APPENDIX A

REGIONAL CLIMATE AND ATMOSPHERIC DISPERSION POTENTIAL FOR THE MPUMALANGA HIGHVELD STUDY REGION

The macro-ventilation characteristics of the region are determined by the nature of the synoptic systems which dominate the circulation of the region, and the nature and frequency of occurrence of alternative systems and weather pertubations over the region.

A.1 Regional Climate

Situated in the subtropical high pressure belt, southern Africa is influenced by several high pressure cells, in addition to various circulation systems prevailing in the adjacent tropical and temperature latitudes. The mean circulation of the atmosphere over southern Africa is anticyclonic throughout the year (except near the surface) due to the dominance of three high pressure cells, viz. the South Atlantic HP off the west coast, the South Indian HP off the east coast, and the continental HP over the interior.

Five major synoptic scale circulation patterns dominate (Figure A-1) (Vowinckel, 1956; Schulze, 1965; Taljaard, 1972; Preston-Whyte and Tyson, 1988). The most important of these is the semi-permanent, subtropical continental anticyclones which are shown by both Vowinckel (1956) and Tyson (1986) to dominate 70 % of the time during winter and 20 % of the time in summer. This leads to the establishment of extremely stable atmospheric conditions which can persist at various levels in the atmosphere for long periods.

Seasonal variations in the position and intensity of the HP cells determine the extent to which the tropical easterlies and the circumpolar westerlies impact on the atmosphere over the subcontinent. The tropical easterlies, and the occurrence of easterly waves and lows, affect most of southern Africa throughout the year. In winter, the high pressure belt intensifies and moves northward, the upper level circumpolar westerlies expand and displace the upper tropical easterlies equatorward. The winter weather of South Africa is, therefore, largely dominated by perturbations in the westerly circulation. Such perturbations take the form of a succession of cyclones or anticyclones moving eastwards around the coast or across the country. During summer months, the anticyclonic belt weakens and shifts southwards, allowing the tropical easterly flow to resume its influence over South Africa. A weak heat low characterises the near surface summer circulation over the interior, replacing the strongly anticyclonic winter-time circulation (Schulze, 1986; Preston-Whyte and Tyson, 1988).

Anticyclones situated over the subcontinent are associated with convergence in the upper levels of the troposphere, strong subsidence throughout the troposphere, and divergence in the near-surface wind field. Subsidence inversions, fine conditions with little or no rainfall, and light variable winds occur as a result of such widespread anticyclonic subsidence. Anticyclones occur most frequently over the interior during winter months, with a maximum frequency of occurrence of 79 percent in June and July. During December such anticyclones only occur 11 percent of the time. Although widespread subsidence dominates the winter months, weather occurs as a result of uplift produced by localized systems.

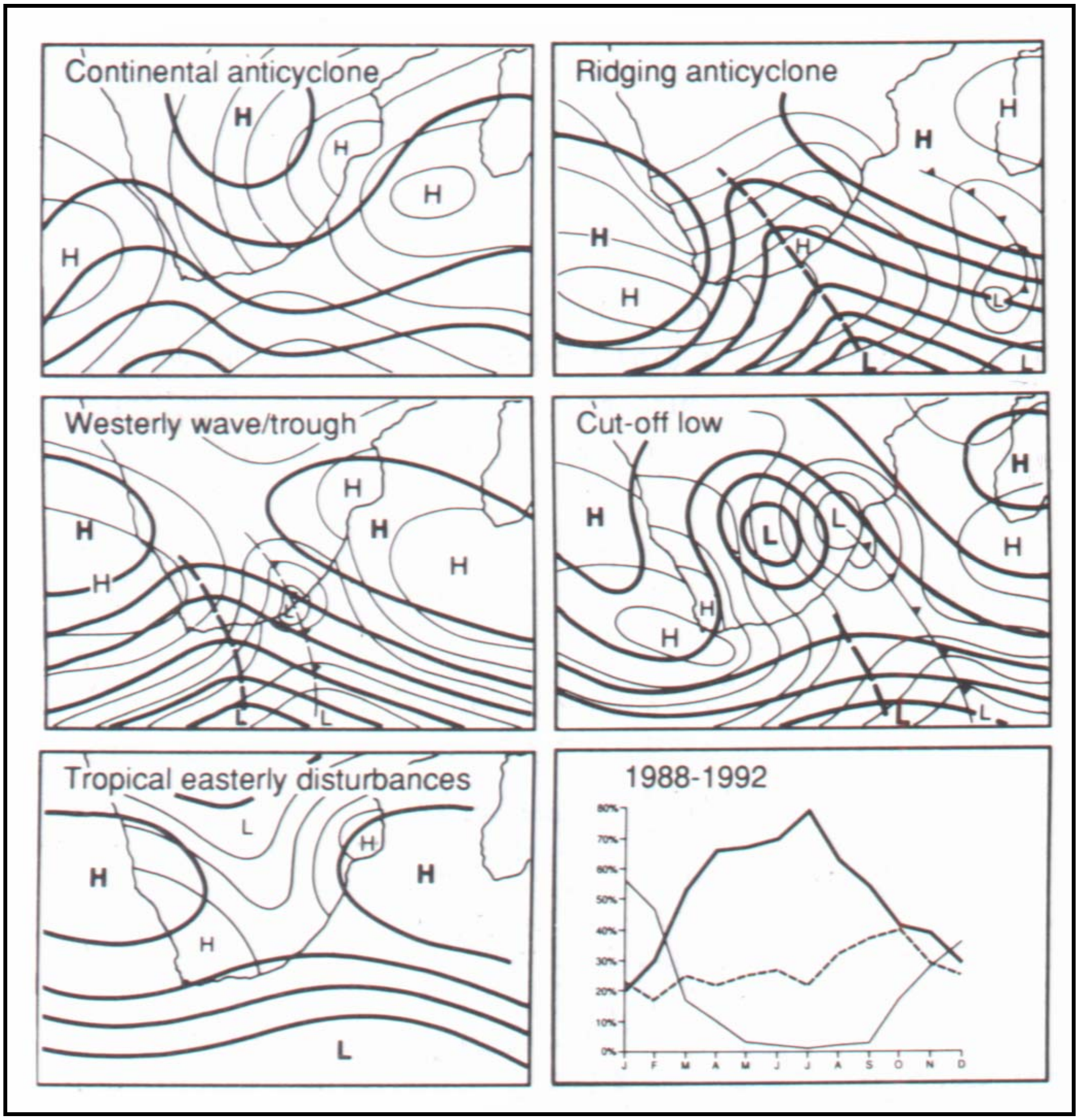

Figure A-1. Major synoptic circulation types affecting southern Africa and their monthly frequencies of occurrence over a five year period (after Preston-Whyte and Tyson, 1988 and Garstang *et al.,* 1996a).

Tropical easterly waves give rise to surface convergence and upper air (500 hPa) divergence to the east of the wave resulting in strong uplift, instability and the potential for precipitation. To the west of the wave, surface divergence and upper-level convergence produces subsidence, and consequently fine clear conditions with no precipitation. Easterly lows are usually deeper systems than are easterly waves, with upper-level divergence to the east of the low occurring at higher levels resulting in strong uplift through the 500 hPa level and the occurrence of copious rains. Easterly waves and lows occur almost exclusively during summer months, and are largely responsible for the summer rainfall pattern and the northerly wind component which occurs over the interior.

Westerly waves are characterised by concomitant surface convergence and upper-level divergence which produce sustained uplift, cloud and the potential for precipitation to the rear of the trough. Cold fronts are associated with westerly waves and occur predominantly during winter when the amplitude of such disturbances is greatest. Low-level convergence in the southerly airflow occurs to the rear of the front producing favourable conditions for convection. Airflow ahead of the front has a distinct northerly component, and stable and generally cloud-free conditions prevail as a result of subsidence and low-level divergence. The passage of a cold front is therefore characterised by distinctive cloud bands and pronounced variations in wind direction, wind speeds, temperature, humidity, and surface pressure. Following the passage of the cold front the northerly wind is replaced by winds with a distinct southerly component. Temperature decrease immediately after the passage of the front, with minimum temperatures being experienced on the first morning after the cloud associated with the front clears. Strong radiational cooling due to the absence of cloud cover, and the advection of cold southerly air combining to produce the lowest temperatures.

A.2 Regional Atmospheric Dispersion Potential

The impact of various synoptic systems and weather disturbances on the dispersion potential of the atmosphere largely depends on the effect of such systems on the height and persistence of elevated inversions. Elevated inversions suppress the diffusion and vertical dispersion of pollutants by reducing the height to which such pollutants are able to mix, and consequently result in the concentration of pollutants below their bases. Such inversions therefore play an important role in controlling the long-range transport, and recirculation of pollution.

Subsidence inversions, which represent the predominant type of elevated inversion occurring over South Africa, result from the large-scale anticyclonic activity which dominates the synoptic circulation of the subcontinent. Subsiding air warms adiabatically to temperatures in excess of those in the mixed boundary layer. The interface between the subsiding air and the mixed boundary layer is thus characterised by a marked elevated inversion. Protracted periods of anticyclonic weather, such as characterize the plateau during winter, result in subsidence inversions which are persistent in time, and continuous over considerable distances. The fairly constant afternoon mixing depths, with little diurnal variation, associated with the persistence of subsidence inversions, are believed to greatly reduce the dispersion potential of the atmosphere over the plateau, resulting in the accumulation of pollutants over the region.

Multiple elevated inversions occur in the middle to upper troposphere as a result of large-scale anticyclonic subsidence. The mean annual height and depth of such absolutely stable layers are illustrated in Figure A-2. Three distinct elevated inversions, situated at altitudes of approximately 700 hPa (~3 km), 500 hPa (~5 km) and 300 hPa (~7 km), were identified over southern Africa. The height and persistence of such elevated inversions vary with latitudinal and longitudinal position. During winter months the first elevated inversion is located at an altitude of around 3 km over the plateau. In summer this inversion is known to increase in to 4 to 5 km over the plateau (Diab, 1975; Cosijn, 1996).

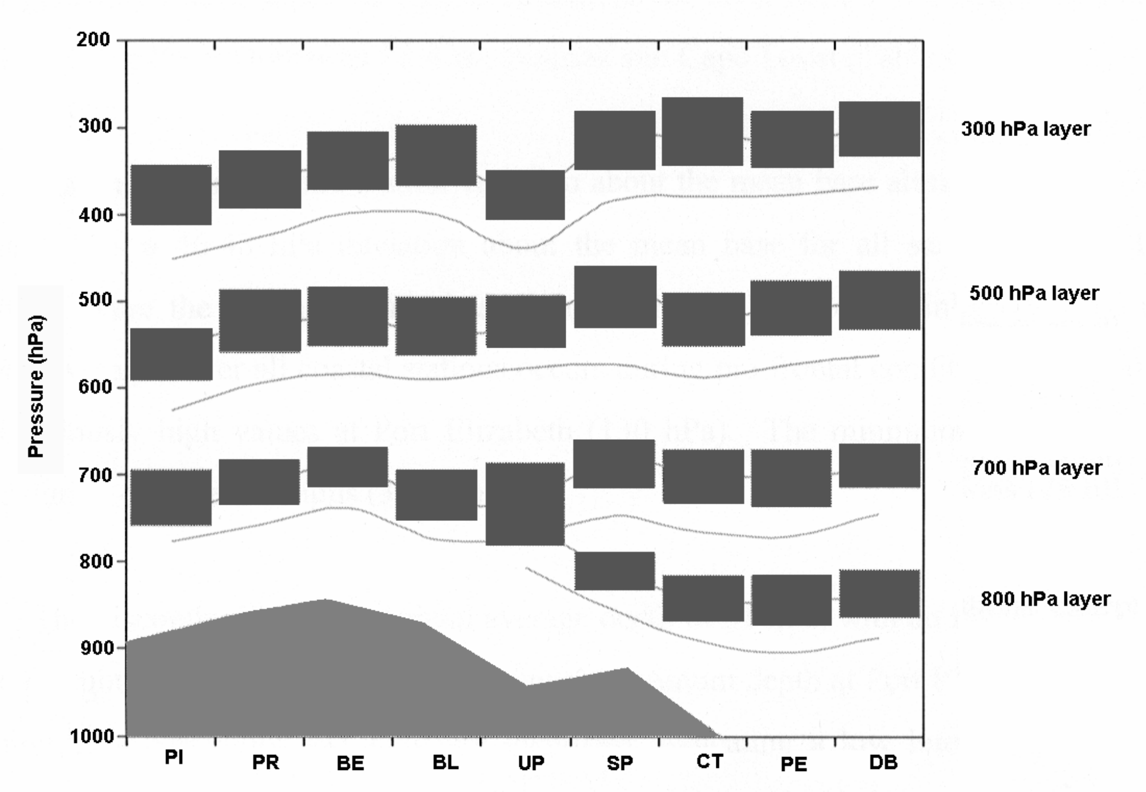

Figure A-2. Mean annual stable layers (shaded) over Pietersburg (PI), Pretoria (PR), Bethlehem (BE), Bloemfontein (BL), Upington (UP), Springbok (SP), Cape Town (CT), Port Elizabeth (PE) and Durban DB). Upper and lower 95% confidence limits for the base heights of the layers are shown in each case (after Cosijn, 1996).

In contrast to anticyclonic circulation, convective activity associated with westerly and easterly wave disturbances hinders the formation of inversions. Cyclonic disturbances, which are associated with strong winds and upward vertical air motion, either destroy, weaken, or increase the altitude of, elevated inversions. Although cyclonic disturbances are generally associated with the dissipation of inversions, pre-frontal conditions tend to lower the base of the elevated inversion, so reducing the mixing depth. Pre-frontal conditions are also characterised by relatively calm winds. Over the interior due to the passage of a cold front, there is a tendency for the lowest mixing depths to coincide with the coldest air temperatures and rising pressure. Following the passage of the front, a gradual rise in the mixing depth occurs over the interior (Cosijn, 1996; Preston-Whyte and Tyson, 1988).

APPENDIX B

AMBIENT AIR QUALITY EVALUATION CRITERIA

Air quality standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site. Ambient air quality guideline values are intended to indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Air quality standards are normally given for specific averaging periods.

Ambient air quality standards for particulate matter, sulphur dioxide and oxides of nitrogen are discussed in Sections B.1 and Section B.2.

B.1 Ambient Air Quality Criteria for Suspended Particulates

The impact of particles on human health is largely depended on (i) particle characteristics, particularly particle size and chemical composition, and (ii) the duration, frequency and magnitude of exposure. The potential of particles to be inhaled and deposited in the lung is a function of the aerodynamic characteristics of particles in flow streams. The aerodynamic properties of particles are related to their size, shape and density. The deposition of particles in different regions of the respiratory system depends on their size.

The nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne particulates. Larger particles are deposited in the nasal region by impaction on the hairs of the nose or at the bends of the nasal passages. Smaller particles (PM10) pass through the nasal region and are deposited in the tracheobronchial and pulmonary regions. Particles are removed by impacting with the wall of the bronchi when they are unable to follow the gaseous streamline flow through subsequent bifurcations of the bronchial tree. As the airflow decreases near the terminal bronchi, the smallest particles are removed by Brownian motion, which pushes them to the alveolar membrane (Figure B-1) (CEPA/FPAC Working Group, 1998; Dockery and Pope, 1994).

Air quality guidelines for particulates are given for various particle size fractions, including total suspended particulates (TSP), inhalable particulates or PM10 (i.e. particulates with an aerodynamic diameter of less than 10 µm), and respirable particulates of PM2.5 (i.e. particulates with an aerodynamic diameter of less than 2.5 µm). Although TSP is defined as all particulates with an aerodynamic diameter of less than 100 µm, and effective upper limit of 30 µm aerodynamic diameter is frequently assigned. PM10 and PM2.5 are of concern due to their health impact potentials. As indicated previously, such fine particles are able to be deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung.

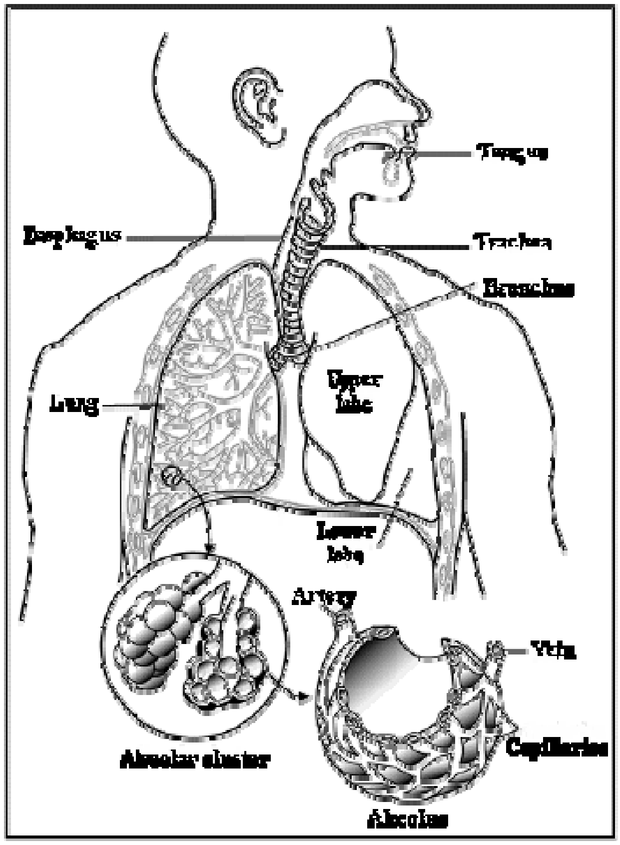

Figure B-1: Schematic diagram indicating the trachea, bronchus and alveolar regions (NCOH, 1992).

B.1.1 Air Quality Guidelines and Standards for Suspended Particulates

Ambient air quality guidelines were initially given in South Africa by the Department of Health for TSP. TSP guidelines were given as 300 µg/m^3 for maximum daily averages and 100 µg/m^3 for annual averages. During the mid 1990s, the Department of Environmental Affairs and Tourism (DEAT), which had taken over responsibility for air quality management from the Department of Health, issued air quality guidelines for PM10. The UK and EC air quality criteria presented in Table B-1 represent objectives/standards to be achieved by the year 2004/2005 and are designed primarily to protect human health. The South African standards are significantly less stringent than the recently issued UK objectives, WB guidelines and EC standards. It is however currently proposed that the South African limits be brought in line with such international criteria. The recently issued SANS limits reflect this (Table B-1).

Table B-1: Air quality guidelines and standards for inhalable particulates (PM10)

Country / Organisation	Inhalable Particulates (PM10)	
	Maximum 24-hour Concentrations (μg/m³)	Annual Average Concentrations (μg/m³)
South Africa - current standards	180(1)	60(2)
South Africa - SANS limits	75(11) 50(12)	40(11) 30(12)
United States EPA (US-EPA)	150(3)	50(2)(4)
European Community (EC) Standards	50(5)	30(6) 20(7)
UK National Air Quality Objectives	50(8)	40(9)
World Bank (WB)	70(10)	50(10)

Notes:

(1) Not to be exceeded more than three times per year.

(2) Represents the arithmetic mean.

(3) Not to be exceeded more than once per year.

(4) Requires that the *three-year* annual average concentration be less than this limit.

(5) Compliance by 1 January 2005. Not to be exceeded more than 25 times per calendar year. (By 1 January 2010, no violations of more than 7 times per year will be permitted.)

(6) Compliance by 1 January 2005.

(7) Compliance by 1 January 2010.

(8) 24-hour mean, not to be exceeded more than 35 times a year. Compliance by 31 December 2004.

(9) Annual mean, with compliance required by 31 December 2004.

(10) Pollutant concentration limit at property boundary (World Bank 1998).

(11) South African limit values, reference: *SANS 1929 - Ambient air quality - Limits for common pollutants (draft document).*

(12) South African target values, reference: *SANS 1929 - Ambient air quality - Limits for common pollutants (draft document).*

An eight-year study of over 550,000 adults living in 151 different U.S. urban areas showed that residents of the most polluted cities lose one to three years of life expectancy. The researchers controlled for physical differences in the adults such as age, gender and smoking habits, and found that particulate pollution caused a significant number of deaths from lung cancer and heart disease (Pope III *et al*, 1995). A 15-year study of 8,000 people showed that those living in areas with higher levels of particulate pollution have a 26% higher risk of early death (Dockery and Pope III, 1993). A Utah study showed that increases in particulate pollution resulted in a 40% increase in overall absences from school by children (Pope III *et al*, 1992).

Based on these scientific data, the US EPA has recently proposed a supplementary sub-standard for PM2.5 (i.e. particulates < 2.5 μm). The PM2.5 standard is given as:

Maximum 24 hr average	-	65 μg/m³
Annual average	-	15 μg/m³

An exceedance of the maximum daily average limit by the three-year average 98th percentile of 24-hour concentrations would constitute a violation of this standard. The PM2.5 three-year annual average needs to be less than the 15 µg/m^3 limit in order to demonstrate compliance with the annual standard (Chow and Watson, 1998).

B.1.2 Dose Response Relationships for Suspended Particulate Exposures

The World Health Organisation (WHO) no longer supports air quality threshold levels for particulates. The WHO stated that the development of a new procedure for the assessment of health impacts occurring due to airborne particulates was necessary since the threshold for the onset of health effects could not be detected (WHO, 2000). The new approach adopted by the WHO is comparable to that for carcinogenic compounds, with linear relationships between PM10 or PM2.5 concentrations and various types of health effects being established. Such linear relationships are presented in Figures B-2 to B-4 for increases in daily mortality rates, hospital admissions and various health endpoints such as bronchodilator use, cough and symptom exacerbation (WHO, 2000).

The WHO recommends that reference be made to the linear relationship of PM10 and PM2.5 with various health effect indicators in determining acceptable levels of risk. In determining 'acceptable' airborne particulate concentrations, a decision-maker will be faced with the following controversial decisions:

- selection of the curve to be used for deriving an acceptable ambient particulate concentration (i.e. decide from which health effect the population is to be protected);

- determine the population or sensitive groups to be protected from air pollution effects. For example, the use of the bronchodilator application curve would imply that asthmatics are a sensitive group to be protected by the chosen standard; and

- set a fixed value for the acceptable risk in a population so that a single value for a given exposure period may be defined (Junker and Schwela, 1998; Schwela, 1998).

The graphs given in Figures B-2 to B-4 were not intended for use for PM10 concentrations below 20 µg/m^3, or above 200 µg/m^3; or for PM2.5 concentrations below 10 µg/m^3 or above 100 µg/m^3. This caution is required as mean 24-hour concentrations outside of these ranges were not used for the risk assessment and extrapolations beyond these ranges would therefore be invalid.

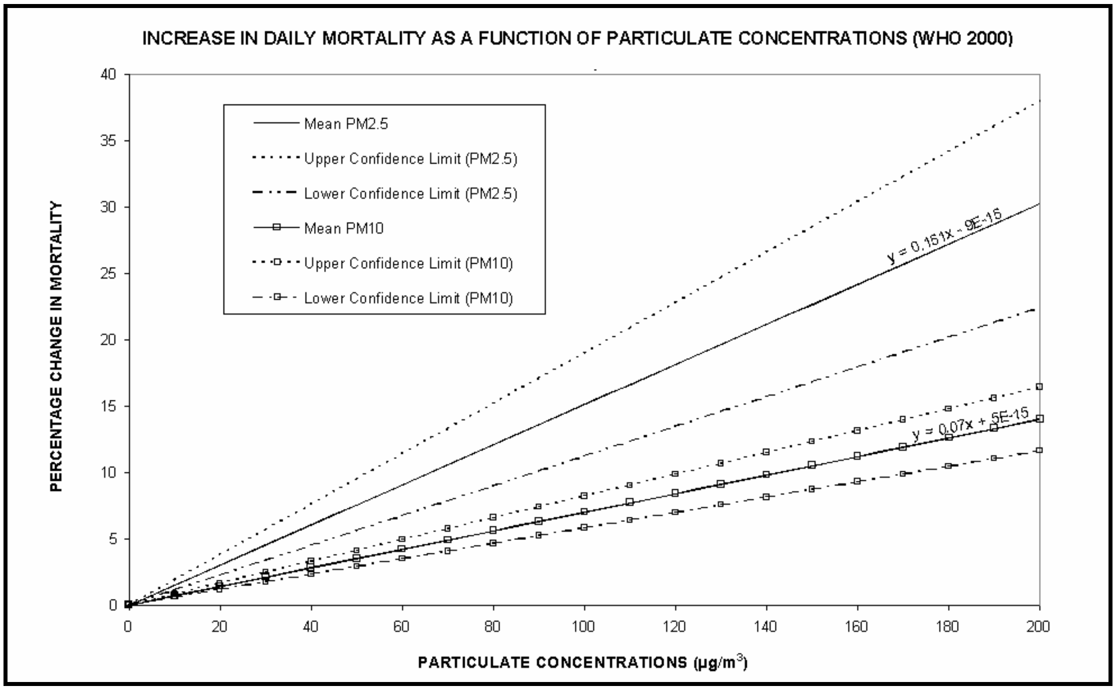

Figure B-2: Increases in daily mortality as a function of increases in PM10 and PM2.5 concentrations (after WHO, 2000).

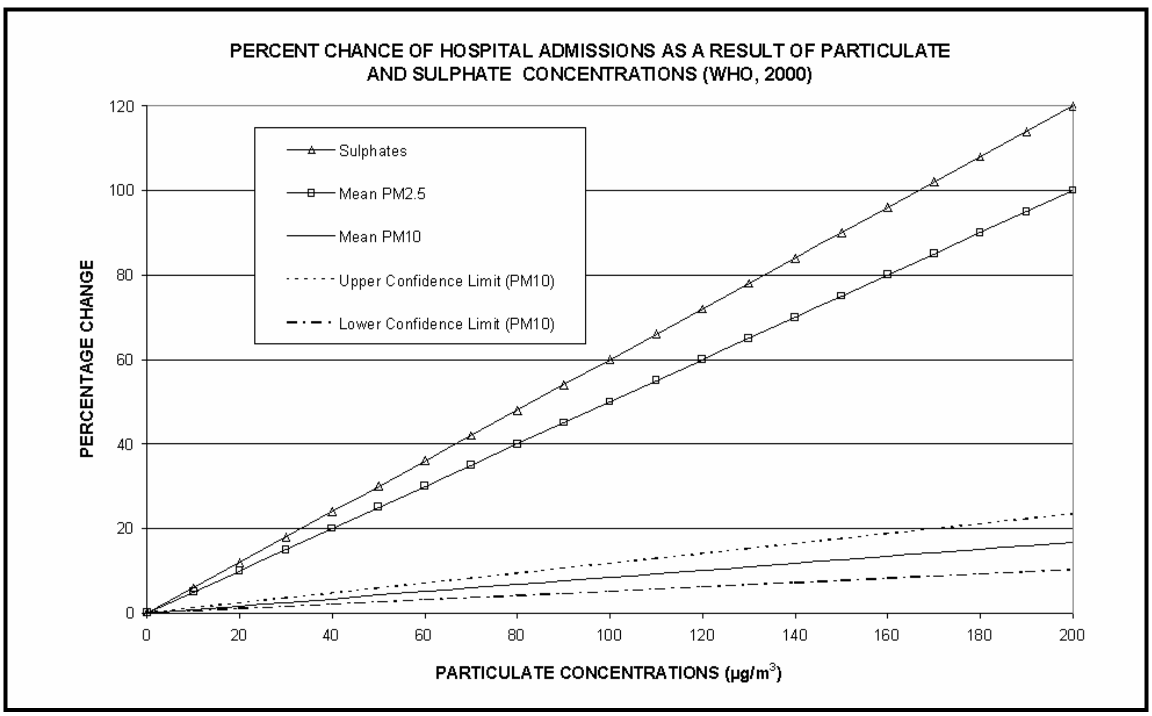

Figure B-3: Increases in hospital admissions as a result of increased PM10, PM2.5 and sulphate concentrations (WHO, 2000).

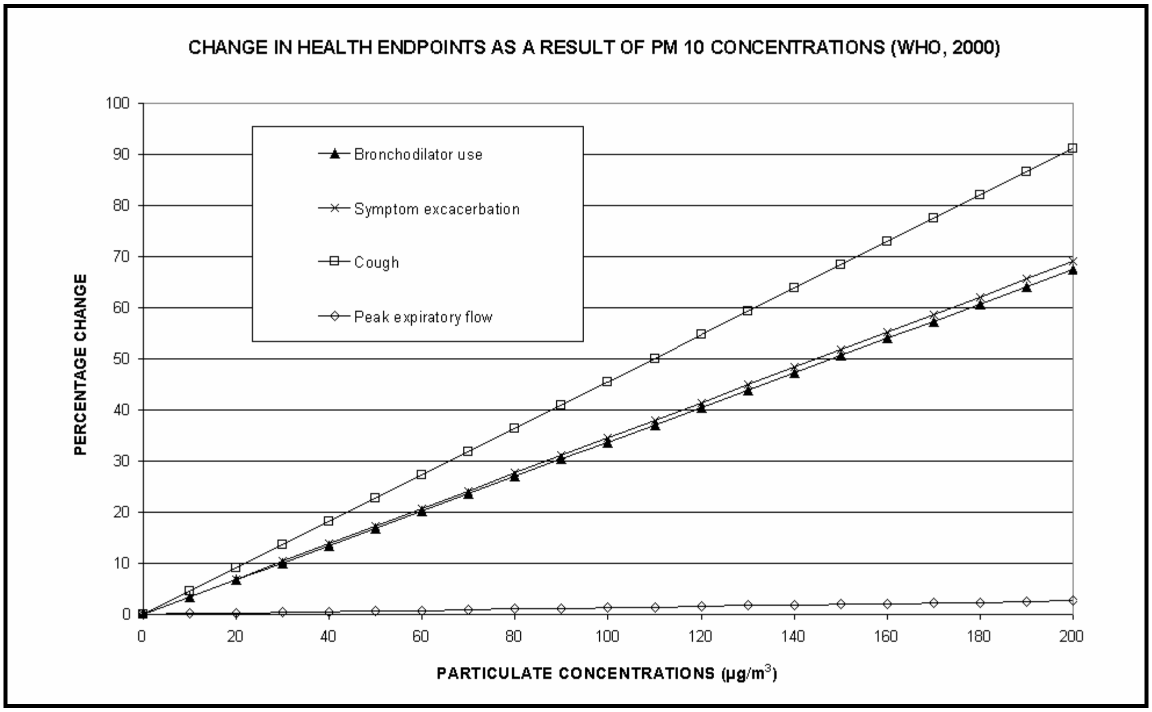

Figure B-4: Percentage change in the occurrence of various health endpoints as a result of changes in ambient PM10 concentrations (WHO, 2000).

The Canadian Environmental Protection Agency (CEPA) has recently undertaken an extensive review of epidemiological studies conducted throughout the world with regard to the relationship between particulate concentrations and human health. The conclusion reached was that daily or short-term variations in particulate matter, as PM10 or PM2.5, were significantly associated with increases in all-cause mortality in 18 studies carried out in 20 cities across North and South America, England, and Europe. The association between particulate concentrations and acute mortality could not be explained by the influence of weather, season, yearly trends, diurnal variations, or the presence of other pollutants such as SO_2, CO, NO_x and O_3 (CEPA/FPAC Working Group, 1998).

In its review, the CEPA could find no evidence of a threshold in the relationship between particulate concentrations and adverse human health effects, with estimates of mortality and morbidity increasing with increasing concentrations. As for the relationship expressed by the WHO, the lack of an apparent threshold suggests that it is problematic to select a level at which no adverse effects would be expected to occur as a result of exposure to particulate matter. The relative risk for PM10 was given by the CEPA as varying between 0.4% and 1.7% per 10 µg/m^3 increase, with an unweighted mean of 0.8% and a weighted mean of 0.5% per 10 µg/m^3 increase. In what the CEPA termed the “best-conducted study” which examined PM2.5, a mean increase in mortality of 1.5% per 10 µg/m^3 was observed (CEPA/FPAC Working Group, 1998) (Figure B-5).

The CEPA recommended that the reference levels for PM10 and PM2.5, for a *daily* averaging period, be 25 µg/m^3 and 15 µg/m^3, respectively. These levels are estimates of the lowest ambient particulate concentrations at which statistically significant increases in health responses can be detected based upon available data and current technology. The CEPA emphasises that the reference levels should not be interpreted as thresholds of effects, or levels at which impacts do not occur (CEPA/FPAC Working Group, 1998).

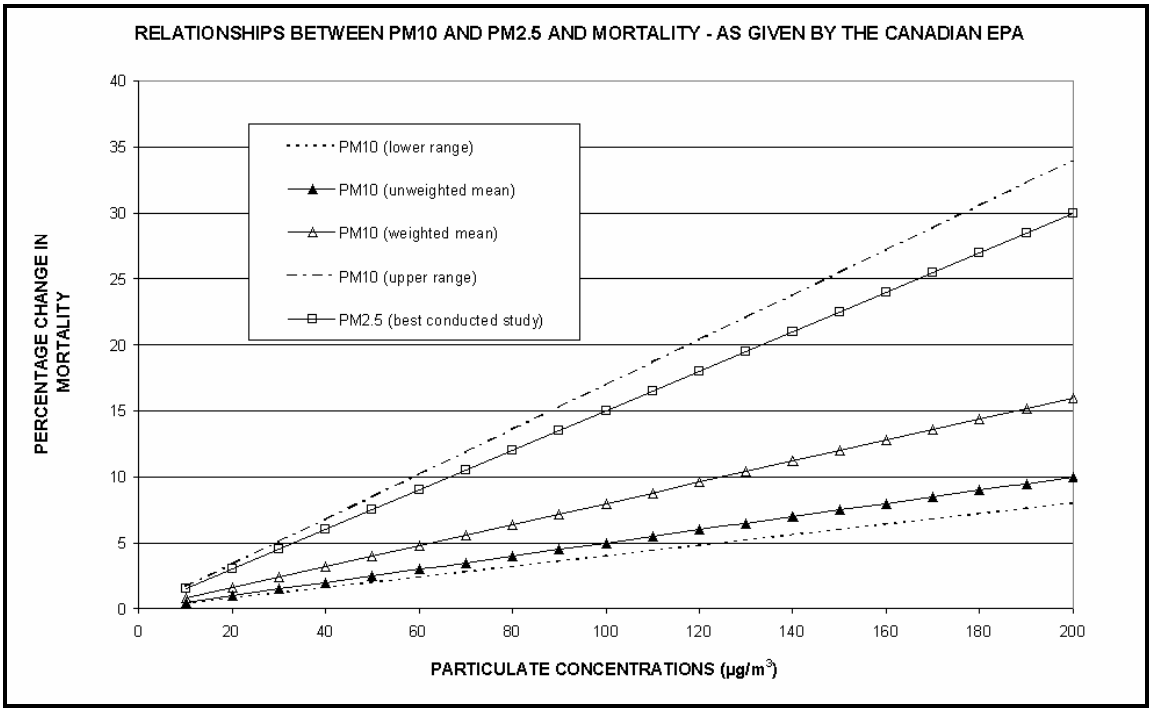

Figure B-5: Relationships between PM10 and PM2.5 and mortality indicated by the Canadian EPA (CEPA/FPAC Working Group, 1998).

A fairly recent review was prepared by CONCAWE (Hext *et al.* 1999) of the health effects of exposure to PM2.5 particles, including the so-called ultra fine particles with aerodynamic diameter of <0.1 µm. The following conclusions were presented in their report:

- *Dosimetric consideration of inhaled PM2.5 suggests that asymmetric deposition patterns in some individuals with obstructive lung diseases might result in localised doses from near ambient concentrations that might enhance the already existing conditions.*

- *Particles of low solubility pose a limited risk to health but animal experiments imply that trace metals and adsorbed components associated with some particle types may enhance pulmonary responses.*

- *Many of the experimental studies have been conducted at high concentrations and used the rat as experimental species. It is now evident that the rat lung may over-respond to the presence of particles in the lung, especially at high doses, and thus results in this species and their extrapolation to man may need to be interpreted with caution.*

- *Ambient acidic particles probably pose the greatest risk to health and there is a suggestion from epidemiological studies that acidity is an important aspect of air pollution with respect to respiratory symptoms.*

- *There is no effect of concern on pulmonary function in normal healthy individuals at concentrations of acidic aerosols as high as 1000 µg/m^3. Effects that may have biological significance may occur at concentrations below 100 µg/m^3 in the most sensitive asthmatic individuals.*

- *There is evidence to suggest that acidic particles may enhance in a synergistic manner the effects of gaseous components of air pollution such as O_3, adding support to the view that health effects associated with episodic increases in urban airborne pollutants arise from an additive or synergistic combination of exposure to both the particulate phase and the gaseous phase.*

- *Ultra fine particles (particles < 100 nm diameter) may pose a greater health risk due to higher particle numbers and deposition efficiencies in the lung and greater biological reaction potential, but further studies or evidence will be required for a full evaluation to be made.*

- *There is a limited number of epidemiological studies that have specifically addressed PM2.5. These appear to provide limited evidence of an association between PM2.5 levels and acute and chronic mortality available at present. However, this is not convincing for several reasons including study design, lack of robust correlation between environmental data and reported exposed population, and inability of identifying or selecting out one individual harmful component (PM2.5) from an ambient mixture of a number of potentially harmful components.*

- *The overall pattern that emerges is that PM2.5, at normal ambient levels or those seen during episodic pollutant increases, poses limited risk, if any, to normal healthy subjects. Individuals suffering already from cardio-respiratory disease or pre-disposed to other respiratory diseases such as asthma may be at risk of developing adverse responses to exposure to increased ambient levels of PM2.5 but more robust evidence is required to substantiate this.*

Dose-response coefficients for PM10 used by the UK Department of Environment, Transport and the Regions in a recent study were given as follows (Stedman *et al,* 1999):

Health Outcome:		**Dose-Response Coefficient:**
Deaths brought forward (all causes)	-	+0.75% per 10 µg/m^3 (24 hr mean)
Respiratory hospital admissions	-	+0.8% per 10 µg/m^3 (24 hr mean)

The United Kingdom Department of Environment classifies air quality on the basis of concentrations of fine particulates as follows (based on 24-hour average concentrations):

< 50 µg/m^3	=	Low
50 – 74 µg/m^3	=	Moderate
75 – 99 µg/m^3	=	High

> 100 µg/m³ = Very high

In estimating the health costs due to road traffic-related air pollution, the WHO Ministerial Conference on Environment and Health used chronic exposure levels (Seethaler, 1999) in three countries namely Austria, France and Switzerland to derive increased frequencies of health outcomes. Seven air pollution related health outcomes were considered. These and the Effect Estimate Relative Risk are summarised in Table B-2.

Table B-2: Additional health cases for exposure to 10 µg/m³ PM10 increments (Seethaler 1999).

Health Outcome	Age	Effect Estimate Relative Risk [1]
Total Mortality	Adults (≥ 30 years)	1.043 (Range: 1.026 –1.061)
Respiratory Hospital Admissions	All Ages	1.0131 (Range: 1.001 –1.025)
Cardiovascular Hospital Admissions	All Ages	1.0125 (Range: 1.007 –1.019)
Chronic Bronchitis Incidence	Adults (≥ 25 years)	1.098 (Range: 1.009 –1.194)
Acute Bronchitis	Children (< 15 years)	1.306 (Range: 1.135 –1.502)
Restricted Activity Days [2]	Adults (≥ 30 years)	1.094 (Range: 1.079 –1.109)
Asthmatics: Asthma Attacks [3]	Children (< 15 years)	1.044 (Range: 1.027 –1.062)
Asthmatics: Asthma Attacks [3]	Adults (≥ 15 years)	1.039 (Range: 1.019 –1.059)

Notes:
[1] Calculated expectancy frequency at the reference level of 7.5 µg/m³ PM10 (±95% confidence interval)
[2] Restricted activity days: total person-days per year
[3] Asthma attacks: total person days with asthma attacks

It is important to note that the linear relationships depicted by the WHO, CEPA and UK Department of Environment, Transport and the Regions are based on *epidemiological* studies. Causal relationships based on *clinical* studies have not yet been established to support such linear relationships. Clinical studies involve controlled human exposure investigations, whereas epidemiological studies are observational in nature. In epidemiological studies, the investigator has no control over exposure or treatment of subjects, but rather examines the statistical relationship between dose and response.

B.2 Ambient Air Quality Criteria for Gaseous Pollutants

B.2.1 Air Quality Guidelines and Standards for Sulphur Dioxide (SO_2)

SO_2 is an irritating gas that is absorbed in the nose and aqueous surfaces of the upper respiratory tract, and is associated with reduced lung function and increased risk of mortality and morbidity. Adverse health effects of SO_2 include coughing, phlegm, chest discomfort and bronchitis.

Short-period exposures (less than 24 hours): Most information on the acute effects of SO_2 comes from controlled chamber experiments on volunteers exposed to SO_2 for periods ranging from a few minutes up to one hour (WHO, 2000). Acute responses occur within the first few minutes after commencement of inhalation. Further exposure does not increase effects. Effects include reductions in the mean forced expiratory volume over one second (FEV_1), increases in specific airway resistance, and symptoms such as wheezing or shortness of breath. These effects are enhanced by exercise that increases the volume of air inspired, as it allows SO_2 to penetrate further into the respiratory tract. A wide range of sensitivity has been demonstrated, both among normal subjects and among those with asthma. People with asthma are the most sensitive group in the community. Continuous exposure-response relationships, without any clearly defined threshold, are evident.

Sub-chronic exposure over a 24-hour period: Information on the effects of exposure averaged over a 24-hour period is derived mainly from epidemiological studies in which the effects of SO_2, suspended particulate matter and other associated pollutants are considered. Exacerbation of symptoms among panels of selected sensitive patients seems to arise in a consistent manner when the concentration of SO_2 exceeds 250 µg/m^3 in the presence of suspended particulate matter. Several more recent studies in Europe have involved mixed industrial and vehicular emissions now common in ambient air. At low levels of exposure (mean annual levels below 50 µg/m^3; daily levels usually not exceeding 125 µg/m^3) effects on mortality (total, cardiovascular and respiratory) and on hospital emergency admissions for total respiratory causes and chronic obstructive pulmonary disease (COPD), have been consistently demonstrated. These results have been shown, in some instances, to persist when black smoke and suspended particulate matter levels were controlled, while in others no attempts have been made to separate the pollutant effects. In these studies no obvious threshold levels for SO_2 have been identified.

Long-term exposure: Earlier assessments, using data from the coal-burning era in Europe judged the lowest-observed-adverse-effect level of SO_2 to be at an annual average of 100 µg/m^3, when present with suspended particulate matter. More recent studies related to industrial sources of SO_2, or to the changed urban mixture of air pollutants, have shown adverse effects below this level. There is, however, some difficulty in finding this value.

Based upon controlled studies with asthmatics exposed to SO_2 for short periods, the WHO (WHO, 2000) recommends that a value of 500 µg/m^3 (0.175 ppm) should not be exceeded over averaging periods of 10 minutes. Because exposure to sharp peaks depends on the nature of local sources, no single factor can be applied to estimate corresponding guideline values over longer periods, such as an hour. Day-to-day changes in mortality, morbidity, or lung function related to 24-hour average concentrations of SO_2 are necessarily based on epidemiological studies, in which people are in general exposed to a mixture of pollutants; and guideline values for SO_2 have previously been linked with corresponding values for suspended particulate matter. This approach led to a previous guideline 24-hour average value of 125 µg/m^3 (0.04 ppm) for SO_2, after applying an uncertainty factor of two to the lowest-observed-adverse-effect level. In more recent studies, adverse effects with significant public health importance have been observed at much lower levels of exposure. However, there is still a large uncertainty with this and hence no concrete basis for numerical changes of the 1987-guideline values for SO_2.

Ambient air quality guidelines and standards issued for various countries and organisations for sulphur dioxide are given in Table B-3. The EC's air quality criteria represent standards to be achieved by the year 2005, and would supersede the EU standards. The ambient air quality standards of the US-EPA are based on clinical and epidemiological evidence.

Table B-3: Ambient air quality guidelines and standards for sulphur dioxide for various countries and organisations

Averaging Period	South Africa (SA standards/SANS)		World Bank (2002)		World Health Organisation (1999)		US-EPA		European Community	
	µg/m³	ppm	µg/m³	ppm	µg/m³	ppm	µg/m³	ppm	µg/m³	ppm
Annual Average	50(7)	0.019(7)	50	0.019	50(3) 10-30(10)	0.019(3) 0.004-0.01(10)	80(1)	0.03(1)	20(2)	0.008(2)
Max. 24-hour Ave	125(7)	0.048(7)	125	0.048	125(3)	0.048(3)	365(4)	0.14(4)	125(5)	0.048(5)
Max 1-hour Ave	-	-	-	-	350(9)	0.133(9)	-	-	350(6)	0.133(6)
Instantaneous Peak	500(7)(8)	0.191(7)(8)	-	-	500(3)(8)	0.191(3)(8)	-	-	-	-

Notes:

(1) Arithmetic mean.
(2) Limited value to protect ecosystems. Applicable two years from entry into force of the Air Quality Framework Directive 96/62/EC.
(3) Air Quality guidelines (issued by the WHO for Europe) for the protection for human health (WHO, 2000).
(4) Not to be exceeded more than 1 day per year.
(5) Limit to protect health, to be compiled with by the 1 January 2005 (not to be exceeded more than 3 times per calendar year).
(6) Limit to protect health, to be compiled with by the 1 January 2005 (not to be exceeded more than 4 times per calendar year).
(7) Recommended interim guidelines for South Africa by DEAT (Government Gazette, 21 Dec. 2001). These limits are also supported by SANS (SANS, 2004).
(8) 10 minute average.
(9) WHO 1994.
(10) Represents the critical level of ecotoxic effects (issued by WHO for Europe); a range is given to account for different sensitivities of vegetation types.

These standards were established by determining concentrations with the lowest-observed-adverse effect, adjusted by an arbitrary margin of safety factor to allow for uncertainties in extrapolating from animals to humans and from small groups of humans to larger populations. The standards of the US-EPA also reflect the technological feasibility of attainment.

Dose-response coefficients for SO_2 used by the UK Department of Environment, Transport and the Regions in a recent study were given as follows (Stedman et al., 1999):

Health Outcome:		Dose-Response Coefficient:
Deaths brought forward (all causes)	-	+0.6% per 10 µg/m^3 (24 hr mean)
Respiratory hospital admissions	-	+0.5% per 10 µg/m^3 (24 hr mean)

In the formulation of the WHO goals, the lowest observed level at which adverse health effects are observed to occur as a result of a particular pollutant is identified and a margin of safety added. Margins of safety are included to account for uncertainties in, for example, extrapolating health effects from animals to humans or from small human sample group to entire populations. The observed effect level and uncertainty factor identified by the WHO for sulphur dioxide are indicated in Table B-4 for each averaging period. From the values given in Table B-4 it is apparent that an exceedance of a WHO goal would not necessarily result in the occurrence of health effects.

Table B-4: Comparison of observed effect levels and WHO SO_2 guidelines (WHO, 2000).

Averaging Period	Observed Effect Level (µg/m³)	Uncertainty Factor	WHO Guideline Value (µg/m³)
10 minutes	1000	2	500
24-hour	250	2	125
Annual average	100	2	50

B.2.2 Air Quality Guidelines and Standards for Oxides of Nitrogen

NO_x is one of the primary pollutants emitted by motor vehicle exhausts. NO_2 is formed through oxidation of these oxides once released in the air. NO_2 is an irritating gas that is absorbed into the mucous membrane of the respiratory tract. The most adverse health effect occurs at the junction of the conducting airway and the gas exchange region of the lungs. The upper airways are less affected because NO_2 is not very soluble in aqueous surfaces. Exposure to NO_2 is linked with increased susceptibility to respiratory infection, increased airway resistance in asthmatics and decreased pulmonary function.

Available data from animal toxicology experiments indicate that acute exposure to NO_2 concentrations of less than 1 880 µg/m^3 (1 ppm) rarely produces observable effects (WHO, 2000). Normal healthy humans, exposed at rest or with light exercise for less than two hours to concentrations above 4 700 µg/m^3 (2.5 ppm), experience pronounced decreases in pulmonary function; generally, normal subjects are not affected by concentrations less than 1 880 µg/m^3 (1.0 ppm). One study showed that the lung function of subjects with chronic obstructive pulmonary disease is slightly affected by a 3.75-hour exposure to 560 µg/m^3 (0.3 ppm) (WHO, 2000).

Asthmatics are likely to be the most sensitive subjects, although uncertainties exist in the health database. The lowest concentration causing effects on pulmonary function was reported from two laboratories that exposed mild asthmatics for 30 to 110 minutes to 565 $\mu g/m^3$ (0.3 ppm) NO_2 during intermittent exercise. However, neither of these laboratories was able to replicate these responses with a larger group of asthmatic subjects. NO_2 increases bronchial reactivity, as measured by the response of normal and asthmatic subjects following exposure to pharmacological broncho-constrictor agents, even at levels that do not affect pulmonary function directly in the absence of a broncho-constrictor.

Some, but not all, studies show increased responsiveness to broncho-constrictors at NO_2 levels as low as 376-565 $\mu g/m^3$ (0.2 to 0.3 ppm); in other studies, higher levels had no such effect. Because the actual mechanisms of effect are not fully defined and NO_2 studies with allergen challenges showed no effects at the lowest concentration tested (188 $\mu g/m^3$; 0.1 ppm), full evaluation of the health consequences of the increased responsiveness to broncho-constrictors is not yet possible.

Studies with animals have clearly shown that several weeks to months of exposure to NO_2 concentrations of less than 1 880 $\mu g/m^3$ (1 ppm) causes a range of effects, primarily in the lung, but also in other organs such as the spleen and liver, and in blood. Both reversible and irreversible lung effects have been observed. Structural changes range from a change in cell type in the tracheobronchial and pulmonary regions (at a lowest reported level of 640 $\mu g/m^3$), to emphysema-like effects. Biochemical changes often reflect cellular alterations, with the lowest effective NO_2 concentrations in several studies ranging from 380-750$\mu g/m^3$. NO_2 levels of about 940 $\mu g/m^3$ (0.5 ppm) also increase susceptibility to bacterial and viral infection of the lung. Children of between 5-12 years old are estimated to have a 20% increased risk for respiratory symptoms and disease for each increase of 28 $\mu g/m^3$ NO_2 (2-week average), where the weekly average concentrations are in the range of 15-128 $\mu g/m^3$ or possibly higher. However, the observed effects cannot clearly be attributed to either the repeated short-term high-level peak, or to long-term exposures in the range of the stated weekly averages (or possibly both). The results of outdoor studies consistently indicate that children with long-term ambient NO_2 exposures exhibit increased respiratory symptoms that are of longer duration, and show a decrease in lung function.

Table B-5: Ambient air quality guidelines and standards for NO_2

Averaging Period	South Africa (SA standards)		South Africa (SANS limits)		World Health Organisation (1994)		US-EPA		European Union	
	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb
Annual Average	96	50	40	21	40	21	100(1)	53(1)	40(2)	21(2)
Max. 1-month Ave	153	80	-	-	-	-	-	-	-	-
Max. 24-hour Ave	191	100	-	-	150	80	-	-	-	-
Max. 1-hour Ave	382	200	200	100	200	100	-	-	200(3)	100(3)
Instantaneous Peak	955	500	-	-	-	-	-	-	-	-

Notes:
(1) Annual arithmetic mean.
(2) Annual limit value for the protection of human health, to be complied with by 1 January 2010.
(2) Averaging times represent 98th percentile of averaging periods; calculated from mean values per hour or per period of less than an hour taken through out year; not to be exceeded more than 8 times per year. This limit is to be complied with by 1 January 2010.

Table B-6: South African air quality standards for oxides of nitrogen(1)

Averaging Period	South African NO Standards		South African NO_2 Standards		South African NO_x Standards	
	µg/m³	ppb	µg/m³	ppb	µg/m³	ppb
Annual Average	188	150	96	50	283	200
Max. 1-month Ave	250	200	153	80	403	300
Max. 24-hour Ave	375	300	191	100	566	400
Max. 1-hour Ave	750	600	382	200	1132	800
Instantaneous Peak	1125	900	955	500	2080	1400

Note:
(1)Although the standards are given by the DEAT in ppb, the equivalent values in µg/m³ were calculated for NO_2 and NO based on the molecular weights of these constituents and the assumption of ambient conditions comprising an ambient temperature of 20°C and a pressure of 1 atmosphere. NO_x concentration limits in µg/m³ were calculated by summing the NO and NO_2 limits.

The standards and guidelines of most countries and organisations are given exclusively for NO_2 concentrations. South Africa's NO_2 standards are compared to various widely referenced foreign standards and guidelines in Table B-5. In addition, South Africa also publishes standards for oxides of nitrogen (NO_x) and nitrous oxide (NO). The standards for NO and NO_x are presented in Table B-6.