formation and breakdown, which depends heavily on the relative concentrations of precursors in the atmosphere (Bridgman, 1990).

Nitrogen dioxide first forms rapidly by the oxidization of nitric oxide,

$$NO + O \rightarrow NO_2$$

and then dissociates again in the presence of sunlight (*hv*) to make more atomic oxygen available for ozone formation.

$$NO_2 + h\nu \rightarrow NO + O$$

Ozone then forms from molecular and atomic oxygen in the presence of a catalyst (*M*),

$$O + O_2 + M \rightarrow O_3 + M$$

but is destroyed by the presence of nitric oxide.

$$NO + O_3 \rightarrow NO_2 + O_2$$

The equilibrium concentration of ozone is thus usually low, but can increase in the presence of reactive hydrocarbons, which are a common vehicular emission. Whilst ozone is only one component of secondary pollution and is not the most reliable indicator of photochemical activity, it is the only component that is commonly measured at present. Ozone concentrations recorded in Pietermaritzburg enable comparisons to be made to standards and levels recorded elsewhere.

The diurnal pattern of ozone formation during the day in Pietermaritzburg has already been shown in Figs.41(a), (b) and (c) and can now be reviewed in light of the equilibrium reactions above. The interaction and levels of nitrogen oxides and ozone recorded during winter 1993 in Pietermaritzburg will be discussed in Section 4.3.4 and 4.3.5 respectively.

4.3 AMBIENT ATMOSPHERIC POLLUTION LEVELS

Direct measurement of ambient concentrations of pollutants is the most commonly used method of establishing the relationship between emissions and ambient air quality. Knowledge of ambient atmospheric pollution levels is also essential for assessment of air quality compared to standards that have been established as goals or limitations to the concentration values that should be allowed.

4.3.1 Air quality standards

Ambient air quality standards are intended to establish limits that protect the public, with an adequate margin of safety, from any adverse health and welfare effects from exposure to various pollutants. The statements of the standards require specification of: (1) numerical limits, (2) the averaging time over which the numerical limit applies, and (3) the number of exceedances of the numerical limit over some time period (e.g., a year) that would constitute a violation of the standard. The stringency of the standard depends critically upon all three specifications (Egan and Vaudo, 1985).

In South Africa, the Department of National Health and Population Development prescribes guidelines which represent threshold safety levels derived with cognizance to the developing state of the economy (Table 7). It is often argued that these guidelines are too lenient and the issue will be raised again later. A list of international air quality standards has also been compiled for comparative purposes in Appendix 2.

Guidelines and standards are nevertheless only what their name suggests. Some people are more sensitive to various pollutants and allergens than others. The criteria levels are scientifically designed to ensure acceptable levels for the majority of people, most of the time. There will always be people susceptible to lower levels, and there will always be times when a person's tolerance level for pollution is lowered. Air pollution can be considered a form of stress and a person's reaction to a certain level of pollution will depend upon other stress factors and how much resistance to stress the individual has.

All of these factors must be considered in the assessment of air quality through analysis of ambient levels if the conclusions are to be as objective as possible.

Table 7: South African environmental guidelines given by the Department of National Health and Population Development, 1987. Concentrations other than annual means are not to be exceeded more than once a year (tabulated from Sherry, 1992, pers. comm. and De Jager *et al.*, 1991).

<table>
<tr><th rowspan="2">Pollutant</th><th colspan="5">ppb</th></tr>
<tr><th>Instant</th><th>1-hour average</th><th>24-hour average</th><th>1-month average</th><th>Annual average</th></tr>
<tr><td>SO_2</td><td>600</td><td>300</td><td>100</td><td>50</td><td>30</td></tr>
<tr><td>Ozone</td><td>250</td><td>120</td><td>50</td><td>30</td><td>10</td></tr>
<tr><td>NO_X</td><td>1400</td><td>800</td><td>400</td><td>300</td><td>200</td></tr>
<tr><td>NO_2</td><td>500</td><td>200</td><td>100</td><td>80</td><td>50</td></tr>
<tr><td>NO</td><td>900</td><td>600</td><td>300</td><td>200</td><td>150</td></tr>
<tr><td>Non-methane HC</td><td>700</td><td>400</td><td>200</td><td>150</td><td>60</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="2">High volume TSP*</td><td colspan="2">350 $\mu g/m^3$</td><td colspan="2">150 $\mu g/m^3$</td></tr>
<tr><td colspan="2">Smoke**</td><td colspan="2">250 $\mu g/m^3$</td><td colspan="2">100 $\mu g/m^3$</td></tr>
<tr><td colspan="2">Soiling index</td><td colspan="2">50 S/m^3</td><td colspan="2">20 S/m^3</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="3">Max ambient lead concentration</td><td colspan="3">2.5 $\mu g/m^3$ monthly average</td></tr>
<tr><td colspan="3">Deposit gauge dust - slight</td><td colspan="3"><0.25 $g/m^2/day$</td></tr>
<tr><td colspan="3">- moderate</td><td colspan="3">0.25 - 0.5 $g/m^2/day$</td></tr>
<tr><td colspan="3">- heavy</td><td colspan="3">0.5 - 1.2 $g/m^2/day$</td></tr>
<tr><td colspan="3">- v. heavy</td><td colspan="3">>1.2 $g/m^2/day$</td></tr>
</table>

* TSP - total suspended particles

** As measured by Soiling index x 5

4.3.2 Particulates and visibility

Particulate air pollutants are very diverse in character, including both organic and inorganic substances with diameters ranging from less than 0.01 μm to greater than 100 μm (Fig. 49). Since very fine aerosol particles grow rapidly by coagulation, and large particles sediment rapidly under gravitational influence, the major part exists in the 0.1 to 15 μm range (Harrison, 1983).

A wide variety of sources contribute to atmospheric particulates in the urban environment. Particles around 2 μm diameter are generally formed by growth of smaller particles generated by condensation processes, whilst larger particles arise from mechanical disintegration processes. Thus, primary aerosols are often natural in origin such as dust, soot and other inorganic matter, and constitute the coarse particles. Secondary aerosols are more anthropogenic in origin, often created from photochemical reactions, and constitute the fine particles.

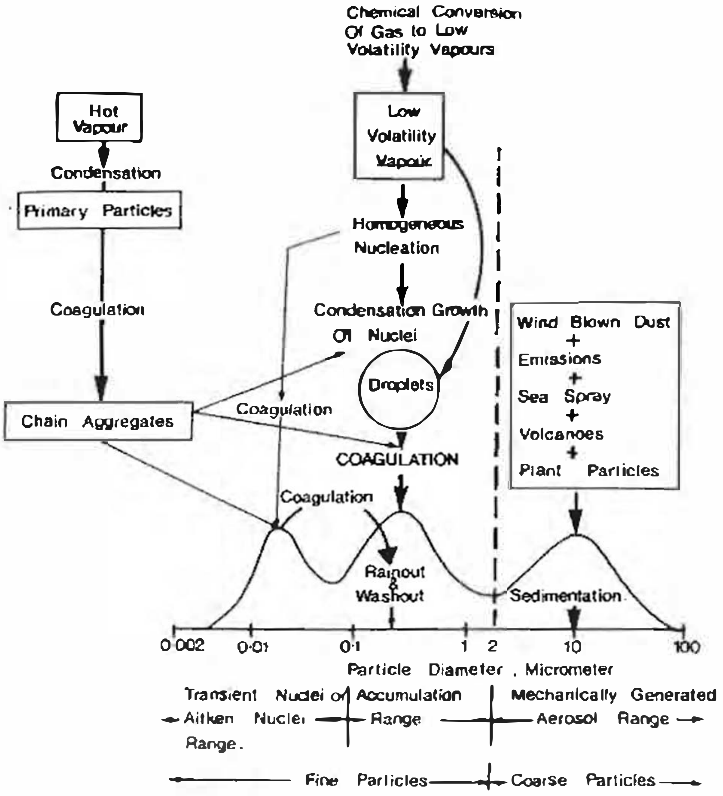


Figure 49: Schematic diagram of the size distribution and formation mechanisms for atmospheric aerosols (after Harrison, 1983).

High concentrations of particulate matter in the atmosphere of a city often create a haze owing to the multiple scattering of insolation, which may severely restrict visibility and, in higher concentrations, interfere with the health of residents. The haze, or smog, that commonly occurs over Pietermaritzburg on winter mornings has been referred to throughout the text, and illustrated in Figs. 9, 28, 30 and 40. In all of these photographs, the haze is accentuated by high atmospheric moisture content in the early morning that forms a valley fog in the cold inversion layer. However, Fig. 50 clearly shows the difference between atmospheric moisture and particulate matter. Figs. 51 and 52 further prove that the haze over the city can legitimately be called smog and is a serious cause for concern.

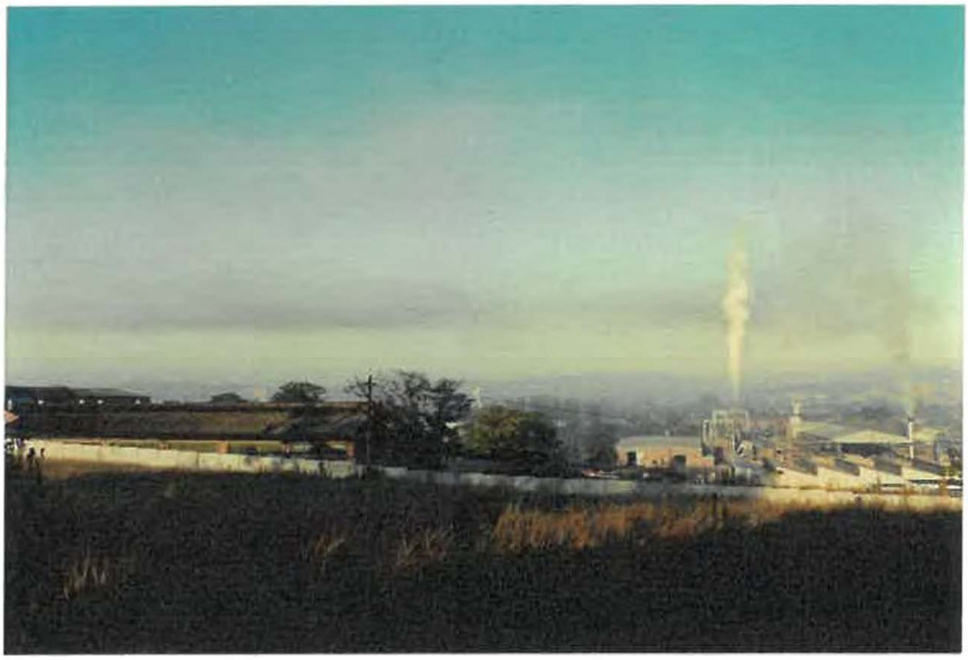


Figure 50: Two plumes rising from the stacks of PG Bison at 07h30 on 8 June 1994. The white plume emerging on the left is largely steam from the drying stack and soon evaporates into the dry air. The darker plume emerging on the right is smoke from the coal-fired boiler and drifts horizontally and undiluted in the calm, stable inversion layer. Later in the morning this smoke will fumigate in the hollow as described.

Figure 51: Dense black smoke hangs in the air over residential areas of Pietermaritzburg at 07h45 on 8 June 1994. The top of the inversion layer can be discerned by the layer of smoke at the level of the top floor of the Natalia building on the right of the photograph.

Figure 52: The view looking across Willowton industrial area from Mountain Rise at 08h00 on 8 July 1994. Visibility is low as smoke from the industrial area is topographically restricted by the ridge from which the photograph was taken. Residential areas adjacent to Willowton suffer from the worst visible pollution in the district.

The six standard filter stations monitor smoke concentrations within the municipal area, supplemented by a real-time nephelometer located in the monitoring laboratory as described in Chapter Two. Average monthly readings of fine particulate mass for the 12-month study period show an initially unexpected trend with the highest mean monthly concentrations occurring during the summer months of December, January and February (Fig. 53). This is in agreement with the trend in the diurnal scattering coefficient trace (Fig. 41).

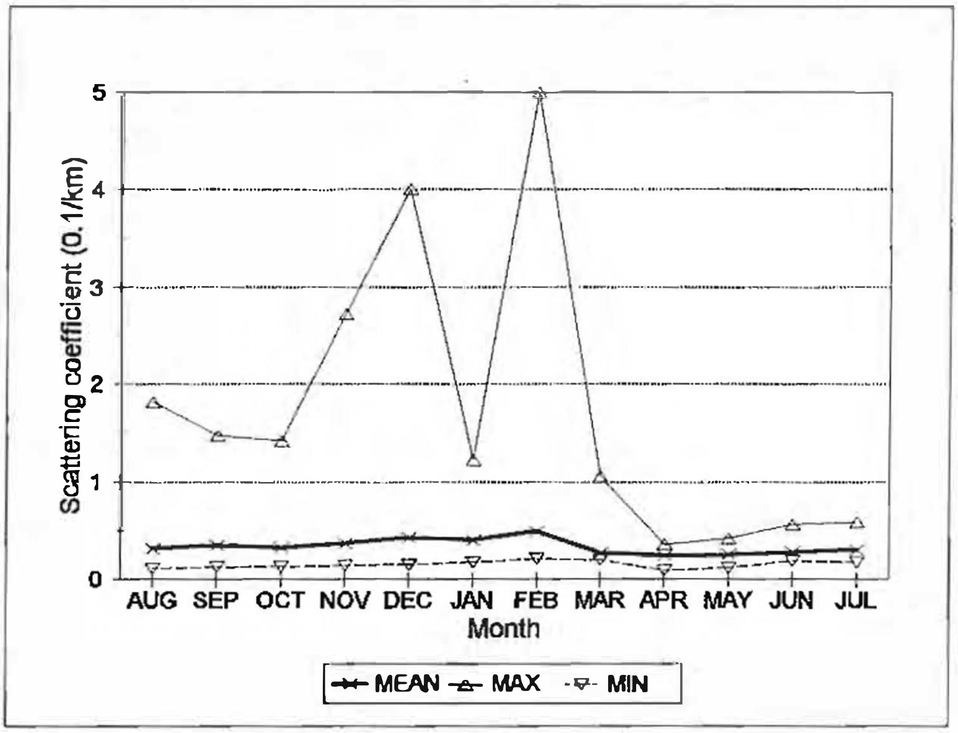


Figure 53: Mean, maximum and minimum hourly particulate scattering coefficients recorded by the nephelometer in central Pietermaritzburg from August 1993 to July 1994.

In order to explain these apparent anomalies, it is necessary to consider the instrument. The nephelometer measures only fine particulate mass, with a maximum diameter of 2.5 μm. It is designed to monitor visibility that does not necessarily correlate well with total suspended particles for the reasons given below.

- A large part of particulate pollution over Pietermaritzburg is of natural or agricultural origin (dust, and smoke from veld fires and cane burning) or from coal combustion (smoke and fly ash). Such particles generally have diameters greater than 2 μm (Fig. 49) and are more abundant during the dry winter season when intense fumigations occur. Consequently, the worst pollution episodes of total suspended particles are largely undetected by the instrument.

- Secondly, nephelometer readings are based on the scattering extinction coefficient of a light beam which is sensitive to the relative humidity of the air. The summer months in Pietermaritzburg are typically very humid and the accessory heating tube may not be able to reduce the humidity of the sample air sufficiently, meaning that the instrument tends to over-read during times of high relative humidity, ie. 05h00 to 08h00. The high humidity may also cause fine aerosol particles to grow rapidly by condensation and coagulation to form secondary particles of 0.1 to 1.0 μm diameter, to which the nephelometer is most sensitive.

- Thirdly, it has been found by Lynch and Snow (1991) that temperatures over 30°C have a dramatic effect on the zero stability of the nephelometer. An air conditioner operates continuously to keep temperatures inside the monitoring laboratory to within the specified operating ranges of the instruments. However, when outside temperatures are often above 36°C, and the hut is in full sunlight, the air conditioner has difficulty in keeping the nephelometer temperature below 30°C, especially with the warm incoming air sample. Thus, upscale drift of the haze coefficient during the summer months is likely.

Provided the above limitations of the nephelometer are realized, analysis of time-exceedance diagrams for fine particulate mass is still valuable (Fig. 54 (a), (b) and (c)). The chosen threshold of 12 μg/m^3 is low for hourly concentrations, but necessary because only fine particles (< 2.5 μm) are being considered. For the months of August 1993 and July 1994, the greatest number of exceedances was recorded at 10h00, with numbers tapering off before and after this time of day. Such trends are in line with the climatological model. However, the greater overall number of exceedances recorded during January 1994 is more likely related to the factors described above.

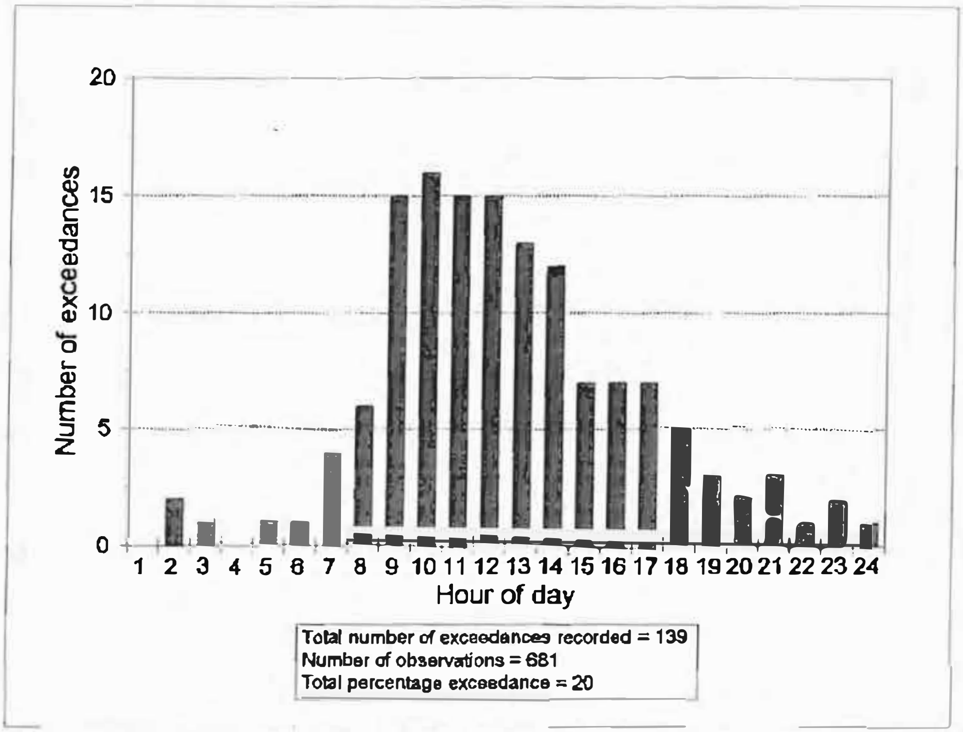


Figure 54(a): Fine particulate mass time-exceedance diagram for August 1993; 12 μg/m^3 threshold level. Graph shows the number of times the hourly mean concentrations of fine particulate mass exceeded the threshold level for given hours of the day.

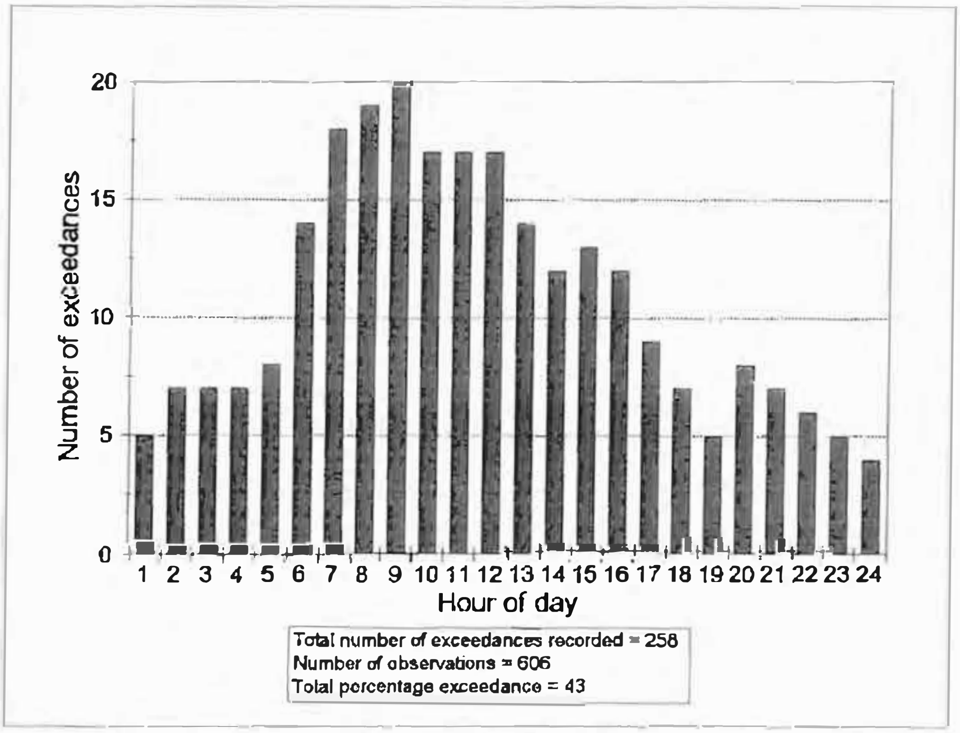


Figure 54(b): Fine particulate mass time-exceedance diagram for January 1994; 12 μg/m^3 threshold level.

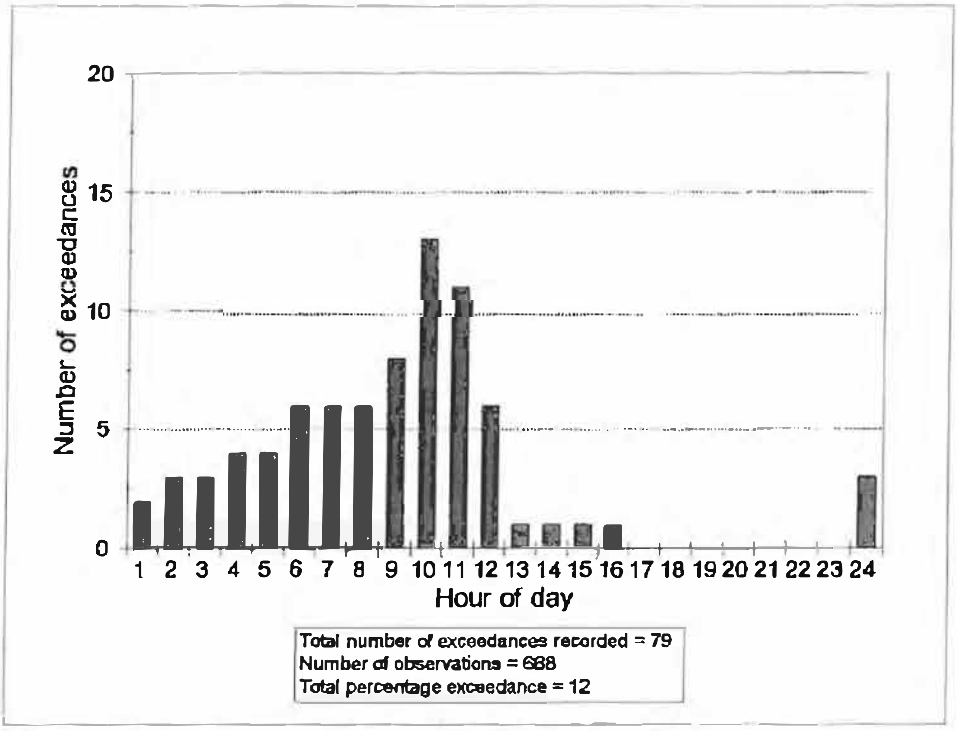


Figure 54(c): Fine particulate mass time-exceedance diagram for July 1994; 12 $\mu g/m^3$ threshold level.

Analysis of the nephelometer data has identified that it is not an appropriate instrument for the measurement of particulate pollution, particularly in Pietermaritzburg. Statistics obtained by the standard filter paper soiling method show more consistent results, showing higher smoke levels recorded for winter throughout the city for many years. Twenty-four hour average smoke concentrations obtained from filter papers changed daily at noon yielded the most informative results, in concordance with observations and climatological measurements taken during July and August 1994 (Fig. 46). Even better results would be obtained using smaller time intervals, which is only practically possible by using automated multi-port sampling equipment.

Monthly smoke levels from the City Hall station are plotted against the nephelometer readings for the study period in Fig. 55. In spite of the two sites being in close proximity, there is little correlation between the two data sets, producing a coefficient of - 0.35. This serves to highlight the confusion that can arise from different monitoring techniques.

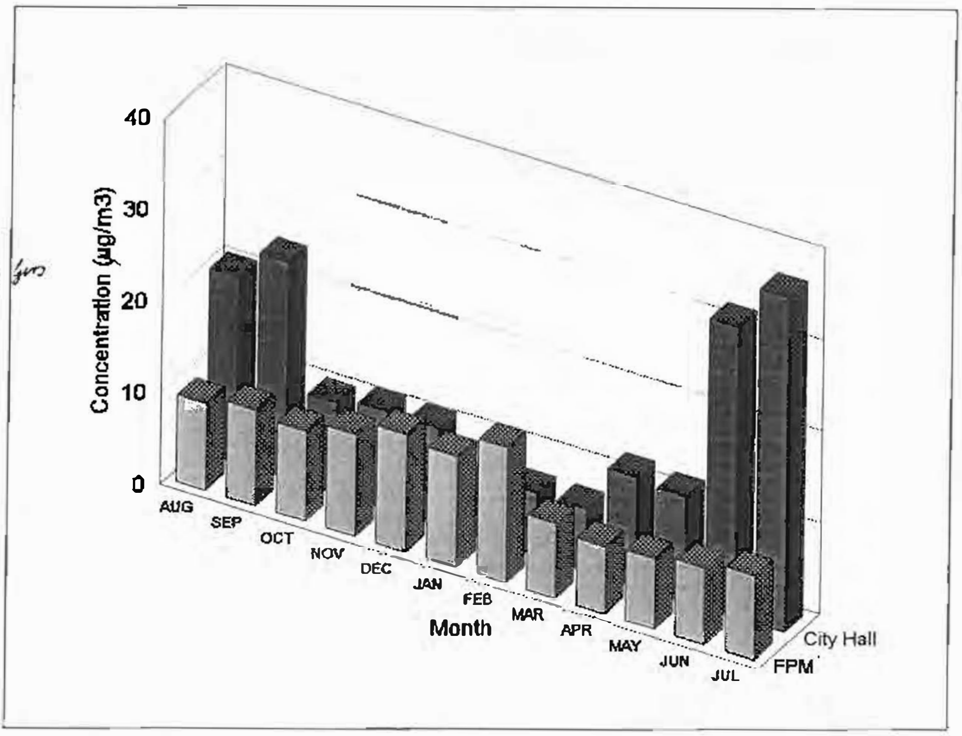


Figure 55: Mean monthly smoke concentrations recorded at the City Hall versus fine particulate mass recorded by the nephelometer located nearby.

The City Hall data show the dramatic increase in smoke levels during winter. Comparing data obtained from all six smoke monitoring stations operated by the City Health Division for the study period gives a crude spatial distribution of smoke pollution over Pietermaritzburg (Fig. 56). Northdale recorded the highest average smoke level (23.94 percent), closely followed by Masons Mill (22.13 percent) and the Old Beer Hall (21.98 percent). Chasedene experienced the lowest levels representing only 4.93 percent of the total. The spatial distribution of smoke levels is therefore largely consistent with the longer-term findings of Simpson (1992), with the exception of Northdale. Levels appear to be increasing in this area owing to the expansion of industry in Willowton along the Greytown Road, although more data are required to validate this trend statistically.

Long-term seasonal trends for all monitoring stations show a slight overall decrease in smoke levels over the past ten years (Fig. 57). Much more evident, however, are the high average winter levels, compared to those of summer and the year as a whole. While yearly averages are all between 25 and 45 $\mu g/m^3$, winter averages range from 47 to 70 $\mu g/m^3$. Three-month

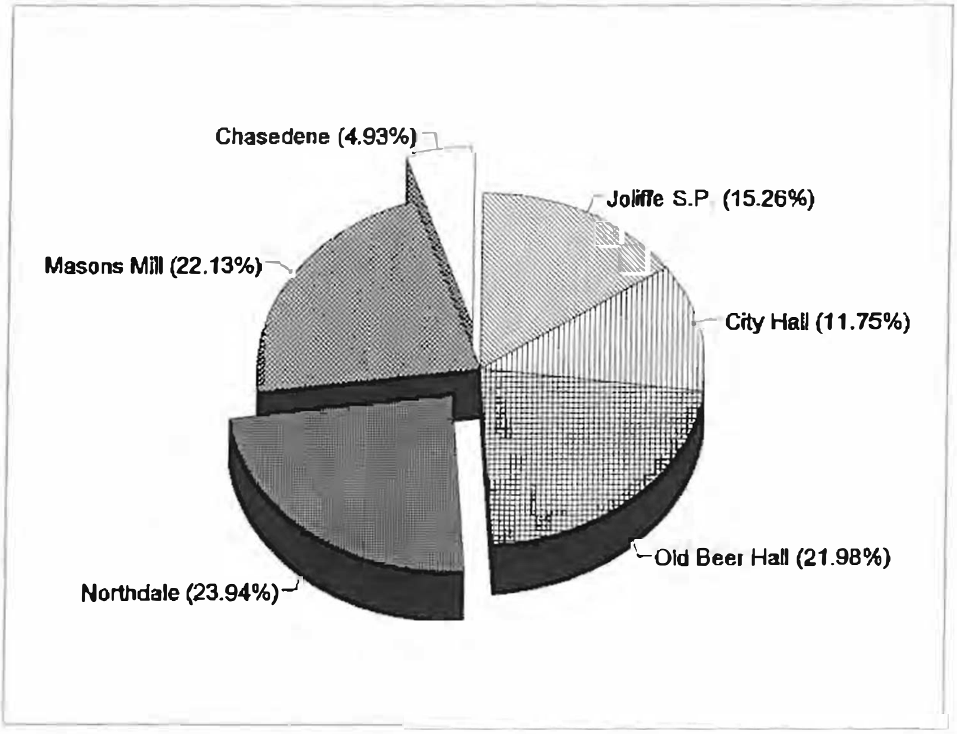


Figure 56: Average monthly smoke concentrations for August 1993 to July 1994 expressed as percentages for each station.

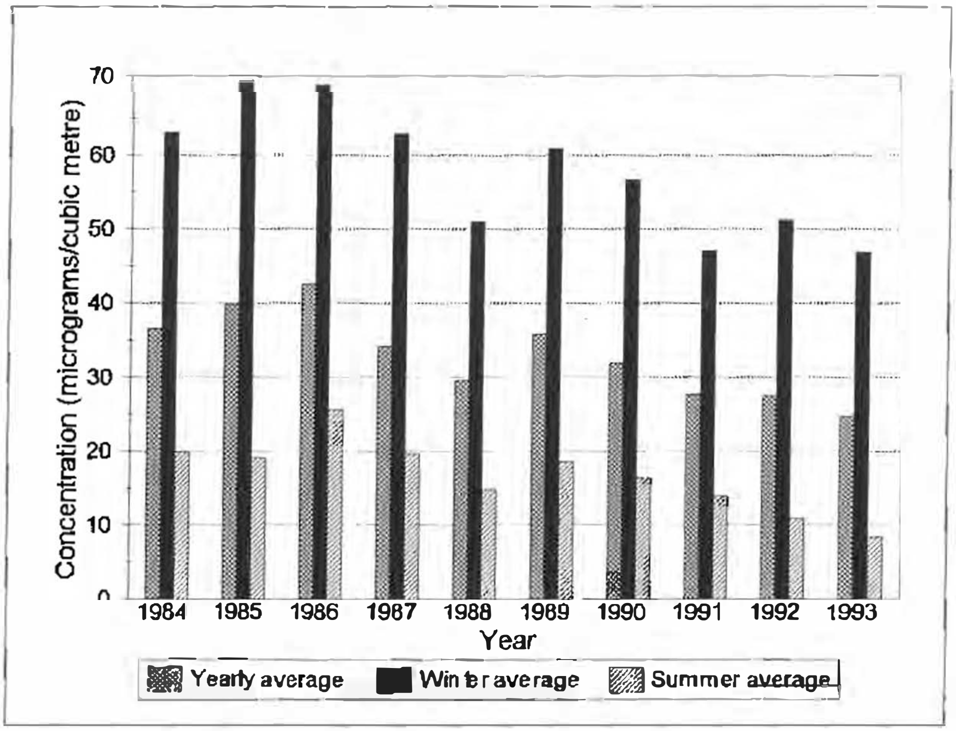


Figure 57: Yearly, winter (June, July, August) and summer (December, January, February) average smoke pollution concentrations in Pietermaritzburg - 1984 to 1993.

averages of 70 $\mu g/m^3$ are high compared to the annual guideline of 100 $\mu g/m^3$, considering that these are averages of all six stations. The situation looks worse if levels are compared to the United States Environmental Protection Agency (USEPA) or World Health Organization (WHO) annual standards of 75 and 50 $\mu g/m^3$ respectively.

In summary, particulate pollution does present a threat in Pietermaritzburg. It is necessary to conduct further monitoring of such pollutants with the appropriate equipment as recommended in Chapter Five.

4.3.3 Sulphur dioxide

The problem with man-made pollution is often one of distribution rather than amount. Sulphur is a case in point. Only one third of the sulphur entering the atmosphere on a global scale is a result of the activities of man (Stoker and Seagar, 1972), but it is concentrated primarily over relatively small urban areas. Nature's two-thirds contribution is much more evenly distributed.

Anthropogenic input is primarily in the form of sulphur dioxide, from the combustion of fossil fuels containing sulphur. These are predominantly coal and fuel-oil, since natural gas, petrol and diesel fuels have a relatively low sulphur content (Harrison, 1983). Sulphur dioxide is also routinely produced as a by-product in metallurgical operations.

The adverse effects of sulphur dioxide include damage to the human respiratory system, especially when exposure is in conjunction with particulates as in the London smogs of the 1950's. Sulphur dioxide is also damaging to plants at even modestly elevated concentrations.

Once in the atmosphere, SO_2 is partially converted to SO_3 , and then to H_2SO_4 (sulphuric acid) in the reactions

$$2SO_2 + O_2 \rightarrow 2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

The ratio of SO_2 to H_2SO_4 depends upon a number of factors including atmospheric moisture, catalytic particulate matter, sunlight intensity and duration, precipitation, and the time the sulphur contaminants have been in the air (Stoker and Seagar, 1972).

Concern over H_2SO_4 derives from its being a major component of acid rain, which has been found to occur in the Eastern Transvaal Highveld (Olbrich, 1993). Rainfall acidity in the KwaZulu-Natal Midlands is also greater than that recorded in pristine areas such as Cape Point. A pH level of 4.3 was recorded in Ladysmith during 1985/6 (Tyson *et al.*, 1988), and a Pietermaritzburg resident claims to have recorded similar levels for Scottsville during 1993 (Nicholls, 1993), compared to pH 5.0 to 5.3 recorded in the so-called pristine areas. However, it is highly unlikely that the acidity of rain in Pietermaritzburg can be attributed to local sulphur dioxide emissions, as the process for the formation of acid rain requires a long duration of residence of the pollutants in the atmosphere. This is normally possible through long range atmospheric transport from tall stack emissions, making it far more likely that any increase in acidity of rain over Pietermaritzburg is a result of pollution from the ETH region, where emissions of SO_2 are far greater, and from tall stacks. The issue of recirculation of pollutants in the atmosphere of the South African Highveld is discussed in a recent paper by Held *et al.* (1994). Budding events, that could lead to peak sulphate concentrations during spring and autumn over KwaZulu-Natal are described. In view of the complexity of such systems, further investigation is required before any conclusions can be reached about acid rain in Pietermaritzburg.

Ambient atmospheric levels of sulphur dioxide recorded at the monitoring laboratory over the study period were low by South African standards (Fig. 58). Mean monthly levels were below 10 ppb for all months except June and July 1994, when levels rose above 15 ppb. Maximum hourly concentrations show a distinct trend with low peak values in summer, increasing to significantly higher peak values during winter. Sources of sulphur dioxide would tend to increase in the winter months with the burning of more wood and coal for space heating, but would not account for the magnitude of the winter increase alone. The high winter peaks conform with the climatological model proposed and highlight the pronounced effect of the inversion-fumigation sequence.

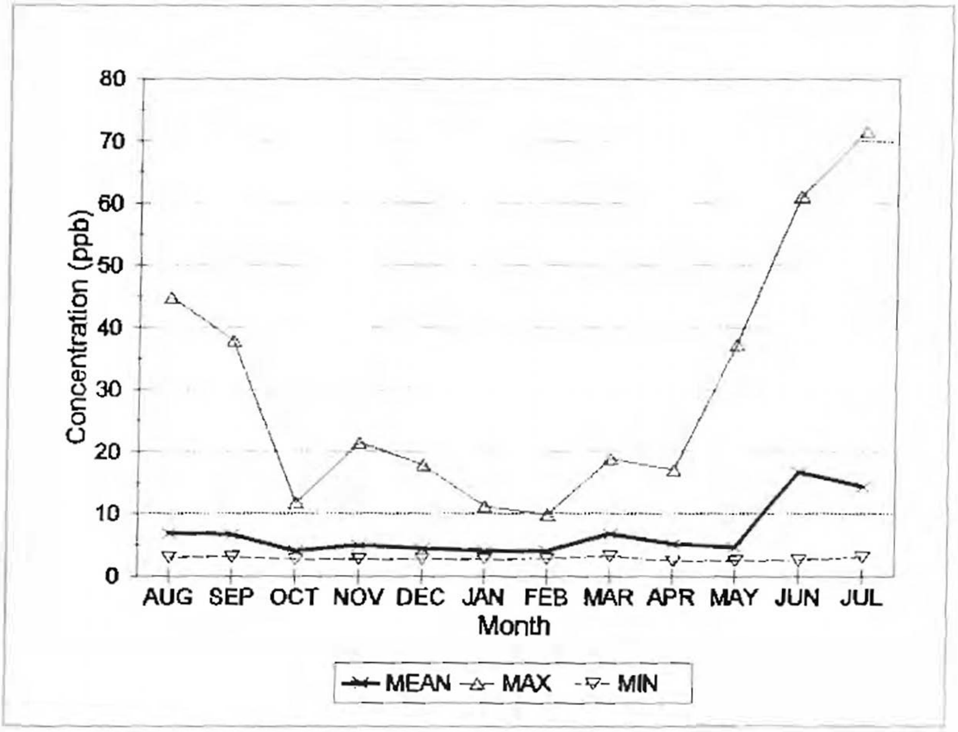


Figure 58: Mean, maximum and minimum hourly sulphur dioxide concentrations recorded in central Pietermaritzburg from August 1993 to July 1994.

Diurnal time-exceedance graphs illustrate the frequency of peak sulphur dioxide concentrations during the fumigation period in concordance with Fig. 41. The number of times the hourly mean concentrations exceeded the threshold level of 15 ppb for given hours of the day during August 1993 and July 1994 are shown in Fig. 59(a) and (b). That 15 ppb represents only five percent of the South African guideline concentration for one-hour averages is indicative of the low levels, although the guideline is lenient by international standards. Forty-two exceedances were recorded in August 1993, compared to 220 in July 1994, and none in January 1994, explaining the absence of a diagram for that month. The greater frequency of exceedance during July 1994 is consistent with higher average sulphur dioxide levels obtained by the standard monitoring method at the City Hall.

Monthly averages for the 12-month study period obtained using the real-time monitor and the standard titration technique for monitoring sulphur dioxide are compared in Fig. 60. A high positive correlation coefficient of 0.74 between the two data sets demonstrates the much higher compatibility of the monitoring techniques than was the case for particulates.

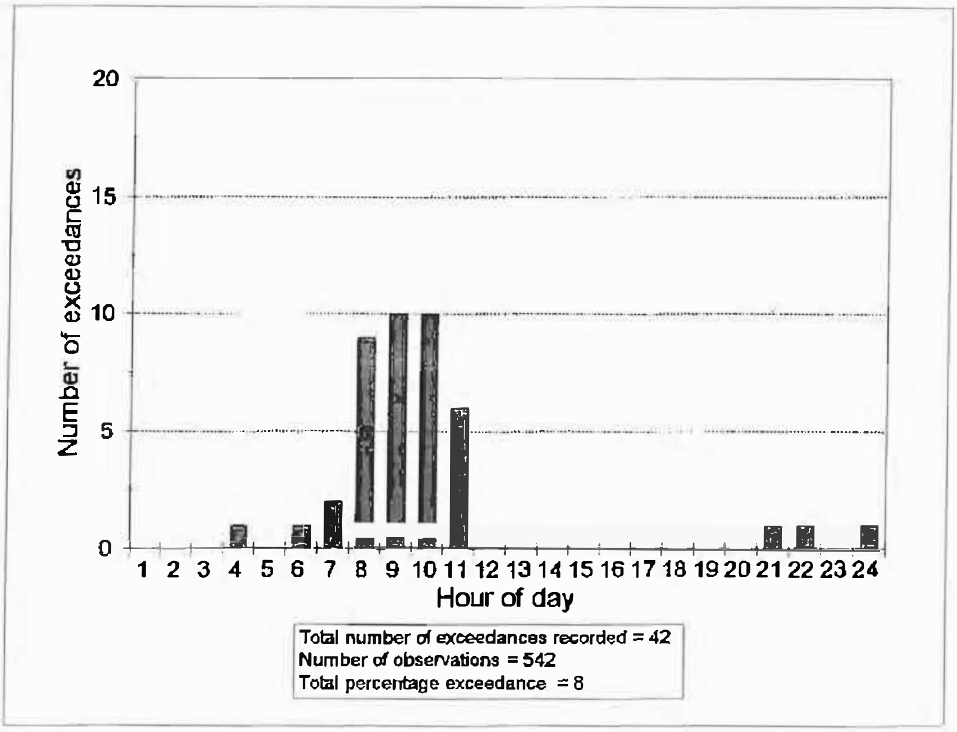


Figure 59(a): Sulphur dioxide time-exceedance diagram for August 1993; 15 ppb (39 $\mu g/m^3$) threshold level chosen to eliminate noise but show a meaningful number of exceedances.

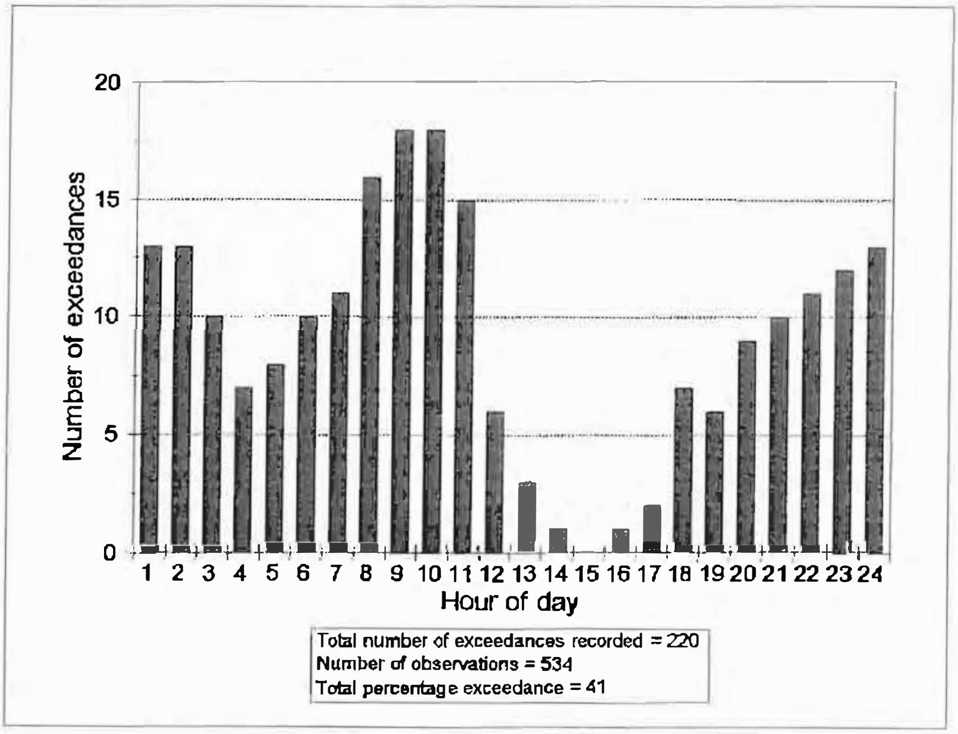


Figure 59(b): Sulphur dioxide time-exceedance diagram for July 1994; 15 ppb (39 $\mu g/m^3$) threshold level.

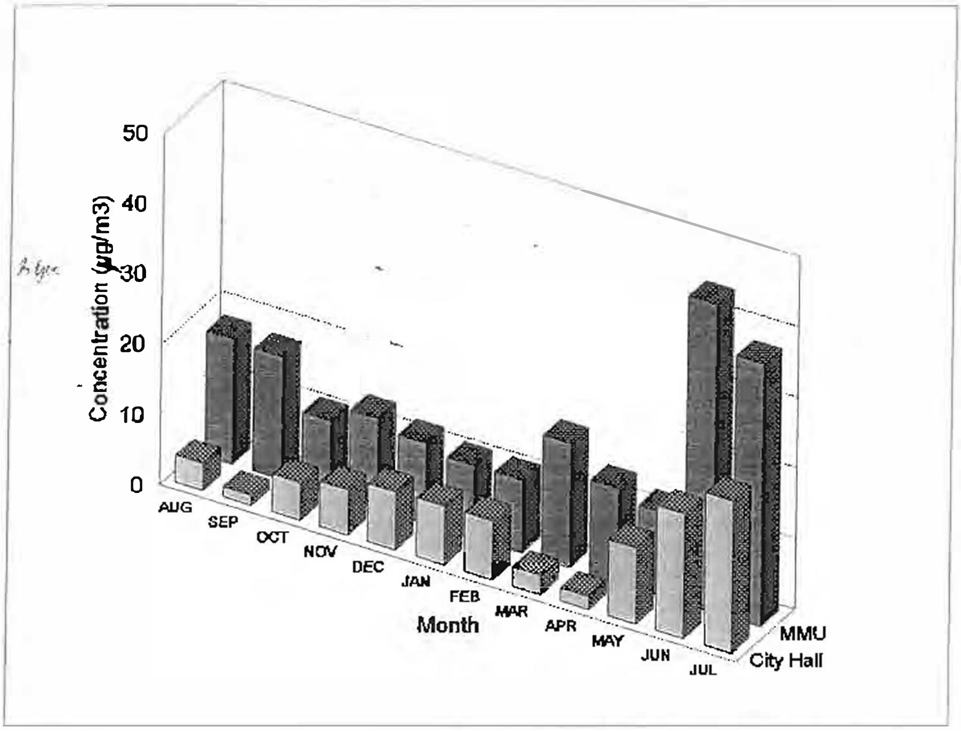


Figure 60: Mean monthly sulphur dioxide concentrations recorded at the City Hall using the standard titration method versus mean concentrations recorded by the real-time monitor located nearby.

Spatial distribution of ambient sulphur dioxide levels during the study period is only possible by calculating the relative percentage contribution recorded at each of the six standard monitoring sites to a theoretical total of all the monthly readings for the study period (Fig. 61). The rank order of the six stations for sulphur dioxide levels is very close to that for smoke, with Northdale recording the highest levels (30.66 percent) and the Old Beer Hall and Masons Mill experiencing the second highest pollution levels (15.23 and 15.22 percent). Chasedene again appears to be the least polluted area on the monitoring network (7.31 percent). The fact that Northdale is even more predominant in terms of sulphur dioxide raises concern about the local air quality which has deteriorated in recent years. However, the spatial resolution of Figs. 56 and 61 is severely limited and again offers opportunity for future research.

Fig. 62 depicts the long-term seasonal trends of sulphur dioxide at all monitoring stations. Higher average levels of sulphur dioxide have been experienced in winter for nine of the ten years, although the increase over yearly levels is not as pronounced as for particulate pollution.

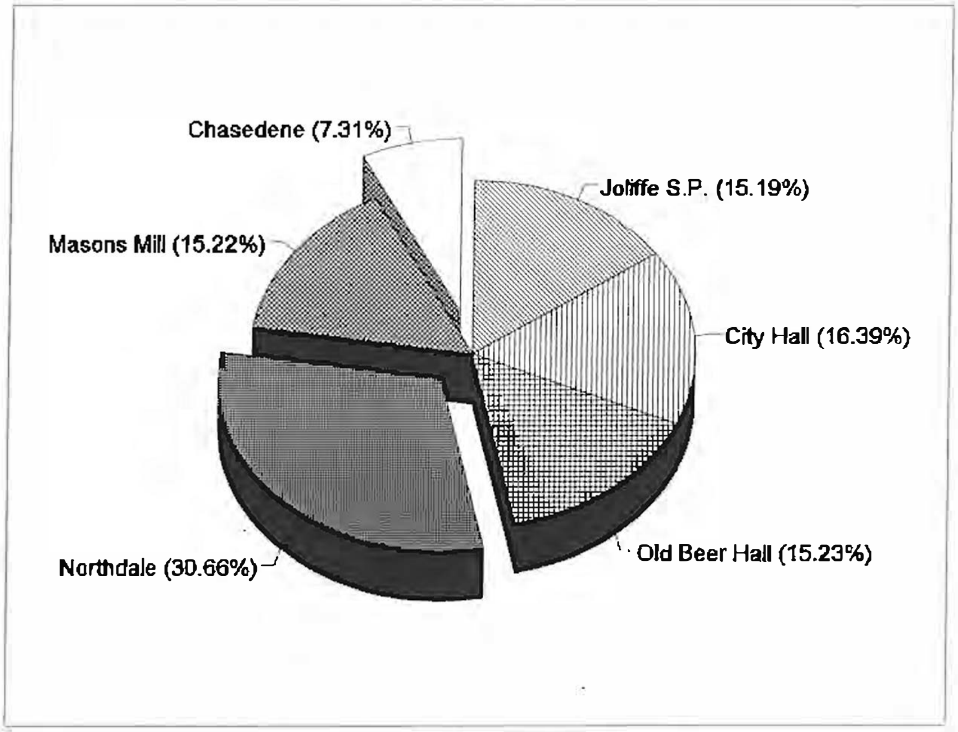


Figure 61: Average monthly sulphur dioxide concentrations for August 1993 to July 1994 expressed as percentages for each station.

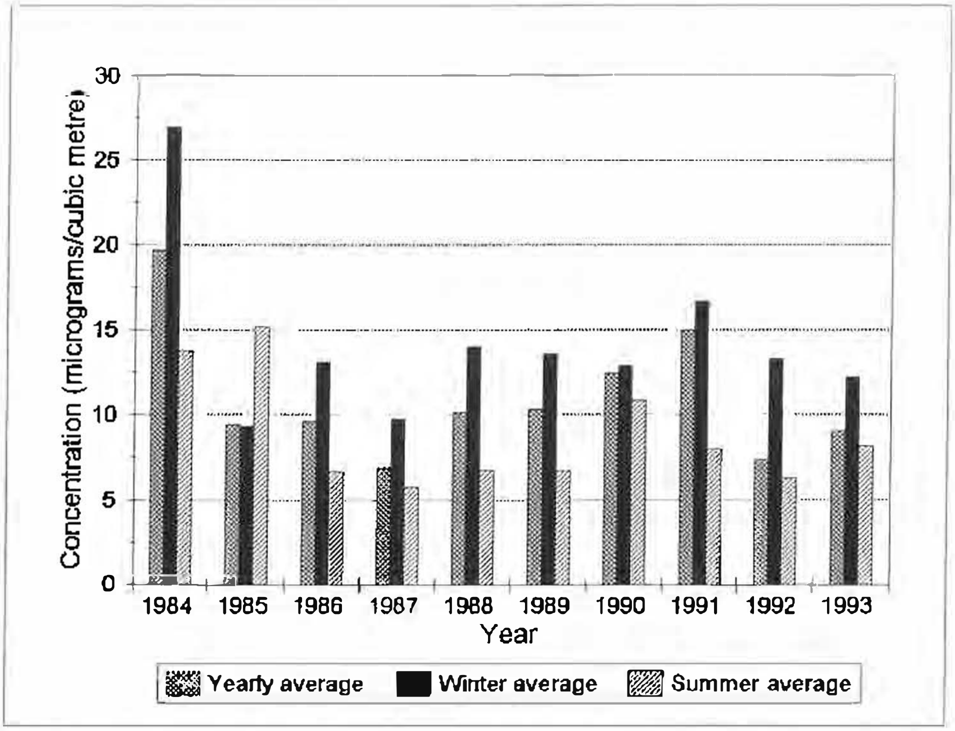


Figure 62: Yearly, winter (June, July, August) and summer (December, January, February) average sulphur dioxide concentrations in Pietermaritzburg - 1984 to 1993.

Summer levels are still significantly lower, indicating that sulphur dioxide levels remain relatively high during the autumn and spring months. It is difficult to say whether this trend results from changes in emission patterns (sources) or as a result of the climatology (dispersion).

The long-term annual trend is erratic, with no significant increase or decrease, except for the marked decrease between 1984 and 1985. Only three stations were monitoring sulphur dioxide concentrations in 1984 (stations 2, 3 & 4), all in areas with high ambient levels. The three stations that subsequently began to monitor sulphur dioxide in 1985 (stations 1, 5 & 6) are all located in relatively clean areas, and their data brought the averages down.

Comparing the highest annual levels of 24 $\mu g/m^3$ (1984) and 15 $\mu g/m^3$ (1991) with the South African guideline concentration of 78 $\mu g/m^3$ (30 ppb) indicates that local levels are very low. Even when considered against USEPA and WHO standards (both 50 $\mu g/m^3$), no exceedances from any of the six stations were recorded in the past ten years. It can therefore be argued that Pietermaritzburg does not currently have a problem with sulphur dioxide pollution. Such findings, however, do not preclude the need to monitor.

4.3.4 Nitrogen oxides

Nitrogen oxides (NO_X) refer to the atmospheric concentrations of the gases nitric oxide (NO) and nitrogen dioxide (NO_2). Although other nitrogen oxides exist, these two, under urban atmospheric conditions, are the ones primarily involved in air pollution. By far the major proportion of emitted NO_X is in the form of NO (Harrison, 1983).

The problem of NO_X pollution from man is similar to that of SO_2, not so much one of amount as it is for distribution. Nitrogen oxide emissions are closely related to population densities, because the major anthropogenic source is combustion; and most combustion is related to the automobile, power production or waste disposal.

Direct effects of exposure to oxides of nitrogen include human respiratory tract irritation and damage to plants. More serious indirect effects of NO_X pollution result from their role in the formation of photochemical oxidants, and oxidation to nitric acid that contributes to acid rain problems.

The photolytic cycle of NO_X was explained in Section 4.2. and should be referred to in the following discussion of diurnal NO_X and ozone trends over Pietermaritzburg (Fig. 63). Ambient NO_X and ozone levels follow a regular pattern related to traffic, sunlight and dispersion climatology that closely resembles classic diurnal trends from Los Angeles, although at much lower concentrations.

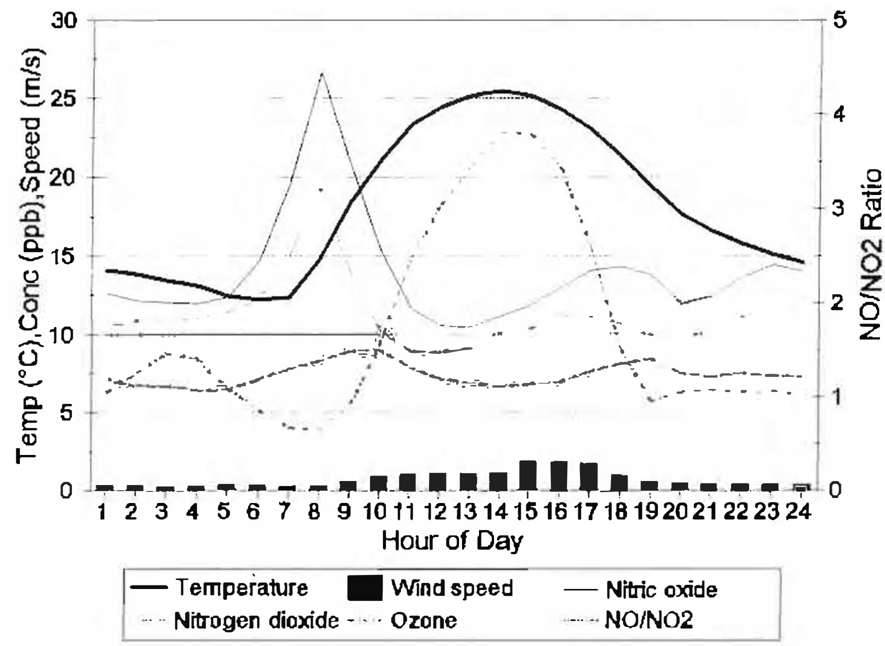


Figure 63: Mean diurnal variation of temperature, wind speed, nitric oxide, nitrogen dioxide and ozone - 18 August to 12 September 1993. This four week period was chosen for analysis to make use of the best NO_X data available in light of the technical problems. The ratio of NO/NO_2 is also shown, being crucial to ozone formation as explained in the text.

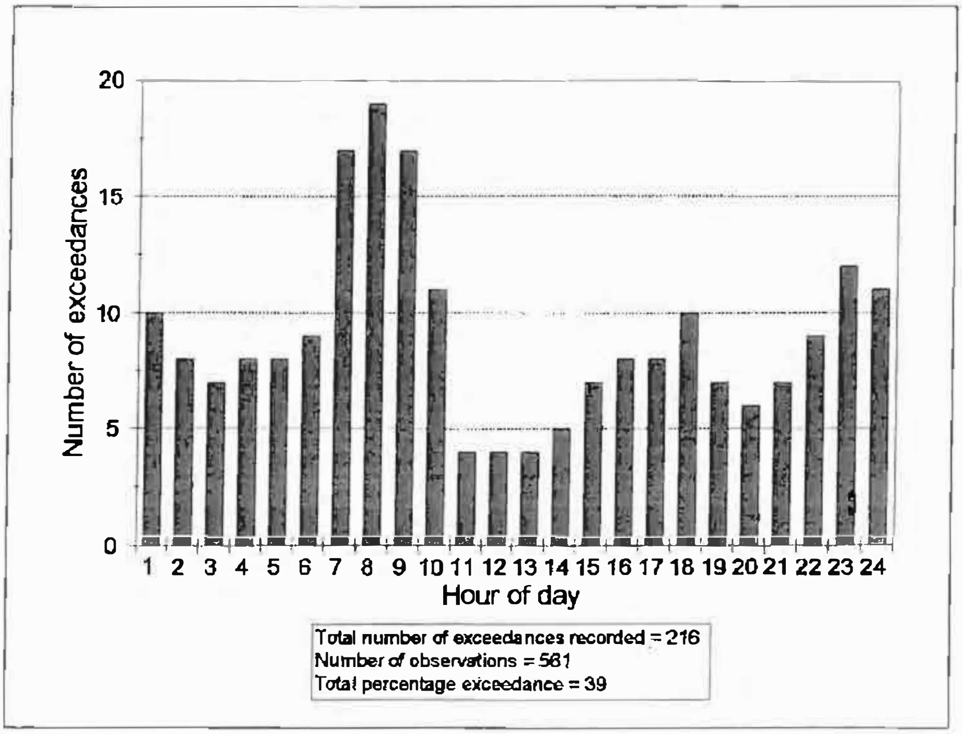
In the early morning, before sunrise, NO and NO_2 remain at low concentrations, slightly higher than the daily minimum. As human activity increases between 06h00 and 08h00, the NO level rises sharply and peaks between 07h00 and 08h00. The rapid increase is mainly associated with the traffic rush hour period, but in Pietermaritzburg also coincides with maximum stability which exaggerates the peak. Since NO reacts with ozone creating dissociation (Section 4.2), ozone concentrations remain at low overnight values.

With the increase in solar radiation, NO_2 soon forms at the expense of NO. Turbulent mixing during the fumigation enhances the rate of this reaction over Pietermaritzburg causing the rapid decline of NO from 08h00. The ratio of NO/NO_2 also diminishes during the mid-morning as NO_2 reaches a peak between 09h00 and 10h00. By the time NO/NO_2 ratio reaches its minimum, ozone is forming rapidly. As a general rule, the smaller the ratio, the greater the possibility for ozone formation which is also assisted by the increasing ultra-violet intensity towards midday.

As solar intensity decreases and vehicle traffic increases in the late afternoon, the concentration of NO again rises to a secondary peak between 17h00 and 18h00 and another at approximately 23h00. The earlier peak is a direct result of traffic emissions but is restricted because this is also the time of day when maximum instability occurs in Pietermaritzburg. The later peak occurs when the atmosphere has become more stable and the inversion is beginning to develop through katabatic flow. Ozone levels decrease rapidly as it dissociates in the presence of NO to form molecular oxygen and NO_2, resulting in a secondary NO_2 peak at approximately 19h00.

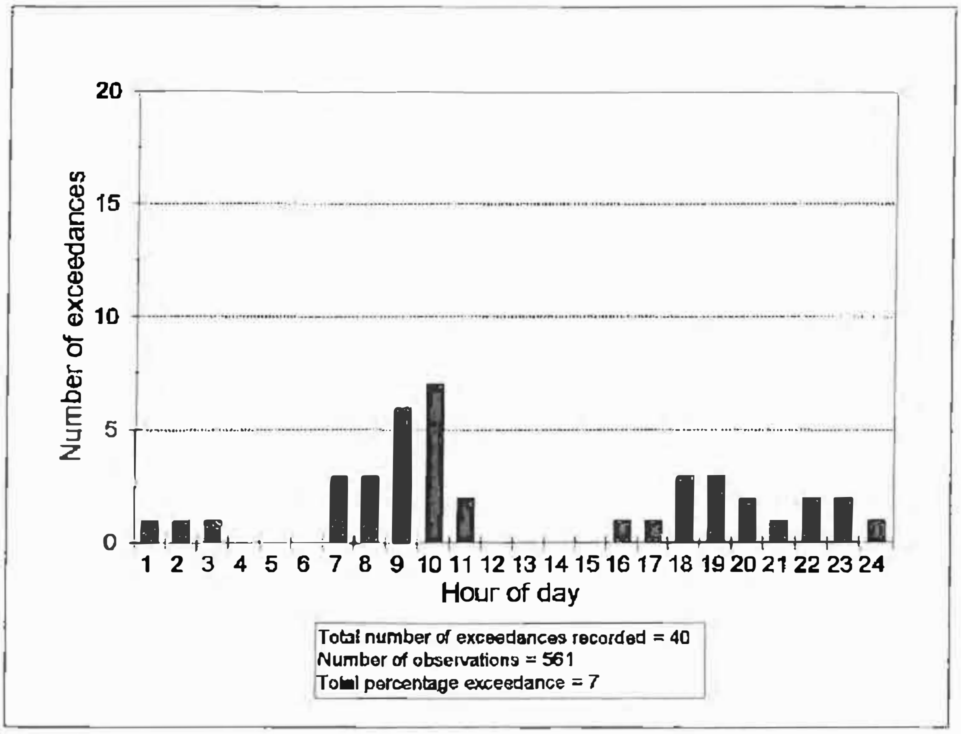
Fig. 63 is thus a text-book example of the diurnal variation of ozone and its precursors except for slight modification by the local climatology and lower levels for all pollutants because of the lower traffic volumes in Pietermaritzburg than in cities such as Los Angeles. The NO_2 trend is also flatter than expected and levels are probably lower than they should have been. Unfortunately, the chemical converter in the analyzer was beginning to fail which would have the effect of lowering these concentrations in relation to NO. The technical description of the Dasibi NO_X analyzer in Chapter Two clarifies this.

Time exceedance diagrams for the four week period chosen for NO_X analysis reveal the same diurnal trend (Figs. 64 and 65). Nineteen out of 28 possible exceedances of the 15 ppb



Total number of exceedances recorded = 216
Number of observations = 561
Total percentage exceedance = 39

Figure 64(a): Nitric oxide time-exceedance diagram for the four-week period between 18 August and 12 September 1993; 15 ppb threshold level.



Total number of exceedances recorded = 40
Number of observations = 561
Total percentage exceedance = 7

Figure 64(b): Nitrogen dioxide time-exceedance diagram for the four-week period between 18 August and 12 September 1993; 10 ppb threshold level chosen because of probable instrument under count.

threshold level for NO were recorded during the eighth hour of the day, representing the primary peak NO concentrations. It is notable that the second highest frequency of exceedance occurs at 23h00, with the third highest at 18h00, in agreement with the explanation above.

A lower threshold level of 10 ppb was chosen for NO_2 because of the technical problems experienced with the instrument. However, the trend from hour to hour is still valid, showing the greatest frequency of exceedance at 10h00 and the secondary peak between 18h00 and 19h00 (Fig. 64).

No long-term trends or seasonal variation of NO_X could be obtained because of the technical problems, but maximum hourly and daily levels of the parameters can be compared to air quality standards. The highest hourly average of NO was 68 ppb from 07h00 to 08h00 on 19 August and the highest daily average was 23 ppb on 12 September. Both concentrations are significantly below the South African guideline concentrations of 600 ppb and 300 ppb respectively. Similar results are found for the dioxide, with the maximum hourly average recorded at 17 ppb from 09h00 to 10h00 on 19 August and a maximum daily average of 10 ppb on 20 August. These, too, fall well within the applicable guidelines of 200 ppb and 100 ppb respectively. One can speculate that higher levels may have been recorded in the winter of 1994, but it is still highly improbable that any levels would increase sufficiently to exceed the guidelines.

According to the limited amount of NO_X data that were recorded, ambient local levels of this pollutant are low by international standards. However, it is necessary to collect more long-term data before any final conclusions can be made about nitrogen oxides pollution in Pietermaritzburg.

4.3.5 Ozone

Much has already been said about ozone in prceeding sections. It is now clear that ozone is a secondary pollutant, largely dependent for its formation upon the concentrations of NO_X, or more specifically, the NO/NO_2 ratio. The basic reactions leading to the formation of ozone were given in Section 4.2.

Real-time ozone levels were recorded for all months of the study period, except for October 1993. A synopsis of the data is presented in Fig. 65.

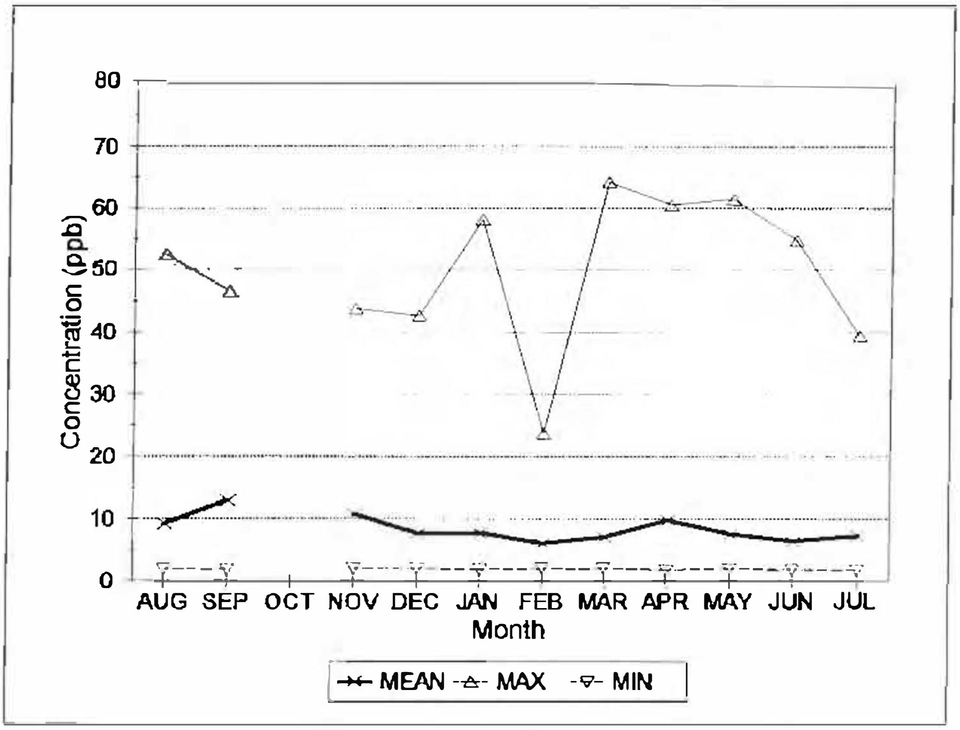


Figure 65: Mean, maximum and minimum hourly ozone concentrations recorded in central Pietermaritzburg from August 1993 to July 1994.

No significant seasonal trend is evident from the mean monthly ozone concentrations, although there is a slight peak during the spring and autumn months. It is likely that the combination of factors required for the formation of ozone were optimal during these months, ie. high ultra-violet radiation and an abundance of reactants. Minimum hourly concentrations are all low and vary little because of the dissociation that occurs diurnally in all seasons.

Maximum hourly concentrations show an increase during late summer and autumn. The concentration for February is an exception to this trend and is due to condensation occurring on the inlet filter of the instrument, greatly reducing the sample volume, and causing low readings.

Ozone exceedance of a 15 ppb threshold limit for each hour of the day is plotted in Fig. 66 (a), (b) and (c) for August 1993, January 1994 and July 1994 respectively, to supplement the existing information. The overall number of exceedances for each of the three months was higher in the two winter months, but this gross number does not take into account the total number of hours the graph is based upon. Only 390 valid hours of ozone data were collected in January 1994, as opposed to 681 in August 1993 and 668 in July 1994. The data loss in January was a result of electrical storms which upset the analyzer.

Nevertheless, the trends shown from hour to hour within each month are still useful. The greatest number of exceedances was recorded between 13h00 and 16h00 for both winter months while the summer month exhibits a slightly earlier peak. The increased sunlight intensity earlier in the day explains this difference. At the other extreme, very few or no exceedances are recorded between 06h00 and 09h00 when NO concentrations are high, prohibiting ozone formation.

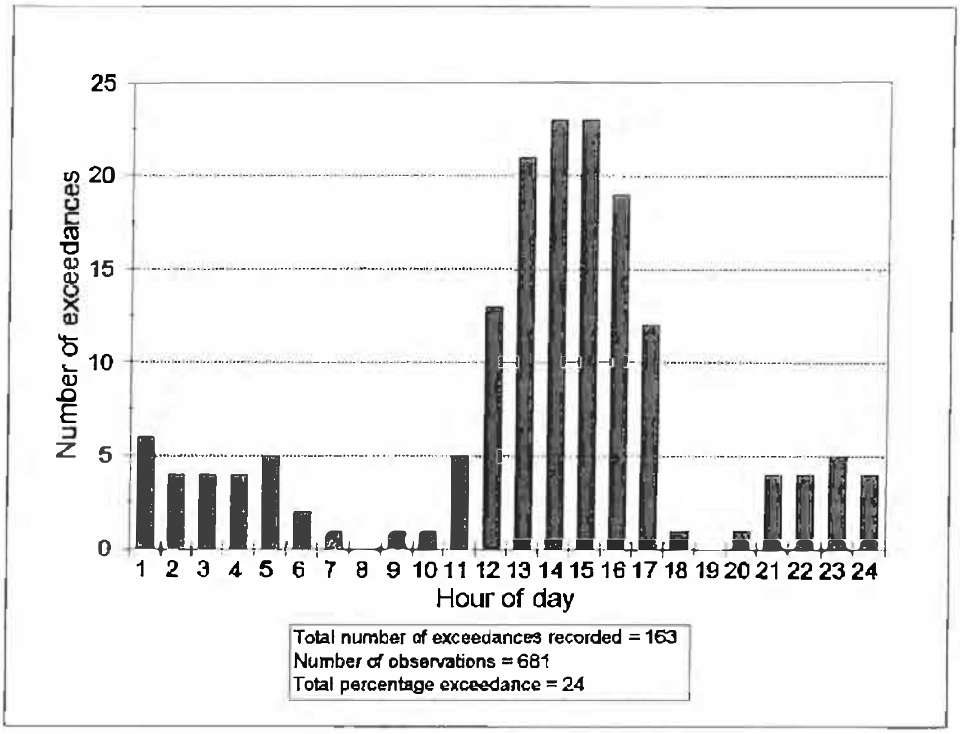


Figure 66(a): Ozone time-exceedance diagram for August 1993; 15 ppb threshold level.

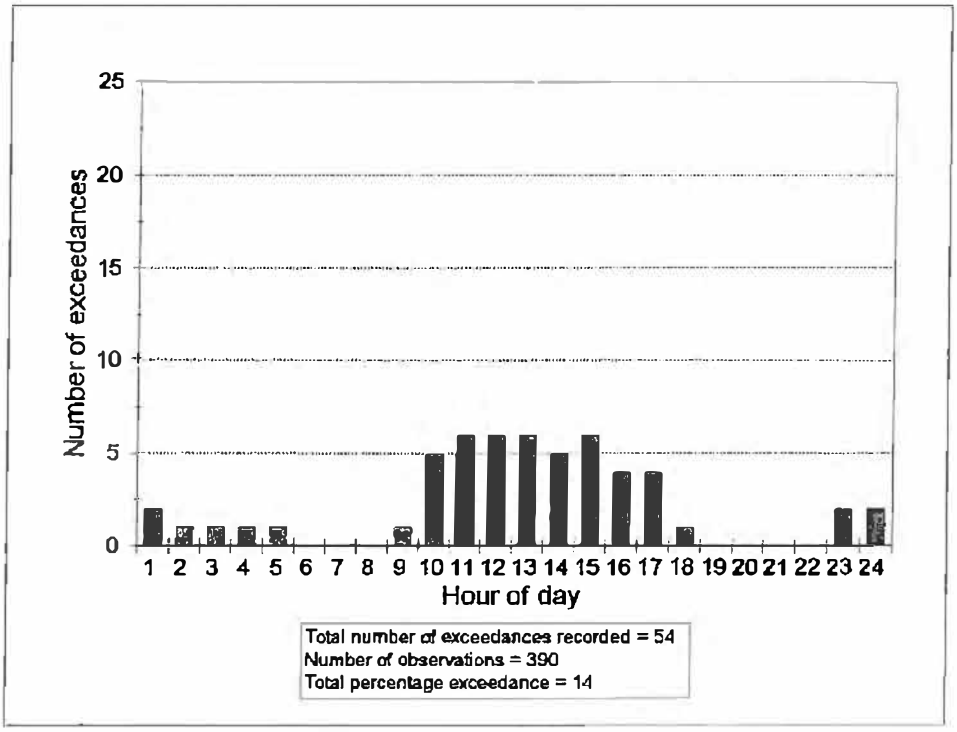


Figure 66(b): Ozone time-exceedance diagram for January 1994; 15 ppb threshold level.

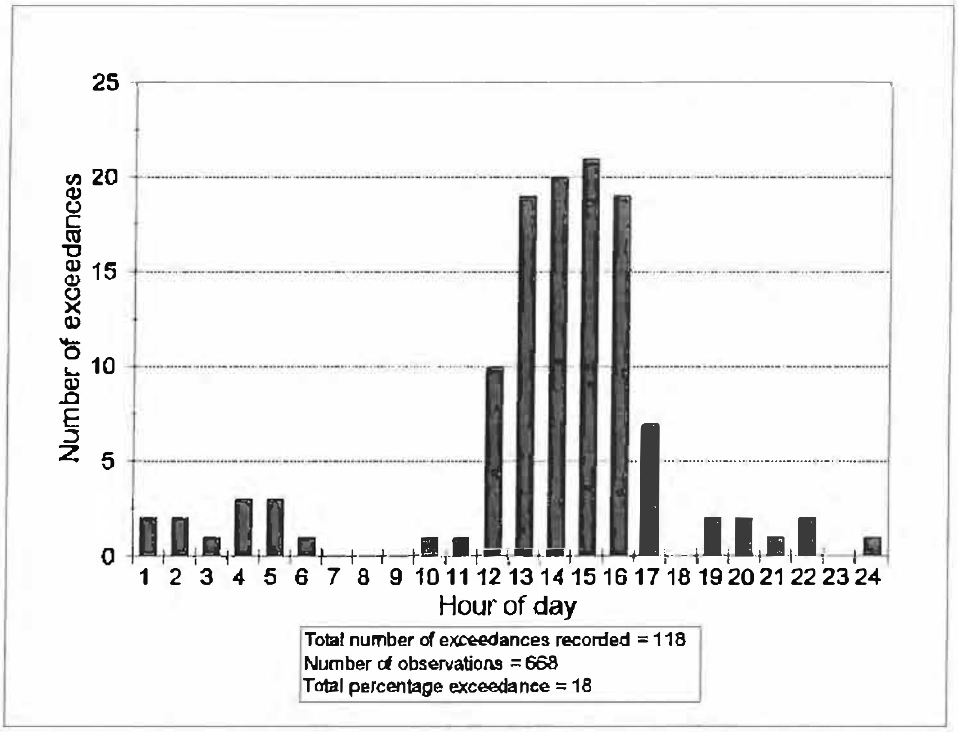


Figure 66(c): Ozone time-exceedance diagram for July 1994; 15 ppb threshold level.

To assess the recorded ozone concentrations in terms of guidelines, it is best to use hourly averages as high oxidant formation in the urban atmosphere occurs in short-lived episodes. The use of long-term averages is not representative of either the concentrations created nor their variations (Bridgman, 1990).

At least one hourly average ozone concentration over 60 ppb was recorded for each of the months March, April and May 1994. The highest concentration was 64 ppb between 16h00 and 17h00 on 23 March 1994. All of these readings represent over half of the acceptable limit in terms of the South African guideline which is set at 120 ppb for hourly averages. The WHO standard is more stringent, at 75 to 100 ppb, but is a time-weighted average.

Ozone concentrations are thus relatively high for a small city such as Pietermaritzburg, especially in relation to the low levels of NO_x. The concentrations must therefore be attributed to local climatological factors such as high sunlight duration and intensity, and the preponderance of stable atmospheric conditions. Growing evidence of damage to plant crops at levels as low as 50 ppb highlights the need to monitor this pollutant carefully in Pietermaritzburg, which is situated in one of South Africa's prime agricultural areas.

4.3.6 Lead

The debate on possible health effects of airborne lead pollution has continued over many years. It is argued in a paper by Gething (1990) that for the majority of people, food and water are the major contributors to body-burden and that lead derived from air makes only a minor contribution.

However, there is still great concern over lead in urban air, 90 percent of which is derived from motor vehicles (Gething, 1990). Stationary point sources such as smelters and furnaces contribute only the remaining ten percent but may be the major contributor in localised areas. It is therefore important that lead monitors be sited appropriately if one is trying to assess the contribution of airborne lead to blood lead levels. Monitors must be sited where people spend most of their day.

The lead monitoring site in Pietermaritzburg is at Publicity House (immediately adjacent to the monitoring laboratory) where there is similar equipment to that used for smoke measurement. Filters are changed monthly and sent to a central national laboratory for analysis of lead content. The results of these analyses since the monitoring began are presented in Fig. 67.

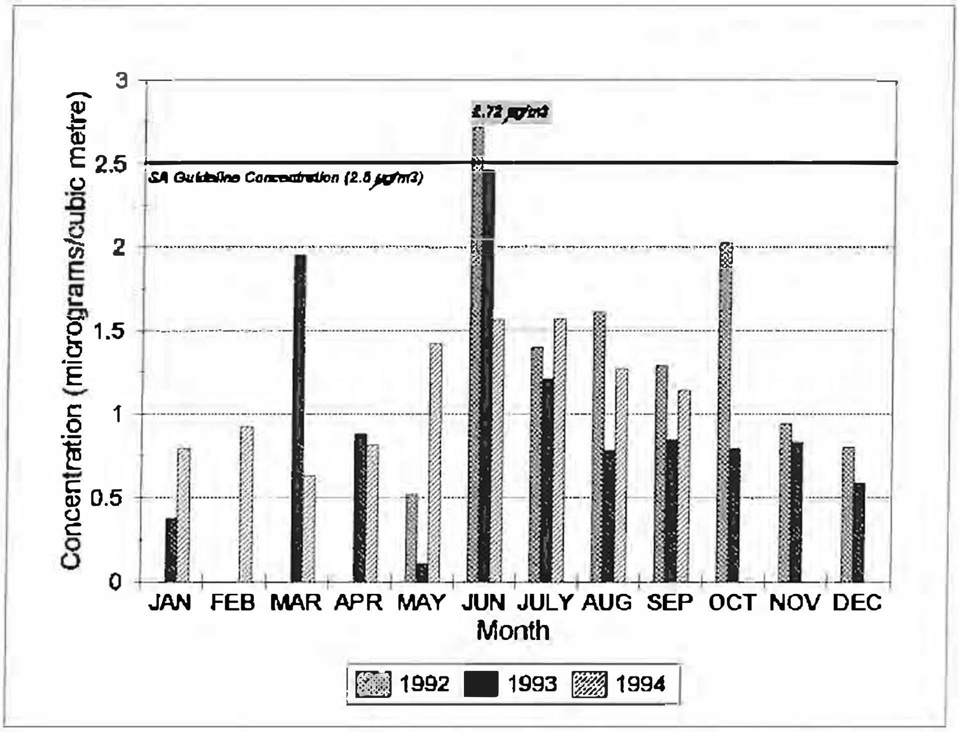


Figure 67: Monthly average lead concentrations recorded in central Pietermaritzburg from May 1992 to September 1994. Monitoring is on-going.

It is apparent that the levels are generally high, even with respect to the relevant South African guideline concentration of 2.5 $\mu g/m^3$. The highest monthly average of 2.72 $\mu g/m^3$ recorded for June 1992 clearly exceeded the safety level. It has been argued that the analysis technique prior to 1994 was inaccurate and that since the city joined the national monitoring programme, the results from the analyses have been lower. However, levels over 1.5 $\mu g/m^3$ were again recorded for June and July 1994. When compared with the USEPA standard of 1.5 $\mu g/m^3$ as a three monthly mean, the winter months of June, July and August exceed this standard in 1992 (1.91 $\mu g/m^3$) as do May, June and July in 1994 (1.52 $\mu g/m^3$). The average for June, July and August 1993 is only marginally less than the USEPA guideline at 1.48 $\mu g/m^3$.

The situation does not look any better when comparing levels in Pietermaritzburg to those in other cities participating in the national lead monitoring programme (Fig. 68). Pietermaritzburg has the highest ambient lead levels for four of the six months shown, even greater than those in Johannesburg and Pretoria.

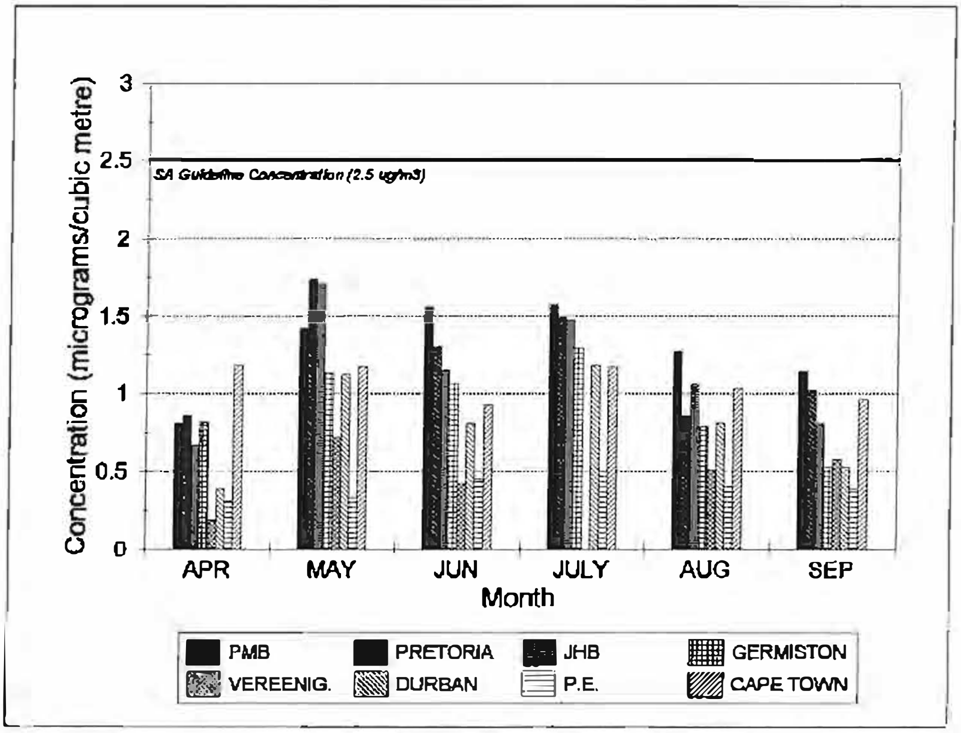


Figure 68: Monthly average lead concentrations during 1994 for eight urban centres participating in the national lead monitoring programme.

It may be argued that different results will be obtained depending upon where the lead monitor is located. Pietermaritzburg's monitor is located next to the busiest traffic intersection in the city and records a worst-case scenario. Nevertheless, the monitors in the other urban centres are also located next to busy roads, so there is a genuine problem.

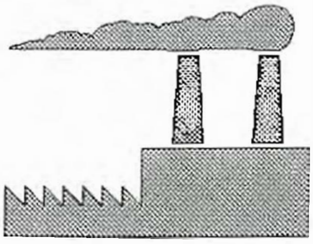
The source of the problem is lead in petrol, combined with a relatively high traffic volume and again, the local atmospheric dispersion. But all of the other cities in Fig. 68 also have large amounts of traffic burning leaded petrol, so the local problem must be a consequence of stagnation of the atmosphere during the winter months as is evident from the high winter lead levels.

It is therefore undeniable that lead is an air quality threat to the local population and was the subject of two recent newspaper articles (Anon, 1994a, 1994b). Whether these airborne concentrations constitute a health risk, and how they can be reduced is discussed in Chapter Five.

* * *

Air pollution levels in Pietermaritzburg have now been described through analysis of the current data in the context of local dispersion climatology. It remains to assess the implications of these findings in order to formulate planning proposals to improve the atmospheric environment.

Chapter Five



Implications for Environmental Planning

5. IMPLICATIONS FOR ENVIRONMENTAL PLANNING

5.1 POLLUTION EFFECTS

There is much controversy over the environmental implications of ambient air quality, particularly in South Africa where little research has been conducted in comparison with the Northern Hemisphere. Such uncertainty is further complicated by the adverse dispersion climatology of Southern Africa and lack of knowledge about resources that could potentially be affected by air pollution.

Against this background of uncertainty and complexity, it is extremely difficult to answer the question that is so often asked, *"How polluted is the air?"*. The lack of a simple answer allows for such unsubstantiated claims as, *'Noxious nights'* (Anon, 1991) and, *'Residents choking on the city's smog'* (Anon, 1992) to be printed in the local newspaper. During the current study, an attempt has been made to establish the *status quo* scientifically by gathering all information possible to assess air quality over Pietermaritzburg as objectively as possible.

Sufficient evidence has been presented in preceding chapters to state that atmospheric pollution in the Greater Pietermaritzburg area is a problem which does have a negative effect on the resources of the region. The extent of the problem is debatable. Long-term levels are not high for any of the pollutants monitored, but there are episodes when concentrations for certain pollutants become unacceptable. Peak pollution episodes most often occur in winter because of the poor local dispersion climatology as identified by real-time monitoring.

To show a worst case scenario, the highest hourly levels of the gaseous pollutants that were recorded during the entire 12-month study period are plotted against the South African guideline concentrations and the World Health Organization time-weighted average standards (Fig. 69). All levels are acceptable in terms of both standards, although it is clear that for sulphur dioxide the South African guideline is very lenient, even when the time weighting is considered (Appendix 2). Comparing local maximum sulphur dioxide and ozone levels to the WHO standards shows that they are still little more than 50 percent of the standard, while both

NO_X concentrations are approximately only 10 percent of the applicable SA guidelines.

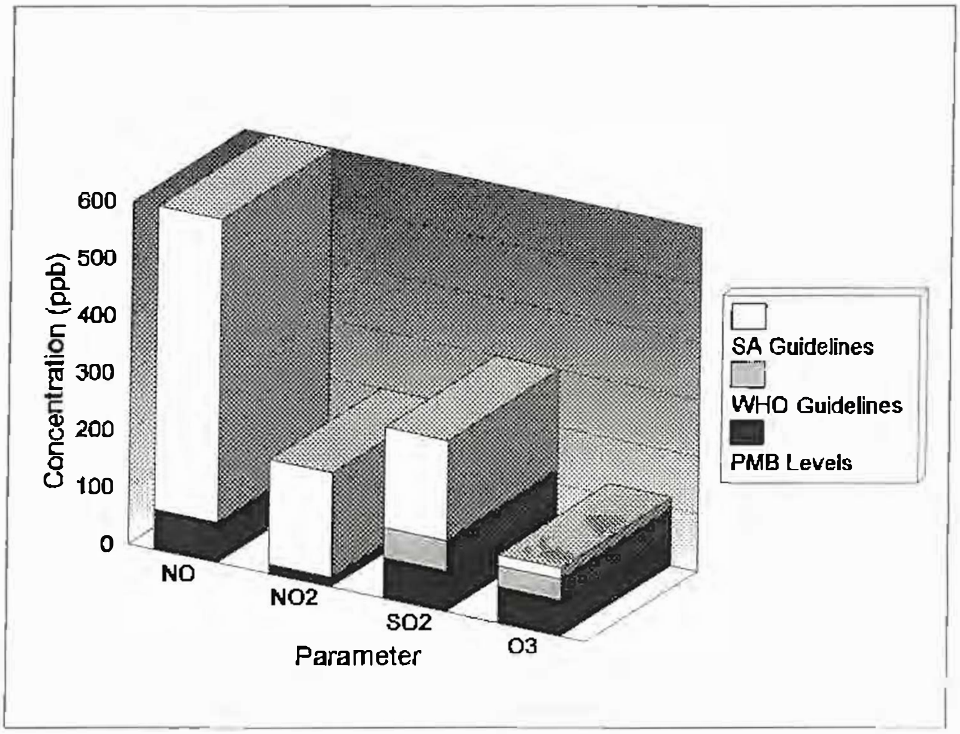


Figure 69: Maximum hourly gaseous pollutant concentrations recorded from 1 August 1993 to 31 July 1994, compared with South African guideline concentrations and World Health Organization time-weighted standards. WHO standards for NO and NO_2 are roughly equivalent to SA guidelines.

However, standards and guidelines are not the last word in air pollution. Maximum hourly concentrations of sulphur dioxide and ozone for each day of the study period show that local concentrations do exceed threshold values that are considered to be phytotoxic (Figs. 70 and 71). Occasional exceedances of the 50 ppb ozone threshold limit occur during most months as a result of ozone's status as a secondary pollutant. Exceedances of the 35 ppb sulphur dioxide threshold limit occur only in winter, and were frequent during June and July of 1994 as a consequence of the climatic conditions described.

A further consideration is that when high levels of gaseous pollutants occur simultaneously, there is much interaction among themselves and with other environmental factors causing stress (eg. high humidity or lack of precipitation). Such combinations cause a synergistic increase in the overall impact of the pollution episode. There are also many pollutants and airborne

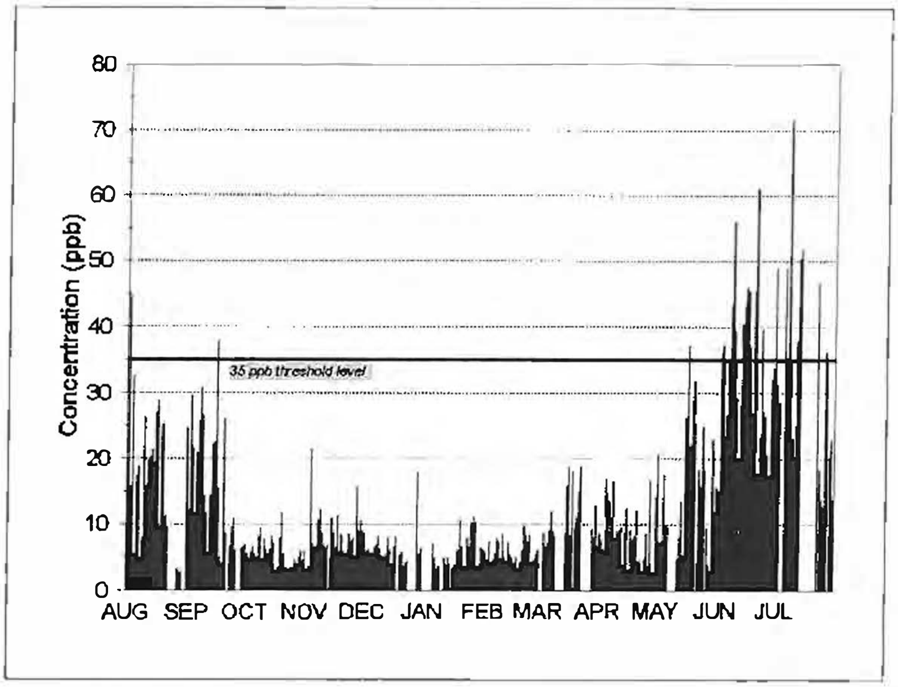


Figure 70: Daily maximum hourly concentrations of sulphur dioxide recorded in central Pietermaritzburg between 1 August 1993 and 31 July 1994. Negative effects on some plant species can be expected with periodic exposures at concentrations exceeding 35 ppb.

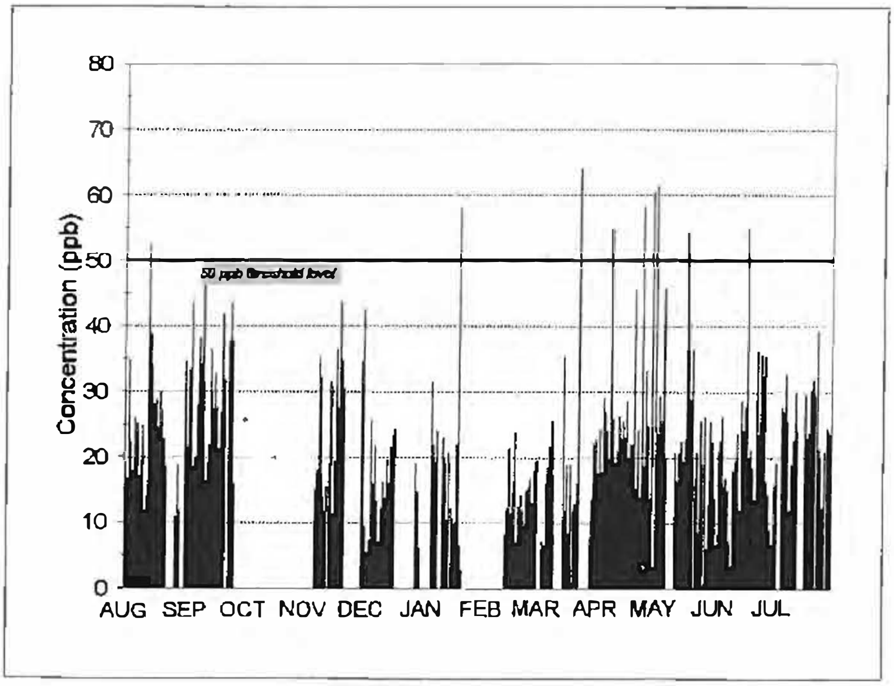


Figure 71: Daily maximum hourly concentrations of ozone recorded in central Pietermaritzburg between 1 August 1993 and 31 July 1994. Negative effects on some plant species can be expected with periodic exposures at concentrations exceeding 50 ppb.

irritants not being monitored, whose effect can enhance the negative impact on organisms, processes or structures of concern.

The threshold values used in Figs. 70 and 71 apply to plant species, but the main concern of urban residents is the impact of air pollution on human health. Air pollution as a health threat is acknowledged to be a major environmental problem in industrialized regions, and is of great concern to the Pietermaritzburg public, as identified by letters to the press and the report by a local medical practitioner (Kirkby, 1992). But great difficulties face health specialists in making such evaluations. The health effects of ambient atmospheric pollution are confounded by the effects of tobacco smoking, occupational exposure to pollutants, exposures in the home, and to other airborne allergens. Much research in the Northern Hemisphere has therefore focused on children to eliminate some of the confounding factors, or has used personal exposure monitors to include all sources (Anon, 1983). Even then, there are such a multitude of other factors that affect an individual's health, that results obtained from dose-response studies have often been contradictory and inconclusive (Holland *et al.*, 1979).

Probably the best research to date on the health risk of air pollution in South Africa was the Vaal Triangle Air Pollution Health Study, conducted by the Medical Research Council, The Department of National Health and Population Development and the CSIR. After three years of monitoring respiratory illness in 11 000 children, in relation to ambient air pollution levels and personal exposure levels, it was concluded that, *'The air pollution in the Vaal Triangle is adversely affecting the health of the population'* (Terblanche, 1992). Supplementary studies by Annergarn (1993) indicate that particulates from household coal burning and dust were largely responsible.

Any conclusions about health effects of air pollution in Pietermaritzburg must therefore be based on carefully designed research, as local ambient particulate levels are unlikely to demonstrate measurable effects on lung function. Links between pharmaceutical sales and respiratory illness are also tenuous as a base for sound conclusions. However, both strategies highlight the need to address air quality in Pietermaritzburg as public opinion is in itself enough reason to take action, even if ambient levels are classified as 'acceptable'. The claims of the majority cannot be disregarded in the quest for a healthier environment.

There is also much public concern over damage to the aesthetic value of the city. This concern is certainly justified by Figs. 5 and 9 which attest to the scenic ruin caused by particulate haze.

Many other effects of pollutant exposures could be discussed, such as effects on structures, soils, forests, agriculture and ecosystems, but are well documented in existing literature for areas already seriously affected. Attention must rather be paid to alleviating the problems before they become critical, so the remainder of the thesis is devoted to solutions in the form of air pollution control policy and planning for cleaner air. There is still time in Pietermaritzburg to implement proactive abatement policies that can preclude the need for remedial damage control.

5.2 AIR POLLUTION CONTROL POLICY

The management of Pietermaritzburg's atmospheric resource is inextricably linked to air pollution control policy on a national scale through the Atmospheric Pollution Prevention Act and its administrative structure described in Chapter One. Any significant progress in the local context therefore hinges largely on the national situation.

5.2.1 National legislation

> *'It is clear that waste and pollution are being generated, as a consequence of normal industrial activity, at levels hitherto unrecognized, and disproportionate to those arising from similar practices in other countries. Air pollution is no exception to this trend.'*
> (Petrie *et al.*, 1992)

Air pollution control policy in South Africa has thus been widely criticized over the past decade. Criticism has come from every sector of society including academics, environmental consultants, politicians, economists, the medical profession, the public and even industrialists.

Regions of particular concern have been identified in the general background to this study and with the evidence subsequently presented, it can be argued that Pietermaritzburg should join this list.

There are a number of reasons why the current control measures are inadequate, as identified by Petrie *et al.* (1992) and Scott and Bothma (1993).

- The present management of the environment is fragmented, especially regarding pollution control. Because of this, no single state institution is capable of monitoring the application of policy on an ongoing, integrated and holistic basis. Each department involved in environmental management is protective of its preserve and resents the advice of others. The result is an insular, compartmentalised approach to a series of problems that require a cooperative and holistic approach.

- The best practicable means (BPM) policy relies heavily upon the subjective evaluation of pollution sources by the chief officer, in consultation with industries concerned. Registration certificates are issued subsequent to this evaluation which in effect establishes the right to pollute. As judicial control over these decisions is minimal, they are seldom contested.

- Information on all forms of pollution and pollution sources has not been freely available to the public. Official secrecy or lack of effective communication has permitted industrial compliance with existing legislation to escape scrutiny until, in some cases, the situation became severe.

- The Department of National Health and Population Development is itself incapable of monitoring compliance with guidelines. An inadequate number of pollution inspectors are employed, training methods do not keep pace with industrial process development, and access to monitoring equipment is limited.

- Penalties imposed on offenders are pathetically trivial, providing little motivation for inspectors and making it easy for industries to deviate from the conditions of their registration certificates. Inspectors are unlikely to be able to convict an offending industry, and even if they succeed, the penalty imposed is an insufficient deterrent. Payment of the fine is vastly cheaper than the cost of abatement equipment.

- The Atmospheric Pollution Prevention Act has several loopholes which allow industries to deviate from the conditions of the certificates. Technical breakdowns, installed technology not meeting design specifications and economic constraints impinging on company viability all favour poor environmental accountability on behalf of the industrialist.

Many of the above failures can be explained in terms of resource economics, which also provides a rational approach to finding appropriate solutions in South Africa's new environmental and economic circumstances. Assuming that urbanisation will continue on an immense scale for at least the next decade, it is imperative that more effective ways are found of controlling the accompanying air pollution problem. Effective air quality management requires the successful blend of technological inventiveness, legal constraints, economic incentives and political willingness (Preston-Whyte, 1989). The first and the last of these should no longer be a problem, but the balance of command-and-control regulations with economic incentives is more intricate. Much can be learned from the experience of others, such as the United States Environmental Protection Agency (Preston-Whyte, 1989) and the European Economic Community (Langston, 1990). Both organizations have evolved environmental policies with varying degrees of success and are now well-advanced compared with those of South Africa.

The following theory forms the basis of the new international approach to pollution control. Production of goods and services in cities generates not only internal costs and benefits, but also external costs that are seldom taken into account. People often do not perceive the links between their consumption of some commodity and the damage that is inflicted on the environment or themselves through the production or consumption of that commodity. Stauth and Baskind (1992) argue that it has only recently become clear that environmental costs are a major consideration in determining whether a proposed resource use is worthwhile. The present system of control in South Africa actually makes it profitable to pollute since the manufacturer is only required to pay the cost of production, while external costs are passed on to the consumer.

Three premises have been derived to take account of environmental costs in the evaluation of proposed resource uses (Stauth and Baskind, 1992).

(a) Whether and to what extent the total benefits would exceed the total costs.
(b) The extent to which different individuals would be made better or worse off.
(c) The extent to which future generations would be made better or worse off.

The policy goal of these premises is to achieve the highest possible level of human well-being over a time period spanning multiple generations (Stauth, 1989). It is based on the utilitarian assumption that both economic progress and environmental quality are needed to improve human well-being. From this goal and the three premises, three criteria can be derived which should be used as tests when any resource management decision is made: efficiency, equity and sustainability.

While the discussion may have digressed slightly from the central issue of national air pollution control policy, it has demonstrated why the atmosphere is a valuable resource that must be incorporated into economic equations. Cost-benefit analysis is one of the most accepted and widely practised methods of resource evaluation. Unfortunately, it is also flawed because of the problem of valuing common property resources. For example, how does one place a value on the pollution capacity of the atmosphere; a typical common property resource that gets abused simply because no one person owns it? No individual is sufficiently motivated to protect clean air on a purely economic basis, which leads to an inefficient use of the resource and gives rise to environmental problems, or more specifically to the current study - air pollution.

When the market mechanism fails to ensure the efficient use of common property resources, it is necessary to establish other mechanisms to make people accountable for how they use them. Best practicable means was an attempt at such a mechanism, but it is no longer adequate and is in need of replacement. The reluctance to change to more rational ways of meeting economic and environmental needs stems from individuals and firms having long enjoyed the privilege of dumping pollutants freely in the atmosphere.

There is no single solution to this problem, but there are several approaches that can and must be explored soon. The United States experience described by Preston-Whtye (1989) demonstrates the need to involve industry in air pollution control through economic incentive schemes, rather than a direct 'polluter-pays' principle. Pollution charges, subsidies, marketable permits, environmental bonds and compensation are all discussed by Stauth and Baskind (1992), while the approach being taken in Pietermaritzburg will be kept for the following section.

The government has finally responded to criticism with the development of a *National Holistic Policy on Integrated Pollution Control for South Africa* (Wates and Rawicz, 1993). The Integrated Pollution Control (IPC) study is still in its infancy but is based on the presumptions that:

- there is a need for an integrated pollution control regulatory system;
- integration does not necessarily involve centralisation, but will involve cooperation;
- effects of pollution emissions will be viewed in the context of the environment as a whole;
- the cost of pollution is to be borne more directly by the polluter;
- pollution control should be based on continued attainment of agreed ambient standards;
- the implementation of the best practicable environmental option (BPEO) is dependent on adopting an integrated approach to pollution control through a single authority.

(compiled from Scott and Bothma, 1993)

From these presumptions it is clear that the government has recognized the weaknesses of the existing legislation and control structure, and looked to international experience and resource economics to find the answers. IPC will certainly rationalise the current situation and reduce the total cost and effort required to achieve national objectives in an holistic and sustainable manner. The need to involve all interested and affected parties has also been recognized to ensure agreement, or at least acceptance, of the principles and aims of the IPC. Provision has been made for both national and local dimensions, where local control will look at emissions in specific environmental circumstances. Whether this will hand control of scheduled industries over to local authorities is, however, uncertain. That particular issue could become a major stumbling block for the IPC in places such as Pietermaritzburg, where local control is essential because of the adverse dispersion conditions.

The shift towards best practicable environmental option (BPEO) is consistent with the holistic approach being proposed. Petrie *et al.* (1992) explain the difference between existing BPM and proposed BPEO to be the greater flexibility afforded by BPEO. It addresses the potential for waste elimination from a given process in the short and long-term, emphasizing the use of inherently clean technology as opposed to quick-fix, end-of-pipe solutions. The sustainability criterion is therefore more adequately met by BPEO.

A final aspect of sustainable development that needs to be considered in the South African context is the relationship between poverty and environmental degradation, as discussed by Harvett (1994). The alleviation of poverty can reduce environmental deterioration directly, by reducing pressure on critical resources exploited by the poor, as well as indirectly, by reducing the high population growth rate which is correlated with poverty. Upliftment of the poor is therefore highly pertinent to issues such as air pollution in townships (the primary environmental concern of the ANC), and must be embodied in the implementation of effective environmental policies.

In conclusion, there are great environmental and economic tasks facing South African policy makers in the nineties and beyond. A dramatic improvement will not happen overnight, and partnership between state, industry and the public is essential if any new policy is to succeed.

5.2.2 Local implementation

Change at the national level obviously has a strong bearing on what can be achieved at local level. By the same token, successful resolution of problems at the local scale can influence the formulation of national policies.

Having worked with the Pietermaritzburg City Health Division for three years, the writer has become familiar with the frustrations of the local air pollution inspectors in dealing with the city's air pollution. As part of the local authority, they must not be seen to perturb industrialists, who bring employment and economic prosperity to the area, but are also responsible to the public, who are greatly concerned about local air quality. The situation is made more difficult by ineffective legislation in terms of best practicable means, and scheduled processes (Table 6) being out of their jurisdiction. Some local industrialists have realized the strength of their position in terms of the current legislation, and openly exploit the atmosphere (Figs. 47 and 48), knowing that there is little chance of prosecution by a relatively toothless control structure. Such abuse of the atmosphere and blatant disregard for the smoke control inspector has been witnessed first hand by the author (Fig. 72).

New national legislation will hopefully arrive soon to empower the local authorities. In the meantime, an innovative approach is being taken by a group of concerned citizens which may prove to be the best solution yet. One of the city councillors, who is particularly concerned about air pollution in Pietermaritzburg, invited a wide range of people, from staunch environmentalists to industrialists, to attend a 'Pollution Breakfast' at the local country club. The time and venue were chosen to get a clear picture of the hollow blanketed by morning smog. In spite of the lack of support from the city council, the meeting went ahead and proved to be both constructive and amicable (Appendix 3). From this initial meeting emerged a core group of people to take the notion forward, known as the Interim Steering Committee on Pollution.

The aim of this committee is to call a public meeting to hear the sentiment of the populace concerning air pollution in Pietermaritzburg. A representative committee will then be formed

Figure 72: Black smoke belching from a stack in the Willowton area photographed after complaints from local residents. The emission continued for a longer period than is acceptable in terms of legislation (10 minutes), but permission to inspect the source was denied on the grounds that it was 'not convenient'. The case continues but a successful prosecution is unlikely as no complainants are willing to declare *locus standi*, ie. a direct personal interest in the matter because of the risk of losing in court.

with the aim of improving the local air quality in cooperation with industry and the City Health Division. Whether or not this initiative succeeds depends largely on the motivation of individuals and the cooperation of industry. Good progress has already been made with one of the city's largest industrial concerns (PG Bison) offering to sponsor an independent ambient air and stack monitoring programme. If such cooperation continues by including all parties in the process, there is a good chance of success, and a win-win situation for both resident and industrialist.

The sole incentive for industrialists to become involved is immense public pressure demanding transparency and accountability. Pietermaritzburg wants industry and employment, but not at the expense of clean air. A fund idea to pay for clean air has even been suggested to assist industries in implementing clean technology (Anon, 1993). Such policies are in line with international thinking that now places sustainability and equity above efficiency; environmental ethics can no longer be pushed aside.

A local solution is being sought for a local problem, but there are much wider implications if this cooperative process succeeds.

5.2.3 Monitoring

Pietermaritzburg's air pollution monitoring programme has been the target of much criticism over the past decade. Accusations have been rife that ratepayers' money is being used without producing results. The purchase of the real-time monitoring laboratory did little to help matters, being plagued by problems from the outset. This culminated in the roof being blown off and the meteorological mast broken by a severe storm in 1992. In short, its track record was very poor for the first three years of operation and most councillors wished it had never been purchased.

However, it must be appreciated that the atmosphere is a most difficult laboratory in which to work. The instrumentation required for real-time monitoring is sophisticated and expected to run continuously for long-term data collection. A simple analogy would be driving a prototype motor car continuously for several years and expecting no components to fail.

The experimental days are now thankfully over, and local skills are being employed to operate and maintain the equipment with a good reliability of data collection (Table 5). Maintenance procedures will be further refined as the people involved become more experienced and down-time will be reduced to acceptable percentages. Some parameters are still not functional, such as the methane and non-methane hydrocarbons analyzer, but are being attended to, and will be operational for future winter seasons. It has been decided to run the Byron instrument only periodically, during potential peak times in concordance with NO_X levels, because of the high cost of instrument grade gases that are continuously consumed. The money thereby saved can be channelled into more appropriate particulate monitoring; the true gravimetric measurement of total suspended particles is recommended from the findings of this research. It is also recommended that collected particulate pollution is analysed for the presence of trace elements to ensure that all potentially hazardous pollutants are monitored.

Monitoring of smoke and sulphur dioxide at the six existing monitoring stations must continue as they provide valuable data on a long-term and spatial basis, in addition to their necessity for the national monitoring programme. It is advisable to consider upgrading these stations to the automated multi-port versions so that peak concentrations are more accurately monitored. Twenty-four hour monitoring periods proved ideal during tests in July and August of 1994 (Chapters Two and Four) and would significantly enhance the temporal and spatial model of pollution over Pietermaritzburg. Measurement of the wind fields and vertical temperature profiles at some of these sites should also be considered to relate the pollution levels obtained to dispersion potential. As a long-term goal, the air pollution potential of the Greater Pietermaritzburg area should be modelled on computer, such that the impact of any new source of pollution at a certain site could be predicted and quantified. Accurate decisions could then be made about the location of industries, roads or any potential pollution threat, based on all considerations - economic, social and environmental. The latter has too often been omitted by decision makers in the past, largely through a lack of information and cooperation.

Monitoring air pollution does not clean the air, but it is the only way to find the balance between economic growth and environmental protection in a developing economy. The knowledge thereby acquired is invaluable for the sustainable management of the atmospheric resource.

5.3 PLANNING FOR CLEANER AIR

5.3.1 Industry

Industries are perceived to be the main culprits of atmospheric pollution in Pietermaritzburg. The validity of this perception is questionable without source inventories, but it can be agreed that their contribution is significant and highly visible. The high visibility of industrial emissions is firstly because they are by nature point sources, and second, because of their location within the hollow. Industry needs flat, level ground, which is found in Pietermaritzburg along the floodplain of the Msunduze as described in Chapter One. The residential areas are largely located on the surrounding hillslopes which gives residents scenic views over the city, but also of the smoke plumes from industrial stacks. Corobrik and PG Bison are most exposed, being visible from almost any suburb in the hollow, and have consequently been the focus of public criticism for many years. Industries further to the north-east of Willowton are more hidden behind a small ridge, and have been lucky to escape criticism until recently, when the anger of the Mountain Rise and Northdale residents has surfaced. Some of these hidden industries are, not surprisingly, amongst the worst offenders.

The question now arises how to ease industrial air pollution in Pietermaritzburg. It is impossible to modify the local climatology which is the root of the problem, and would be foolish to force existing industries to relocate outside of the hollow as has been suggested by more radical factions (Anon, 1986). This would merely shift the problem to a new location, and in the process devastate the city economically. The fact has to be faced that industries are already in the city hollow and will remain and grow in their present locations for the foreseeable future. The interdependence of industry, infrastructure, labour and markets is too great to be broken as was demonstrated by the failure of the former government's border industries policy. A city always provides the best home for industries because of the diverse support structures that it intrinsically offers.

Options for *in situ* solutions therefore need to be examined. The building of tall stacks does not offer a solution in the local situation, and is no longer a popular option internationally because of the implications for long range atmospheric transport. Each industry that contributes to air pollution needs to evaluate its process and emissions in cooperation with the City Health Division and independent consultants. Emissions need to be compared with international standards for the relevant process (eg. brick making, wood processing) in the light of local dispersion potential. Such evaluation may require stack monitoring, further ambient air monitoring and climatological information to decide what action needs to be taken. In most cases it is likely that suitable scrubbing equipment or cleaner process technology is available and will have to be implemented. There is obviously a cost involved to the industrialist, but the argument that such costs would render a process uneconomical and non-viable is no longer defensible, unless proven by the industrialist. The tide has turned, and it is the responsibility of industries to prove that they are environmentally conscious and proactive, rather than the authorities trying to prove the contrary. As stated by Frederick (1990), in his introduction to *Business, Ethics and the Environment, 'when business activities cause damage to the environment, which in turn causes a certain type of harm to persons, then businesses are morally required to alleviate that harm ... by either stopping the activity ... or modifying it so as to minimise the harm it causes.'*

Apart from this ethical obligation, Henning and Wells (1993) point out that domestic industries must take account of environmental laws in the rest of the world. Exporters may find trade barriers to their products if other countries, especially competitors, see South African environmental controls as being inadequate. It is also claimed that unacceptable emissions often result from poor process control or outdated technologies, representing a waste of resources. Companies that have already achieved good environmental standards found that tighter control or implementation of newer and cleaner technology made their operation more profitable. The abatement of air pollution thus paid for itself through innovative management.

The location of future industries in Greater Pietermaritzburg must be carefully planned. It is advisable to restrict areas within the hollow to clean processes, subject to environmental impact assessments. New sources of air pollution must be avoided or kept to an absolute minimum as the local population is now sensitized to the issue and will demand stringent control measures. Any new factory must be designed so that it can harmoniously coexist with other industries and the local community. The proposed expansion of Hulletts Aluminium at Mason's Mill is a case in point - the investment and employment is obviously wanted, provided it is realized with an environmental conscience.

5.3.2 Domestic burning

The significance of the combustion of traditional fuels for domestic purposes in under-developed areas has already been indicated in Chapter One. Domestic smoke from Edendale and surrounding townships south-west of central Pietermaritzburg contributes to the smoke problem in the hollow, particularly during the winter months when the need for warmth in informal dwellings coincides with the thermal inversion over the city.

Coal burning for domestic purposes is the most important risk factor for respiratory illnesses among town dwellers. Whereas wood in the primary fuel source in rural areas, coal is the most important fuel in urban areas, providing household energy for some 15 to 20 million South Africans (Terblanche, 1992). Incomplete combustion of coal liberates large volumes of smoke and sulphur dioxide, usually in poorly ventilated shacks. Indoor air pollution levels are thus several times the outdoor ambient levels, and the exposure times are long. Personal total suspended particulate exposures for 12-hour periods in cooking and sleeping areas constituted serious health risks in the Vaal Triangle, as did maximum hourly average levels of sulphur dioxide, nitrogen dioxide and carbon monoxide. Sulphur dioxide levels exceeding 3000 ppb were recorded during cooking periods inside the dwellings, compared to the health standard of 400 ppb (Terblanche, 1992). Indoor levels will be much the same for any township in the country where coal is used for cooking and space heating.

It was commented in a previous report by the writer that a solution to the problem of domestic burning will be difficult as many township residents could not afford to replace coal or wood stoves even if electricity were made available (Simpson, 1992). Smoke as a pollution hazard is also not well recognized in black communities through lack of education and its strong traditional value. The poor success of smokeless stoves was partially a result of this attitude. However, prospects have improved over the past two years with Eskom developing innovative systems for providing electricity to township and rural dwellers. The provision of electricity to large numbers of people has also become a subsidised national priority under the Reconstruction and Development Programme, to offer an improved standard of living and alleviate air pollution. Nearly three million, or 44 percent of all dwellings in South Africa are already electrified and it is estimated that this can be doubled by the turn of the century (Lennon and Turner, 1993). Electrification is being accompanied by a substantial educational and public awareness programme to ensure the efficient and effective use of this clean source of energy.

There is still much debate about Eskom's vision of 'electricity for all'. Electricity generation is seen as both a saviour and a villain by relieving urban pollution during the winter months, yet being responsible for increasing power station emissions in the Eastern Transvaal Highveld (Petrie *et al.*, 1992). Eskom argues that the reduction in township air pollution and attendant socio-economic upliftment derived from increased urban electrification far outweighs the positive environmental benefit of an equivalent investment in power station pollution controls (Lennon and Turner, 1992). The trade off is inevitable and acceptable, providing there is a net environmental benefit in the process.

It can also be argued that electrification will result in substantial national health benefits. Viljoen (1992) has estimated that the direct costs attributable to poor health from coal-using households in the former PWV region alone, could amount to R 280 million per annum based on the cost of health care services and foregone production by employees.

Ambivalence is still present in the local context, as although there are no power stations in Pietermaritzburg, emissions from the ETH could be affecting the air and rain quality of KwaZulu-Natal as described in Chapter Four. It is, however, far less an environmental or health threat than thousands of ground-level pollution sources, although further research is necessary to substantiate this presumption. Van Horen (1993) suggests that a national programme should be established to identify the areas of major health risk resulting from the use of dirty fuels by the urban and rural poor. The lack of information for areas such as Edendale and Vulindlela certainly supports this, and the planned public meeting will hopefully begin to meet this gap in existing knowledge through community participation.

Eskom is clearly aware of all these factors, and is the best equipped and informed to make the right decisions in the long-term. Vast sums of money are spent on researching the effects of its pollution and the organization is world-renowned for its innovative approach to problems. South Africa, as a Third World country, may have to live with the so-called 'brown agenda' until at least the next century, and the debate surrounding the total benefit of electrification is but one of the implications.

5.3.3 Agricultural and veld burning

Much of the particulate pollution in Pietermaritzburg derives from veld, cane and forestry fires in and around the city limits. In the environmental section of the *Annual Report of the Medical Officer of Health* it states,

> *'the continued 'burn-off' from the green belt around the city can be regarded as one of the major sources of pollution. The fly-ash fall out is distributed throughout the borough as a primary pollutant only to be redispersed as a secondary pollutant by vehicular traffic and other factors.'*
> (Walters, 1989).

The burning occurs mainly in winter and exacerbates the smoke problem in the critical winter months. Elevated smoke levels from June to August were illustrated in Fig. 57 and the emissions from these fires are an increasing contributory factor. Fly-ash particles from cane fires of up to 20 cm in length fell on city suburbs several times during the winter of 1994.

The proportion of planned agricultural burning to accidental veld-fires is unknown, but planned burning must be controlled. The Senior Smoke Control Officer has discussed the matter with public, private and corporate landowners to restrict burning to times when prevailing winds blow away from the city and pollutants are adequately dispersed. Smoke from several kilometres out can be drawn into the hollow by katabatic flow (Fig. 73) and the responsible parties must realize the consequences of their burning under such conditions.

Figure 73: Smoke draining into the Pietermaritzburg hollow by katabatic flow from a small fire on the ridge in the centre of the photograph. The extent of forestry plantations to the north of the city is also evident as a potential source of smoke and fly-ash when waste burning takes place.

Government departments such as the Natal Provincial Administration, the Municipal Parks and Forestry Departments are equally responsible for the burning of rubbish, veld and forest waste. Alternative methods of waste disposal must be sought were possible, making use of new biological technologies that are being developed. Kleyn (1987) comments that at the very least, agricultural burning of land surrounding Pietermaritzburg must be restricted to early autunm or after the first spring rains to reduce pollution and fall in with good veld management practices.

The consultative process being initiated with industries must also involve local farmers, cooperatives and government departments to assess their contribution to atmospheric pollution and find long-term solutions for sustainable and equitable development. These criteria are currently not being met.

5.3.4 Vehicle emissions

Perhaps the greatest area of concern in Pietermaritzburg is that of vehicle emissions. It has been largely neglected in the past owing to staff shortages and the lack of suitable equipment.

5.3.4.1 Diesel

Diesel vehicles emit smoke for a number of reasons, including the inherent inefficiency of the engine and incomplete combustion owing to poor mechanical condition or incorrect engine adjustment (Dept. of Health and Welfare, 1984). Inefficient driving of vehicles by inexperienced drivers and overloading also contribute to poor engine performance. Many vehicle owners do not realize that proper engine adjustment and maintenance not only reduces pollution, but also reduces fuel consumption and increases efficiency.

Part Five of the Act concerning atmospheric pollution deals with pollution from diesel-engined vehicles (Chapter One). Tests are performed by use of a Hartridge meter which is satisfactory if carried out regularly and properly enforced. It is suggested that the Traffic Department and the City Health Division should liaise at least monthly on the issue and that the public play an active role by reporting offenders. The present system requiring a certificate of roadworthiness (COR) only when a vehicle changes ownership means that many vehicles currently operated on South Africa's roads are in poor condition. Appalling smoke pollution is one of the milder consequences and the high frequency of road accidents one of the more serious. A system similar to that in the UK should be implemented whereby any vehicle over a certain age requires an annual inspection before the vehicle licence disk will be issued.

Bus and trucking companies should take the initiative to ensure that their vehicles are properly maintained to meet safety and emission standards. Any company whose vehicles continually fail tests should then be prosecuted. The proposed N3 freeway bypass will also reduce heavy goods vehicle traffic and emissions in the city hollow.

The main concern about the health effects of diesel emissions is centred around the particulate fraction and its carcinogenic potential rather than the gaseous emissions. Human epidemiological studies have not yet proven this potential, but it can still be said that the particulate matter in diesel emissions constitute a health risk because the particles are in the size range that penetrate deep into the respiratory tract. Large quantities of these respirable particles have a large total surface area which absorbs other gaseous emissions, leading to the accumulation of harmful materials in the lungs (Terblanche and Ler Murray, 1990).

With the use of diesel engines in South Africa likely to increase in forthcoming decades, constant evaluation of the nature and extent of emissions must be conducted. The implied health risks further enforce the need to apply abatement policies already described and to consider alternatives both nationally and locally (Section 5.3.4.3). The need for chemical analysis of particulates in Pietermaritzburg is also further emphasized.

5.3.4.2 Petrol

In the case of the petrol engine, fuel composition and the ignition process are different to that of a diesel engine and exhaust emissions differ significantly (Table 8).

Table 8: A comparison of diesel and petrol exhaust emissions (modified from Acres, 1991).

Engine type	Carbon monoxide %	Hydro-carbons ppm	Nitric oxide ppm	Sulphur dioxide ppm	Particulates g/m^3
Diesel	0.1	300	4000	200	0.5
Petrol	10	1000	4000	60	0.01

A further difference not identified in Table 8 is that lead represents a significant proportion of particulates emitted from petrol engine exhausts, whereas the bulk of particulates from diesel engines are carbonaceous matter. The presence of lead in both the emission and the fuel of petrol engines is significant; ambient air lead concentrations were illustrated in Chapter Four and the reason for lead in fuel will now be explained as summarized from an article by Wright (1994).

Prior to 1923, all cars ran on lead-free fuel until General Motors discovered that lead was an efficient knock retardant. Knocking is the tendency for the fuel/air mixture to detonate too early in the combustion cycle and can be extremely damaging to the engine. The octane rating of petrol is a measure of its resistance to knock, and consequently of the amount of lead in the fuel. Modern high-compression engines have a greater thermal efficiency (and hence more power), but also a greater tendency to knock, and therefore need higher octane fuel. It is possible to produce high octane fuel without the addition of lead, but is also more expensive because for every barrel of crude oil going into the refinery, less petrol will be produced.

The move towards lead-free petrol started because of the need to reduce atmospheric pollution in developed countries such as the USA and Japan. Photochemical smog, a combination of sceondary pollutants as described in Chapter Four, was first observed in the early 1950s in Los Angeles, California (Acres, 1990, 1991). This caused great concern over the health effects of emissions from untreated exhaust gas in urban areas with high vehicle densities.

Motor manufacturers responded to public and governmental concerns by developing catalytic converters composed of fine ceramic monoliths coated with platinum and rhodium to act as catalysts to convert carbon monoxide, hydrocarbons and nitrogen oxides to less environmentally active compounds. Bringing exhaust gas into contact with current three-way catalytic converters promotes high temperature reactions that remove up to 95 percent of the harmful substances (Fig. 74(a) and (b)) by the reaction:

$$2CO + 2NO \rightarrow 2CO_2 + N_2$$

$$4HC + 10NO \rightarrow 4CO_2 + 2H_2O + 5N_2$$

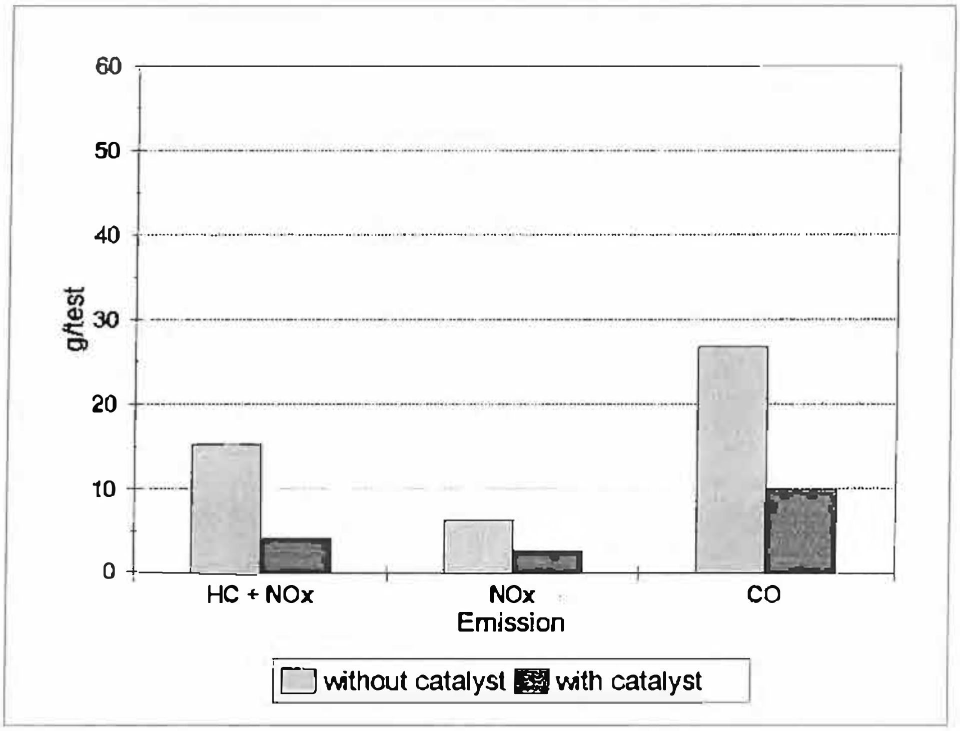


Figure 74(a): A comparison of emission levels from a Fiat Uno with and without a catalytic converter during a 15 cycle test run (data from Acres, 1991).

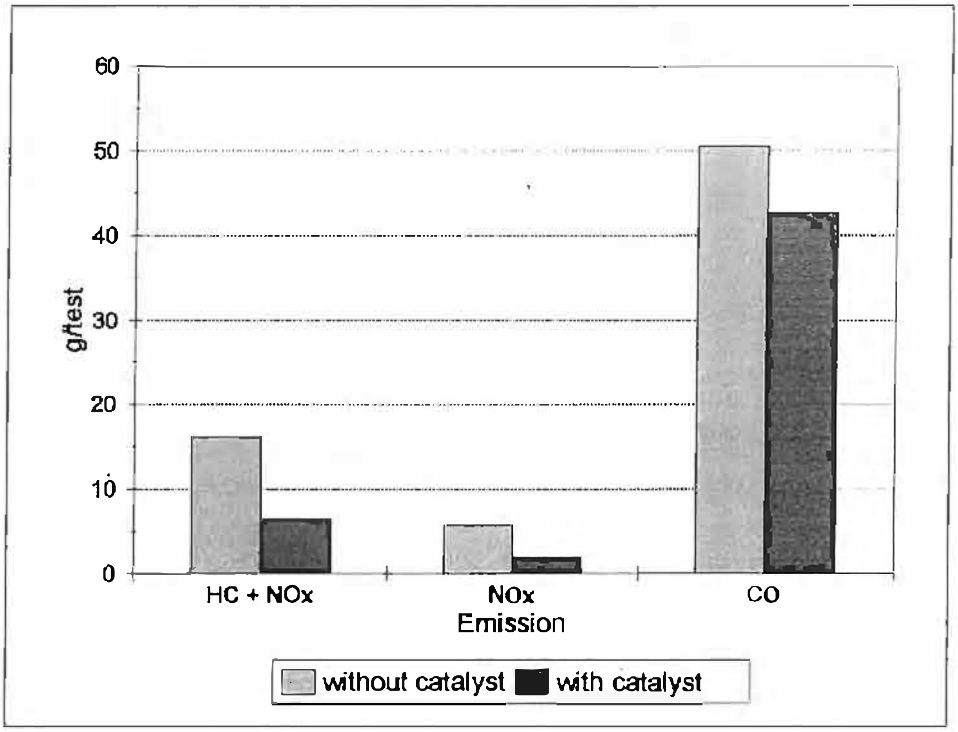


Figure 74(b): A comparison of emission levels from a VW Golf with and without a catalytic converter during a 15 cycle test run (data from Acres, 1991).

The snag is that if leaded fuel is used, the exhaust gas poisons the catalyst by coating its surface with lead. This promotes carbon build up and eventually blocks the exhaust. Hence, the main reason for changing back to lead-free petrol overseas was to clean up the gaseous emissions, rather than the lead itself. This explains a common misconception in South Africa, and corresponds with Gething's (1990) article which argues that the effect of changing to lower-lead petrol on blood lead concentrations is minimal according to data collected by the United Kingdom Department of the Environment (Fig. 75).

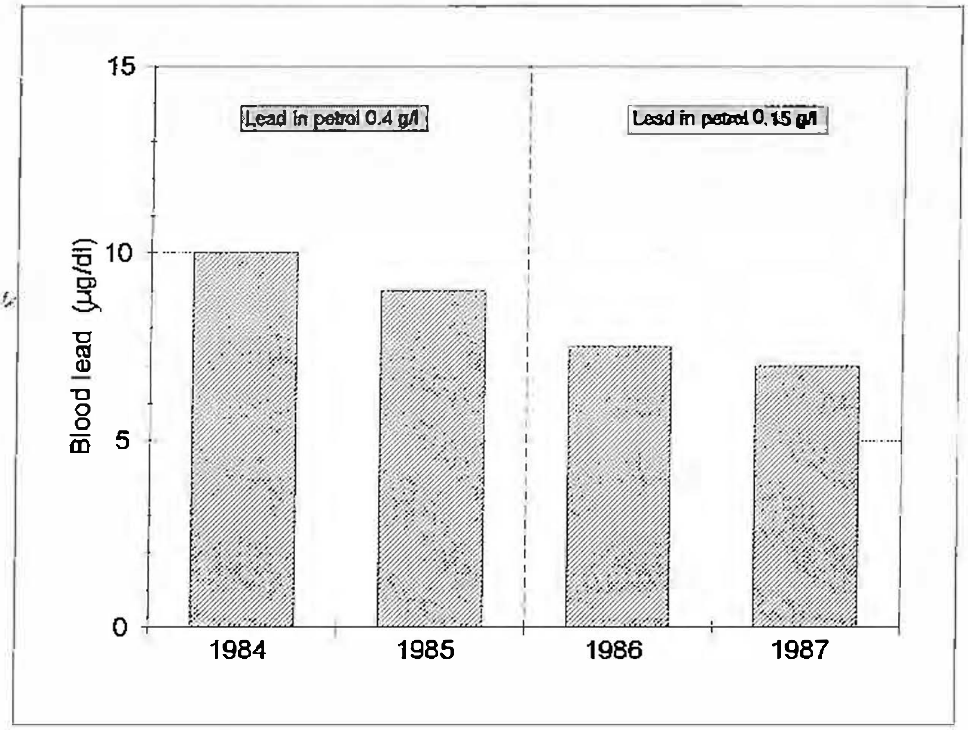


Figure 75: Blood lead concentrations of children in central London - 1984 to 1987. The average fall in blood lead concentrations in 1986 was approximately 0.75 µg/dl greater than the long-term downward trend, suggesting that this was the contribution made by fall in air lead caused by the decrease in lead petrol levels from 0.4 g/l to 0.15 g/l (after Gething, 1990).

However, it is also noted that ambient air lead levels in central London were below 1.0 $\mu g/m^3$ even in 1985 when petrol lead levels in the UK were still 0.4 g/l (UK Department of the Environment, 1989). Pietermaritzburg, a far smaller city, with much lower vehicle densities than London, still records average air lead levels well above 1.0

$\mu g/m^3$ in 1994. This calls for the urgent introduction of lead-free petrol in South Africa to reduce lead levels, and the gaseous primary vehicle pollutants through catalytic converters. Ozone concentrations were noted to be relatively high in Pietermaritzburg for the size of the city and would undoubtedly be reduced by the use of catalytic converters which is only possible once the switch to lead-free petrol has been made.

In spite of the health benefits, it also makes economic sense to change to lead-free petrol as 90 percent of all the automotive petrol engines being built world-wide are designed for unleaded fuel (Wright, 1994). Thus, the pressure to switch in South Africa has come from the motor manufacturers who are being increasingly cut-off from current engine technology. Engines are largely designed overseas and have to be converted for the South African market, a task that is becoming more difficult.

Oil companies are finally responding to this situation, and their obligation to protect the atmospheric environment. It is likely that the new fuel will be introduced in South Africa by October 1995. But the change has called for capital expenditure of around R 1.5 billion, and with the increased refining and distribution costs, it is estimated that the fuel will cost between 8 and 10 cents a litre more to manufacture. To amortise the capital expenditure, the oil industry will need at least a 25 percent market share for unleaded, so motorists will need to be encouraged by making unleaded cheaper than leaded fuel. This artificial price differential will probably be achieved by taxing leaded fuel in order to subsidize lead-free fuel, which has significant economic and political implications. Only the new high-tech cars will need lead-free and the man in the street with an old car or taxi might well have to pay for it. The subsidy would also be self defeating as the greater the consumption of unleaded petrol, the higher the tax on leaded fuel will have to be. For these reasons, the introduction of lead-free petrol may be delayed (Wright, 1994).

It is hoped that the government's long-term commitment to the environment is not overridden by short-term social and economic factors while cities such as Pietermaritzburg need this relief for the sake of air quality and human health. Current legislation places no control on pollutants from petrol vehicles, leaving the onus on the owner of the vehicle to show concern for the environment.

5.3.4.3 Alternatives

Pietermaritzburg is a car dependent city, but the environmental implications are forcing people to question the wisdom of this addiction. Individual transport in cars is also becoming highly inefficient through traffic problems and the cost of running motor vehicles. It is time to look more seriously at practical alternative modes of transport.

The two prime reasons for dependence on cars are the disaggregated spatial form of the city and the almost complete lack of public transport. Planners need to start consolidating existing urban areas, while accessibility and minimising journeys should be a priority for new development. Drastic improvements are needed in public transport, in terms of performance, convenience and security. Public transport serves a very important social function, apart from its environmental and economic benefits. The real issue must be to create effective transport by taking all the associated costs and benefits into account.

Much can be learnt from the experience of the UK in this regard. In 1991, the UK Departments of the Environment and Transport commissioned a study to look into the relationships between land-use, travel demand and transport emissions, in order to advise on how planning might help to reduce atmospheric pollution. The key finding related to population density (Allen, 1994).

'Higher population density results in a wider range of easily accessible social amenities. It also means that more commercial initiatives can be supported, reducing the need to travel further afield. Higher density will also tend to reduce distances between place of residence and place of work. Generally, the greater the concentration of people, the more viable are public transport systems and the more constraints on motor car use.'

South African cities are well-known for their overall low population densities, but also for their irregular distribution of density, with the former black townships generally having much higher densisties than the former white areas. The fragmented spatial pattern is a large part of the barrier to implementing an economic and efficient public transport system in Pietermaritzburg and many other South African cities. Light rail systems now being used widely in the UK win over the car in terms of emissions and energy efficiency, but require fairly high population densities to be viable (Allen, 1994).

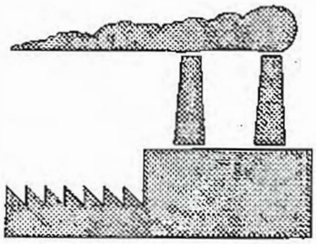
Taviv *et al.* (1990), compared the impact of alternative mass transportation modes on air quality in the Johannesburg metropolitan area. Three transport systems were assessed (existing, bus-orientated and light rail) by applying local data to a USEPA model, and it was found that neither system would make a major long-term contribution to a reduction in metropolitan vehicle emissions. Low mass transit occupancies were the main cause of the failure and were also the reason for the collapse of public transport in Pietermaritzburg. There are simply not enough people going in the same direction at the same time.

Public transport may come of age when the city grows and densifies in the future, but in the meantime, a proposal by Earthlife Africa may offer a good alternative. *Reviving the steel steed* (Sherriffs, 1994) describes how Pietermaritzburg could be turned into a bicycle friendly city. Bicycles are quiet, do not pollute and require less space than cars when in motion and when parked. They are also cheap and energy efficient. The linking of Edendale and Imbali to the city centre with flat and easy cycle routes would make this form of transport a more viable option to the population sector that most needs it. Obviously there are some drawbacks, such as hills to climb and adverse weather, but none sufficient to ignore this potential. The provision of dedicated cycle tracks and secure parking facilities needs to be examined and acted upon by local authorities. Pietermaritzburg should take note of the success of cycling in Europe and Asia as an efficient and environmentally friendly mass transport system that still allows individual choice.

In summarising the problem of vehicle emissions, the real solution lies in measures to reduce the need to travel. Improved legislation is required in the short-term to control emissions, but only sustainable land-use and transport planning will ensure a long-term improvement in air quality and efficiency.

An holistic appraisal of atmospheric pollution and its implications in Pietermaritzburg has now been presented. In summary and conclusion, the Pietermaritzburg air pollution system will be reviewed.

Chapter Six



Conclusions

6. CONCLUSIONS

The conceptual framework of an air pollution system is appropriate to synthesize the findings of the current research. Atmospheric pollution involves many factors, both within and beyond the control of people, that combine to determine the quality of the air upon which all forms of life ultimately depend. In order to assess how these factors interact in a specific environment, and more important, how they can be controlled, it is necessary to break down the complex system into a chain of components. A simplified flow chart that can be applied to any scale of air pollution problem is shown in Fig. 76 and discussed for Pietermaritzburg below.

Pollution sources are emitted from industrial, domestic, agricultural and transport sources within the hollow. The macroscale weather conditions prevailing over Southern Africa allow the local topography to control the local air circulations to a large extent and consequently the dispersion of these pollutants over the city. Gaseous and particulate pollutant levels are monitored along with meteorological conditions at the monitoring laboratory in the central district, while smoke and sulphur dioxide are also monitored at six outlying stations. Collected data are then graphically and statistically analysed to find out how the emitted pollutants are dispersed and transported in the local atmosphere, which depends on the local dispersion climatology. During dispersion, chemical and physical transformations occur to create secondary pollutants as explained by atmospheric chemistry.

Ambient air quality is then assessed in terms of its environmental implications. These are expressed by the impact of pollution levels on a variety of receptors, with human health being the main concern in urban environments such as Pietermaritzburg. Standards and levels recorded in other metropolitan regions provide a measure against which local air pollution levels can be compared. When the current situation is known, existing environmental control measures are evaluated to decide if they are effective. Where they are found inadequate or unsustainable, recommendations and planning proposals are made to alleviate the current situation and protect the future atmospheric resource.

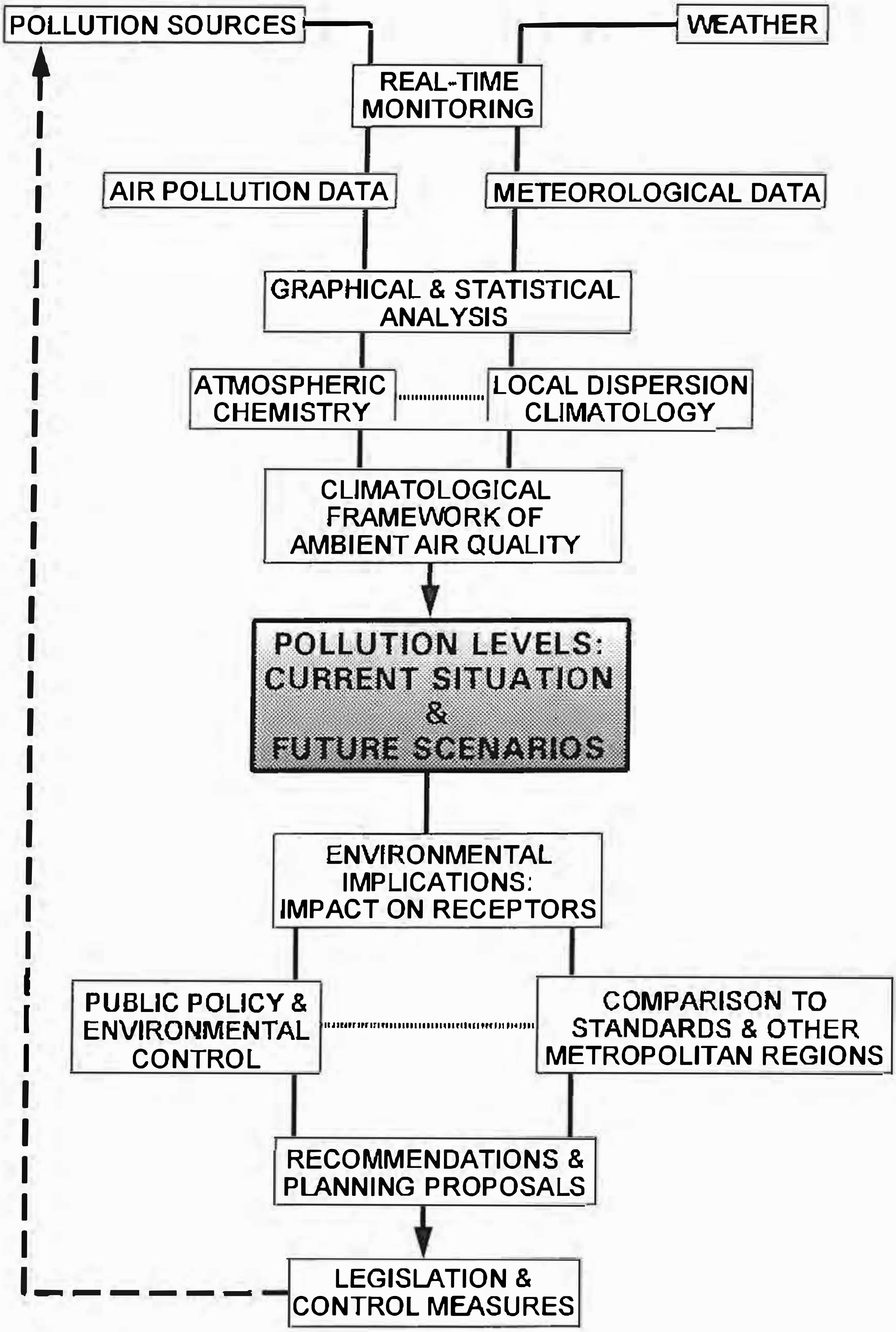


Figure 76: The air pollution system in Pietermaritzburg as derived from the conceptual framework of Finlayson-Pitts and Pitts (1986).

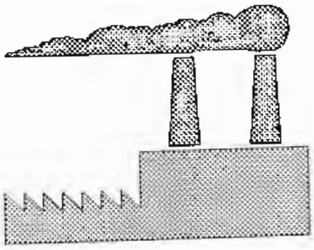
Hence, the temperatures, wind fields and stability regimes form the climatological framework that largely determines the ambient air quality at any place or time. If this framework can be further developed to the extent that dispersion can be accurately and reliably modelled, concentrations of primary and secondary pollutants can be predicted as a function of time at various locations in a given airshed. Such information is imperative for management of the atmospheric environment because it provides knowledge about effects of existing and planned pollution sources, so that the appropriate legislation and control measures can be implemented. Each link is essential to controlling the system as any gap in the regulatory structure will allow pollution problems to develop and persist.

The responsible authorities in Pietermaritzburg therefore need to examine the local pollution system in view of the current research. Several weak links have been clearly identified by the study, relating to national and local control strategies, the effective use of real-time monitoring techniques, and communication between the City Health Division, industry, and the public. The research itself has shown the value of effective monitoring and further refined the dispersion model for Pietermaritzburg. A new approach to the abatement of local air pollution has also been initiated with the help of a group of committed local people.

It is hoped that the findings reported in this document will be actively incorporated into the urban planning process. Many recommendations and suggestions have been derived from the study, some of purely local relevance and some of national significance. Each approach to air pollution control has associated costs and benefits that must be weighed against the value of clean air - a resource that everybody treasures, but few are willing to protect.

Abatement of air pollution in Pietermaritzburg and sustainable environmental planning must include economic, political and social perspectives, grounded on a sound scientific base. The holistic approach presented by this thesis is a step towards the achievement of a cleaner environment.

* * *



Appendices

APPENDIX ONE
COMPUTER CALIBRATION GRAPHS

The relationship between the output signal from each sensor or instrument in the monitoring laboratory and the actual reading in the appropriate units is linear. A multiplier and offset is therefore required by the software for each of the parameters being logged. These were found by taking two or more known reference points and calculating the linear regression equation in the form:

$$y = mx + c$$

where the gradient (m) is equal to the multiplier and the y-intercept (c) is equal to the offset.

The following remarks are made for each of the parameters.

Wind speed and direction

Fixed multiplier values for the anemometer and wind vane were supplied by S I Analytics.

Temperature

Two known values were obtained by using ice and body temperature. The exact temperatures were given by a pre-calibrated digital thermometer with a precision of 0.1°C.

Relative humidity

Two values were obtained using known relative humidities over saturated salt solutions of lithium chloride (RH = 12.5% at 20°C) and sodium chloride (RH = 75.5% at 20°C) in sealed containers. One hour was given for equilibrium to be established over each solution and ambient air temperatures were kept constant.

Sulphur dioxide, ozone and oxides of nitrogen

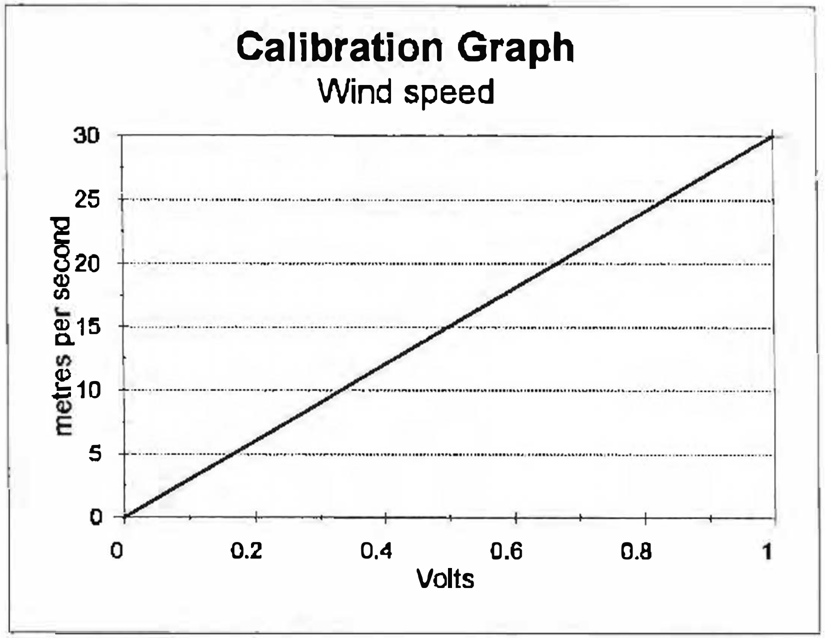
Several readings were taken for each instrument of the output in millivolts, as read off the computer, and the corresponding value in ppb, given by the instrument display. Exact readings in millivolts were verified using a digital multimeter and it was found that outputs from the Dasibi analyzers are stepped. The sulphur dioxide and ozone analyzers both use 5 mV intervals, while the oxides of nitrogen analyzer uses 1.9 mV intervals for both oxides. Each step equates to 1 ppb, corresponding with the manufacturers specifications.

Nephelometer

Two readings were taken using the analogue display on the front of the instrument and the corresponding output in millivolts as read from the computer and verified by the digital multimeter.

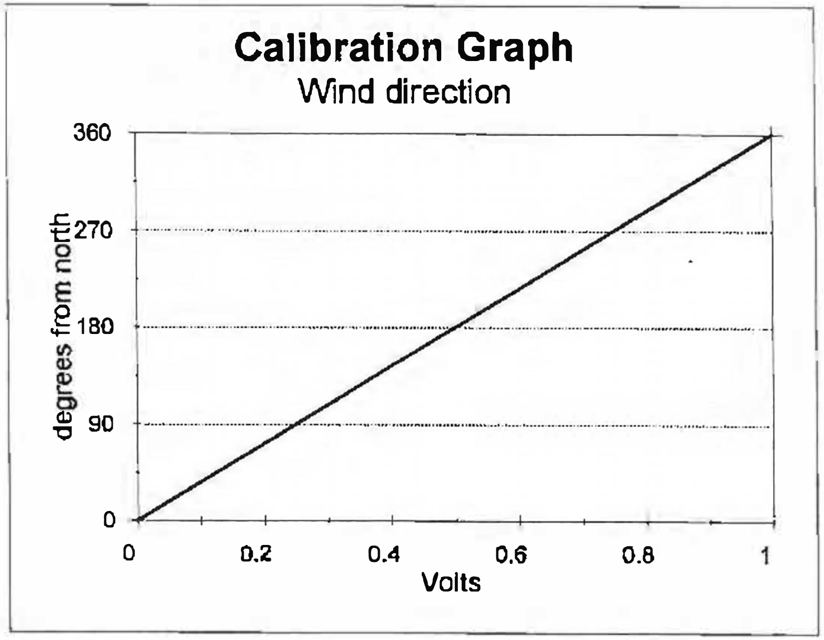
Mr B. Jarmain of the Electronics Workshop, University of Natal and Ms D. Yoell of the Department of Chemistry, University of Natal assisted with the calibration procedures.

Data, graphs and results for each parameter were presented to the City Health Division as shown on the following pages.



V	m/s
0	0
1	30

Multiplier	**30**
Offset	**0**



V	degrees
0	0
1	360

Multiplier	**360**
Offset	**0**

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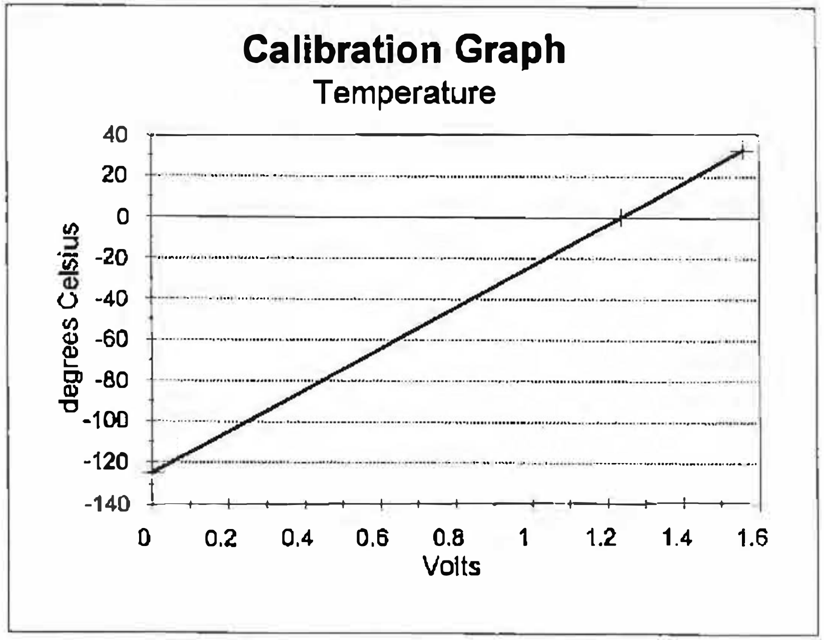
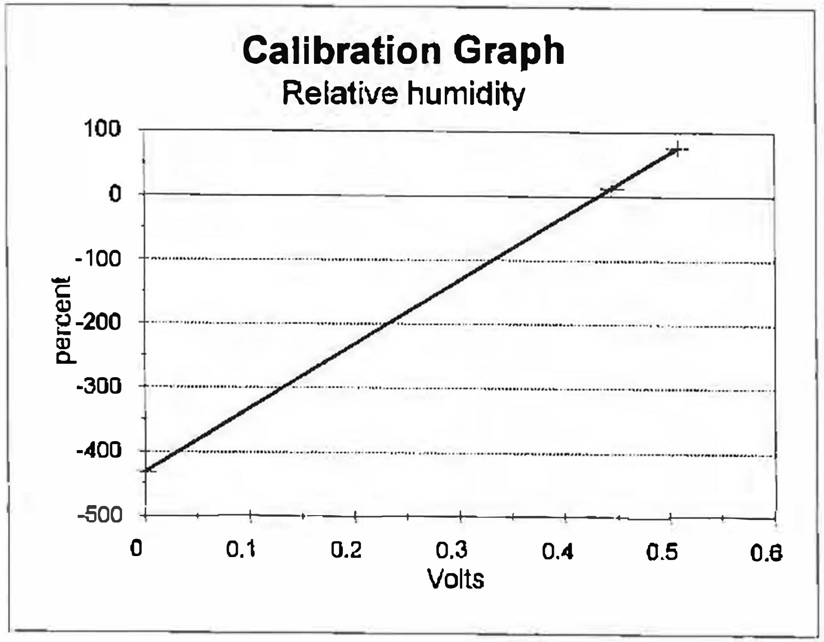


V	°C
0.000	-125.4
1.235	0.0
1.558	32.8

Multiplier	**101.5**
Offset	**-125.4**



V	%
0.000	-432.5
0.445	12.5
0.508	75.5

Multiplier	**1000.0**
Offset	**-432.5**

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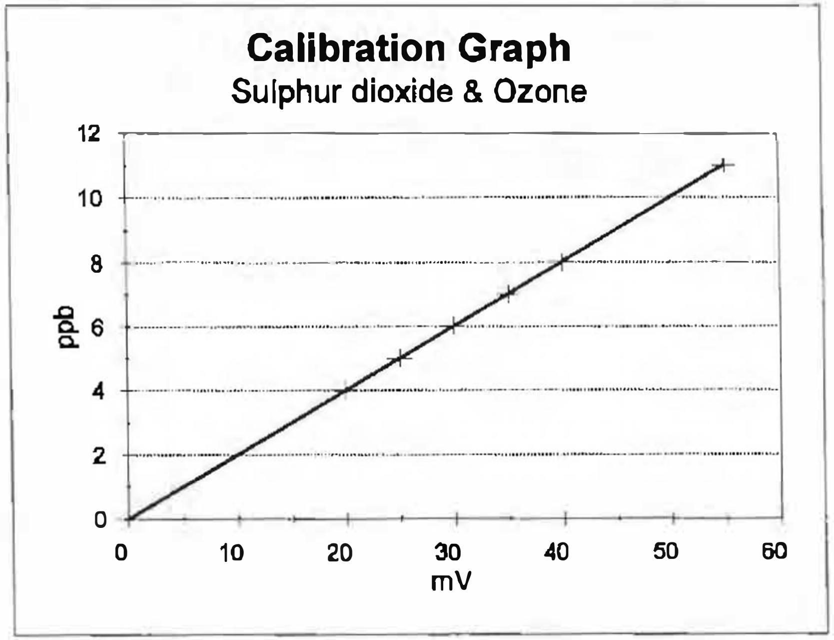
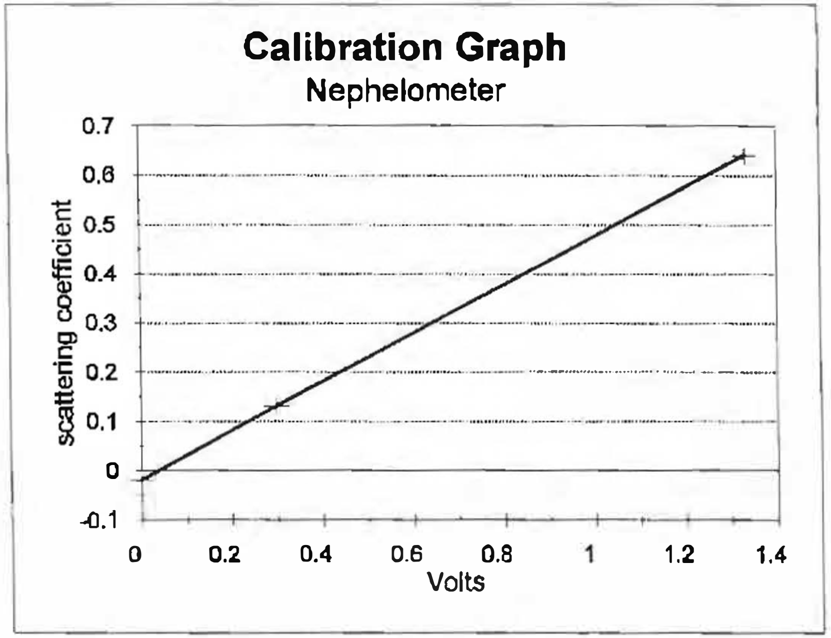




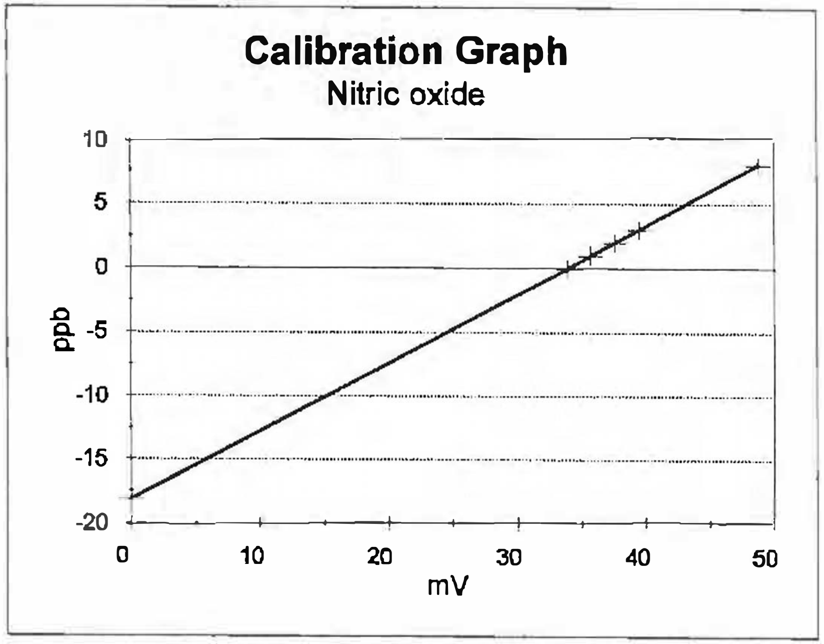
mV	V	ppb
0	0.000	0
20	0.020	4
25	0.025	5
30	0.030	6
35	0.035	7
40	0.040	8
55	0.055	11

Multiplier	**200.000**
Offset	**0.000**

V	s.c.
0.000	-0.018
0.300	0.130
1.333	0.640

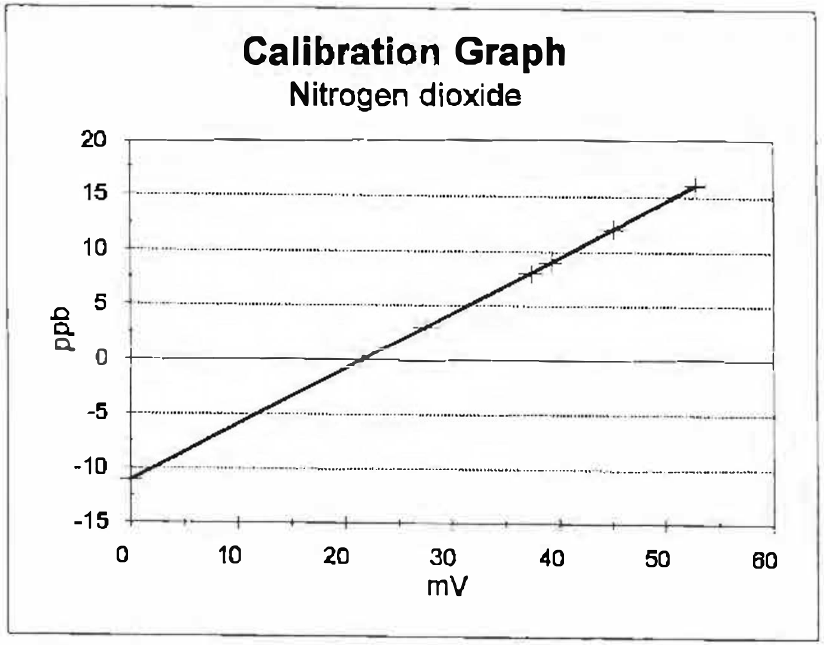
Multiplier	**0.494**
Offset	**-0.018**

Produced by A.Simpson & B.Jarmain *30/7/93*



mV	V	ppb
0	0	-18.143
33.9	0.0339	0
35.7	0.0357	1
37.6	0.0376	2
39.5	0.0395	3
48.8	0.0488	8

Multiplier	**535.714**
Offset	**-18.143**



mV	V	ppb
0	0	-11.128
21.7	0.0217	0
27.6	0.0276	3
37.4	0.0374	8
39.3	0.0393	9
45.2	0.0452	12
52.9	0.0529	16

Multiplier	**512.821**
Offset	**-11.128**

Produced by A.Simpson & B.Jarmain *30/7/93*

APPENDIX TWO

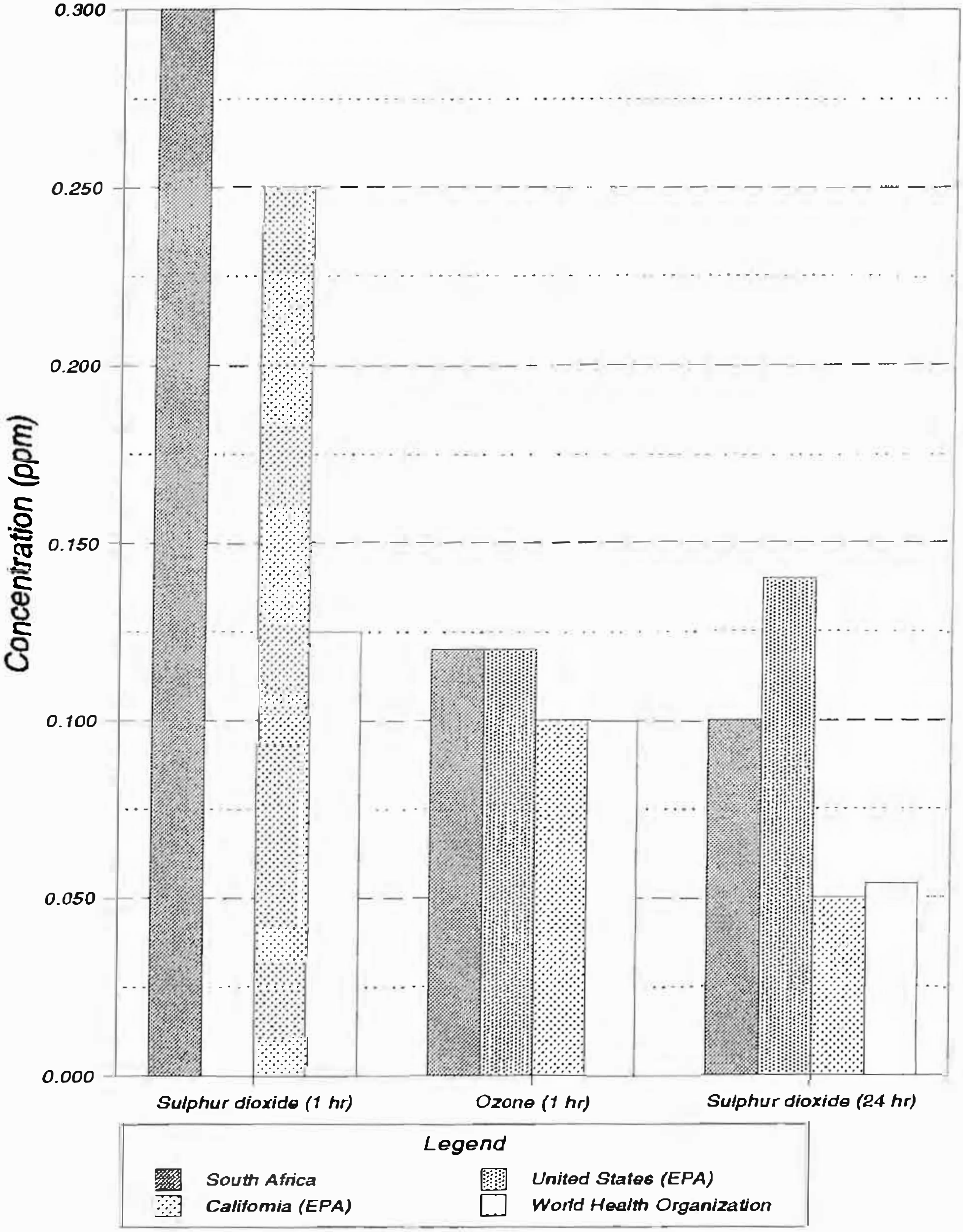
COMPARATIVE AMBIENT AIR QUALITY STANDARDS

South African ambient air quality guidelines (Table 7) are often criticized for being too lenient and thereby allowing unacceptable levels of pollution. Guidelines for ambient sulphur dioxide and ozone concentrations are compared in the graph overleaf to examine this claim.

It is evident that the one-hour sulphur dioxide guideline of 0.3 ppm (300 ppb) is more lenient than the California EPA standard and more than double the WHO standard at 0.125 ppm (125 ppb). However, it is important to realize that the WHO standards are long-term goals intended for all countries, and not actual standards that are enforced by any country. Further, they are time-weighted average concentrations, meaning that several individual exceedances of these levels are acceptable provided the average is low enough. Different time weightings apply to different pollutants and the number of exceedances allowed depend upon average concentrations over the year, but under most situations allow more than the one exceedance per year specified for South African guidelines.

The one-hour ozone concentration suggested for South Africa is well in line with international standards, as is the 24-hour sulphur dioxide guideline that is noticeably less than the USEPA standard. It can therefore be concluded that the local ambient air quality guidelines are on average only slightly more lenient than either USEPA or WHO standards. The problem arises in that they are only guidelines and not standards, making it difficult for authorities to enforce these levels as discussed in Chapters One and Five.

Comparative Air Quality Standards



Note: 1ppm = 1000ppb

APPENDIX THREE

MINUTES OF POLLUTION BREAKFAST HELD ON 15 SEPTEMBER 1994 AT THE MARITZBURG COUNTRY CLUB, PIETERMARITZBURG

Present:	Y Spain (chairperson)	City Councillor
	R Haswell	Chair, Environmental Committee, City Council
	I Cronjé	Chair, Prov. Standing Committee for the Env. MPP, ANC
	M Lakhani	Earthlife Africa
	F Talbot	Environmental Consultant
	B Talbot	Environmental Consultant
	M Mentis	Envirobusiness Consultant
	J Howard	Water Quality Manager, Umgeni Water
	A Simpson	MSc. Student, University of Natal
	B J Sekete	Siyanani Womens Forum
	R Kirkby	General Practitioner
	J White	Environmental Lawyer
	M Tarr	MPP, IFP
	T Millin	MPP, IFP
	M Sikhosana	ANC
	P Barnard	DP
	T Volker	MPP, NP
	P Bhengu	COSATU
	J Maphalta	COSATU
	F Dlamini	COSATU
	T S Mokonyana	COSATU
	T Nzuza	FAWU
	I Amla	The Natal Witness
	J R Smith	PCCI
	F van Rensberg	PG Bison
	G van Niekerk	PG Bison
	A A Moosa	Willowton Oil Mills
	A representative	Capital Oil Mills

1. BREAKFAST

Breakfast was served at 07h30

2. OPENING ADDRESS BY YVONNE SPAIN

Yvonne Spain officially opened the meeting and welcomed all present at 08h05. Peter Millin was thanked for making the morning possible.

It was noted that certain industrialists were conspicuous by their absence and those present were reassured and thanked for attending. The politicians present were challenged to take action over the environmental concerns of the Pietermaritzburg public.

A list of wishes for future action was then identified.

(1) Politicians make it their responsibility to press for new and effective legislation. Guidelines are outdated and the air pollution control officer for KwaZulu/Natal resides in Pretoria and is out of touch with Pietermaritzburg.

(2) Nominees to the pre-interim city council and future councillors be required to state their views unequivocally on the protection of the environment and be made accountable for policies and decisions at a public environmental forum to be convened annually.

(3) Industries, agriculture and forestry be required to clean up their act in terms of new legislation and fund pollution monitoring.

(4) An ombudsperson or group be instated to whom concerned citizens could report, and who in turn could have a direct link to the Provincial Standing Committee for the Environment.

(5) A public vehicle emission monitoring campaign be undertaken in conjunction with the traffic department.

(6) Assistance be offered to the Earthlife Citizen Monitoring Programme.

(7) Copies of tabled documents and minutes of the meeting be circulated to the Council's Environmental Committee, the Transitional Council of Local Unity, consultants appointed to the Urban Reconstruction Programme, and to the Industrial Development Consultant (Terry Thompson).

In conclusion, it was commented that Pietermaritzburg cannot hope to attract tourists until air pollution is reduced. Hope was expressed that the meeting would mark the beginning of a healthier balance between industry and the environment.

3. A MEDICAL PERSPECTIVE BY A LOCAL DOCTOR

A local medical doctor addressed the meeting at 08h20. It was claimed that so-called 'acceptable limits' are not acceptable at all. Pietermaritzburg's local climatology makes the city especially prone to air pollution problems.

Respiratory ailments are consequently a major problem in Pietermaritzburg as documented in a paper by Dr Kirkby. It was stated that asthma was as prevalent in the city as in the heavily industrialised Vereeniging and Vanderbiljpark region in 1990. Sales of asthma medication to the private sector in 1990 amounted to R1.5 million.

The extent of this problem should be made known to the public so that they can make a stand. Abatement of pollution is also the social responsibility of the industrialist. Further, the current legislation needs to be updated as it does not give pollution inspectors enough power to effectively control air pollution. To make this happen, politicians and councillors need to take a stand. Finally, electrification schemes and the proposed freeway bypass were mentioned as partial solutions to the problem.

4. THE NEW CONSTITUTION AND POLLUTION BY JON WHITE

Jon White, an environmental lawyer, made the final address at 08h30.

It was pointed out that an objective approach to air pollution control needs to be taken. The legal situation concerning the environment has changed dramatically with the political changes that have recently taken place.

In the old order, prosecution for environmental pollution offences was very rare because of:

- official secrecy about emissions causing a lack of knowledge on behalf of the public;
- the issue of *locus standi* whereby individuals wanting to prosecute would have to prove a direct, personal interest in the matter;
- the heavy onus placed on the individual in bearing the burden of proving the case; and
- ineffective state intervention.

In the new South Africa, prosecution for such offences is made much easier because:

- the public now has the right to information about emissions which gives legal power to the individual;
- any person has the right of access to court when acting in their own interest or in the public interest;
- every person has the right to a healthy environment; and
- the onus shifts to the offender/polluter to prove the right to pollute.

Mention was also made of the new policy toward the environment as identified in the Reconstruction and Development Programme.

5. DISCUSSION

At 08h40 the discussion was opened to the floor.

J Smith commented that the Pietermaritzburg Chamber of Commerce and Industries (PCCI) would also like to receive a copy of the minutes of the meeting as it has an infrastructure committee that deals with pollution issues.

P Bhengu responded by questioning whether the PCCI is aware of the extent of odour and smoke pollution in Edendale. He stated that Edendale should not be seen as an industrial dumping ground.

J Smith responded that there are several contributors to air pollution in Pietermaritzburg, and that industry is only one of them. He asked that people keep industrial pollution in context and stated that industry would like to be part of the solution.

M Mentis then suggested that we look for a way forward to find a solution. A new environmental policy and vision for the city needs to be formulated, possibly through a workshop.

I Cronjé agreed that a vision is needed and proposed community forums as a bottom-up approach.

M Lakhani reminded those present of the Greater Pietermaritzburg Environmental Coalition (GPEC) and the draft environmental manifesto that already provided such a vision. It is a people driven document and the first of its kind in South Africa. He offered to send copies with the minutes of the meeting and emphasised Earthlife's role in solving the air pollution problem. Moving to the issue of industrial pollution, he argued that class action is required to control industry. Also, monitoring is essential and can be inexpensive as Earthlife's Citizen Monitoring Programme demonstrates with a simple monitoring kit costing only R10. Concerning guidelines, Muna said South African air pollution limits are half as stringent as those set by the World Health Organisation. Legislation should follow the principle that all emissions are harmful.

P Barnard continued that the Council's Environmental Committee is not taken seriously, being a toothless entity. Noise pollution and litter are also growing problems in the city.

B Sekete introduced herself as a health worker. She raised the issue of smoke emissions in Edendale, forwarding suggestions such as the use of suitable pollution control equipment, electrification and effective legislation as solutions to the problem. Noise pollution was reiterated as a problem.

M Tarr added that the local parliament have created a portfolio committee on the environment that will give more power to pollution control. He stressed, however, that the move toward a cleaner environment must not become a witch hunt. A better approach is to monitor and control air pollution in cooperation with industry.

I Cronjé denied that the town council is apathetic. Pressure from the community is in any case the best cure for apathy. The press was asked to give publicity to the issue and industrialists were again thanked for their attendance.

R Haswell cautioned the meeting that it would achieve nothing by passing the blame and should focus on being constructive. His opinion was that Pietermaritzburg is more concerned with conservation than with equity and sustainability. The community at large is apathetic, meaning that legislation alone is not the solution. Motivated individuals must take the issue forward as citizen action and interaction will find the only true solution.

M Sikhosana said that there is a need to link with work already done as all aspects of pollution are expensive. He commented on the stench at Sobantu which is adjacent to the Msunduze, Darvill purification plant and the city dump. The marginalization of environmental issues is seen as a barrier to their effective resolution.

F van Rensberg explained that he only arrived in Pietermaritzburg on 1 September, so he would prefer to concentrate on the future of PG Bison in the context of air pollution. He assured the meeting that PG Bison will be proactive towards air pollution. In this vein, he recognized that there would always be scepticism about their internal monitoring and suggested the appointment of an independent consultant for whom PG Bison would pay. In this respect, PG Bison would be the leader with its environmental policy in Pietermaritzburg.

R Haswell moved that the meeting should accept the offer immediately.

T Volker explained that finding solutions to pollution problems in a developing society requires a holistic approach. A local person should be appointed to deal with such issues and the public needs to be educated as public awareness will go a long way to solving the problem. Negotiation and consultation should be sought with polluters before confrontation.

P Bhengu disagreed, arguing that people from industry cannot sit on an air pollution committee, being responsible for the pollution in the first place. He proposed that the appointed consultant should report to a standing committee chaired by Yvonne Spain.

Y Spain responded that she would be on leave for the next three weeks, but would be available thereafter.

P Bhengu said that this would not be a problem and plans must go ahead to form a committee.

J White added that environmentalists must head the committee, but that it must be broad-based and inclusive if it is to be effective.

R Haswell reminded the meeting that a preliminary committee would formed first.

F Talbot explained that a variety of people will be needed as air pollution and control demands an interdisciplinary approach. He therefore suggested that the expertise offered by the University of Natal be fully utilised. In this regard, Andrew Simpson has already been researching air pollution in Pietermaritzburg for over two years and his skills and experience should not be wasted.

A Simpson introduced himself as a full-time Masters student in the Faculty of Science at the University of Natal. His current research is based on climatological and pollution data obtained from the City Health Division's monitoring 'caravan' which was recommissioned for the project, and intends to provide a holistic assessment of air pollution in Pietermaritzburg. He pointed out that while he is currently busy writing up the thesis, he would be keen to serve on the proposed committee and felt that the initiative was a significant step towards cleaner air.

B Talbot commented that he had no objections to industrialists being involved in the committee and in fact felt that they should be.

Y Spain concluded the meeting by resolving that the coordinating committee will meet in three weeks. Community involvement will be sought to effectively forward the process. The committee will be convened by Yvonne Spain and Rob Haswell with the following members:

Yvonne Spain
Rob Haswell
Ina Cronjé
Andrew Simpson
Jon White

and representatives from:

Earthlife Africa
Greater Pietermaritzburg Environmental Coalition (GPEC)

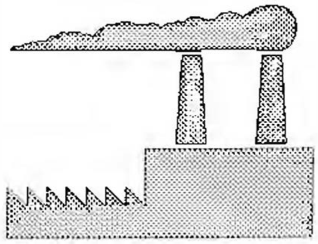
Pietermaritzburg Chamber of Commerce and Industry (PCCI)
Congress of South African Trade Unions (COSATU)
Urban Reconstruction and Development Programme (URDP)

6. CLOSURE

Yvonne Spain was thanked by all for convening the meeting. Andrew Simpson was thanked for taking minutes.

The meeting was officially closed at 09h30

A Simpson 15/10/94 c:\office\wpwin\wpdocs\notes\minutes4.wpd



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