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GENERAL NOTICE

NOTICE 1404 OF 2001

DEPARTMENT OF ENVIRONMENTAL AFFAIRS AND TOURISM

INVITATION FOR PUBLIC COMMENTS ON THE TECHNICAL BACKGROUND DOCUMENT FOR THE DEVELOPMENT OF A NATIONAL AMBIENT AIR QUALITY STANDARD FOR SULPHUR DIOXIDE

The document **Technical Background Document for the Development of a National Ambient Air Quality Standard for Sulphur Dioxide**, as set out in the Schedule, is hereby published for public comment, before the new ambient air quality guideline for sulphur dioxide, as proposed in the document, is considered for official adoption. The new ambient air quality guideline, once adopted, will be enforceable in terms of the Atmospheric Pollution Prevention Act, 1965 (Act No. 45 of 1965) and therefore repeal the current South African Guideline for Sulphur Dioxide.

All interested parties and organisations are invited to comment in writing on the document and to direct comments to:

Dr N Tsengwa, Deputy Director-General, Department of Environmental Affairs and Tourism, Private Bag X447, PRETORIA, 0001, fax (012) 322-2602 and/or e-mail ntsengwa@ozone.pwv.gov.za

Kindly provide the name, address, telephone number, fax number and/or e-mail address of the person or organisation submitting the comments.

Comments should reach the department not later than 29 June 2001.

SCHEDULE

(Document to follow)

Technical Background Document for the Development of a National Ambient Air Quality Standard for Sulphur Dioxide

Department of Environmental Affairs and Tourism

Foreword

The Environmental Quality and Protection Office of Department of Environmental Affairs and Tourism has prepared this technical background document on the effects of sulphur dioxide on human health and vegetation to serve as a source document to support decision-making in the implementation of a National Ambient Air Quality Standard (NAAQS) for South Africa.

In the development of this document, the scientific literature has been reviewed, key studies have been evaluated, and conclusions have been prepared so that the impacts of sulphur dioxide could be assessed in the South African context.

The emphasis of this document is a detailed discussion of the relevancy and potential applicability of the World Health Organisation's guidelines for sulphur dioxide under the socio-economic conditions and health status of the South African developing nation.

Authors and contributors

The Environmental Quality and Protection Office of the Department of Environmental Affairs in Pretoria prepared this document.

Author

Willie van Niekerk PhD QEP (USA)

Outside contributors

Marlene Fourie PhD (Medical Science), INFOTOX (Pty) Ltd
Yvonne Scorgie MSc (Air Quality Management), Matrix Environmental Consultants

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List of abbreviations

APHEA	Air Pollution and Health: A European Approach
AQMO	Air quality management plan
COPD	Chronic obstructive pulmonary disease
DALYs	Disability-adjusted life years
DEAT	Department of Environmental Affairs and Tourism
DETR	UK Department of Environment, Transport and the Regions
FEV_1	Forced expiratory volume in one second
ICD	International classification of diseases
IUFRO	International Union of Forest Research Organisations
LOAEL	Lowest-observed-adverse-effect level
NAAQS	National ambient air quality standard
PM_{10}	Particulate matter smaller than 10 μm in aerodynamic diameter
$PM_{2.5}$	Particulate matter smaller than 2.5 μm in aerodynamic diameter
ppm	Parts per million
PSD	Prevention of significant deterioration
RV/TLC%	Residual volume as a proportion of the total lung capacity
SIP	State implementation plan
UK DETR:	UK Department of the Environment, Transport and the Regions
UN/ECE	United Nations Economic Commission for Europe
USEPA	US Environmental Protection Agency
WHO	World Health Organisation

Glossary of terms

Adverse effect Change in morphology, physiology, growth, development or life span of an organism exposed to air pollution, which results in impairment of functional capacity or impairment of capacity to compensate for additional stress or increase in susceptibility to the harmful effects of other environmental influences.

Asthma A disease caused by increased responsiveness of the tracheobronchial tree to various stimuli, which results in paroxysmal constriction of the bronchial airways. Also see paroxysm.

Bronchi The two main branches leading from the trachea to the lungs, providing a passageway for air.

Bronchiole One of the smaller subdivisions of the bronchial tube.

Bronchiolitis Inflammation of the bronchioles.

Bronchitis Inflammation of the mucous membrane of the bronchial airways.

Cardiovascular Pertaining to the heart and blood vessels.

Chronic obstructive pulmonary disease A disease process that decreases the ability of the lungs to perform ventilation. Diagnostic criteria include a history of persistent dyspnea and exertion, with or without chronic cough, and less than half of normal predicted maximum breathing capacity. Diseases that cause this condition are chronic bronchitis, pulmonary emphysema, chronic asthma, and chronic bronchiolitis.

Dyspnea Air hunger resulting in laboured or difficult breathing, sometimes accompanied by pain.

Emphysema A chronic pulmonary disease marked by an abnormal increase in the size of air spaces distal (farthest from the center) to the terminal bronchioles with destructive changes in their walls.

Expiration Expulsion of air from the lungs in breathing. Normally the duration of expiration is shorter than that of inspiration. In general, if expiration lasts longer than inspiration, a pathological condition such as emphysema or asthma is present.

Exposure assessment Quantitative or qualitative evaluation of the contact of a chemical with the outer boundary of the human body, which includes consideration of the intensity, frequency and duration of contact, the route of exposure (e.g. dermal, oral or respiratory), rates (chemical intake or uptake rates), the resulting amount that actually crosses the boundary (a dose), and the amount absorbed (internal dose).

Forced expiratory volume (FEV) The volume of air that can be expired after a full inspiration. The expiration is done as quickly as possible and the volume measured at precise times; at ½, 1, 2 and 3 seconds. This provides valuable information concerning the ability to expel air from the lungs.

Glottis The narrow opening at the upper end of the larynx.

Guideline Any kind of recommendations or guidance on the protection of human beings or receptors in the environment from the adverse effects of air pollutants. As such, it is not restricted to a numerical value but might also be expressed in a different way, for example as exposure-response information or as a unit risk estimate.

Larynx The organ of voice, which also forms one of the higher parts of the air passages.

Lowest-observed-adverse-effect level Lowest concentration of amount of a substance, found by observation or experiment, which causes an adverse effect.

Lowest-observed-effect level Lowest concentration or amount of a substance, found by observation or experiment, which causes an effect.

Morbidity The number of sick persons or cases of disease in relationship to a specific population.

Morphological Pertaining to the science of structure and form of organisms without regard of function.

Mortality The death rate; the ration of the number of deaths to a given population.

No-observed-adverse-effect level Greatest concentration or amount of a substance, found by observation or experiment, which causes no detectable adverse effect. Effects may be detected at this level, which are not judged to be adverse.

No-observed-effect level Greatest concentration of amount of a substance, found by observation or experiment, which causes no detectable effect.

Oedema Abnormal accumulation of fluid beneath the skin, or in one or more of the cavities of the body.

Paroxysm A sudden, periodic attack or recurrence of symptoms of a disease; an exacerbation of the symptoms of a disease.

Particle aerodynamic diameter Diameter of a sphere of density 1 g/m3 with the same terminal velocity due to gravitational force in calm air as the particle, under the prevailing conditions of temperature, pressure and relative humidity.

Standard A level of an air pollutant, e.g. a concentration or a deposition value, which is adopted by a regulatory authority as enforceable. Unlike a guideline value, a number of elements in addition to the effect-based level and the averaging time must be specified in the formulation of a standard. These elements include the measurement strategy, data handling procedures and statistics used to derive, from measurements, the value to be compared with the standard. The numerical value of a standard may also include the permitted number of exceedances.

Trachea A cylindrical tube from the larynx to the primary bronchi.

Uncertainty factor A factor that allows for a variety of uncertainties, for example, possible undetected effects on particularly sensitive members of the population, synergistic effects of multiple exposures, the adequacy of existing data, the extrapolation from animals to humans and the extrapolation from a small group of individuals to a large population. Uncertainty factors are based on scientific judgements in a complex decision process, involving the transformation of mainly non quantitative information into a single number.

Wheeze A continues musical sound caused by narrowing of the space of a respiratory passageway.

Section 1

The standard-setting process

1.1 Introduction

Air pollution has been recognised as a major cause of environmental health problems, affecting developed and developing countries around the world. The purpose of ambient air quality guidelines or standards is to provide a basis for protecting public health from the adverse effects of air pollution and for eliminating, or reducing to a minimum, those air contaminants that are known to be, or are likely to be, hazardous to human health and well being.

1.1.1 Air quality guidelines

An ambient air quality guideline is defined as a set of concentrations and exposure times that are associated with specific effects of varying degrees of air pollution on man, animals, vegetation and on the environment in general (WHO, 1964). In developing a guideline concentration, a health-risk based ambient air quality goal is derived.

The original paradigm for regulatory human health risk assessment in the USA was developed by the USA National Research Council (NRC, 1983). This model has been adopted and refined by the US Environmental Protection Agency (USEPA), and essentially divides human health risk assessment into the following steps:

- ***Hazard assessment*** is the identification of chemical and biological contaminants suspected to pose hazards and a description of the types of toxicity that they evoke.

- ***Dose-response assessment*** (toxicological assessment) addresses the relationship between levels of biological exposure and the manifestation of adverse health effects in humans, and/or how humans can be expected to respond to different doses or concentrations of contaminants.

- ***Exposure assessment*** includes a description of the environmental pathways and distribution of hazardous substances, identification of exposed individuals or communities, the routes of direct and indirect exposure, and an estimate of concentrations and duration of the exposure.

- ***Risk characterisation*** involves the integration of each component described above, with the purpose of determining whether specific exposures to an individual or a community would lead to adverse health effects.

More recent approaches for full risk characterisation examine hazard assessment, dose-response assessment and exposure assessment in a more interactive way. The procedures involve knowledge of what is known and not known about the toxicant, its modes of action and effects in target tissue, what the assumptions and uncertainties are, and the level of confidence in extrapolating from animals to humans, and from high dose to low dose. This differs from the original stepwise concept of risk assessment, going from hazard assessment to dose-response assessment to exposure assessment and risk characterisation in an almost linear fashion. It is important to recognise limitations in toxicological and epidemiological data, and to account for these in the risk quantification step.

The approach in developing an ambient air quality goal for an air pollutant is basically a "backwards" risk assessment, starting from risk levels that are considered to be acceptable in a population (target risk levels). The various elements of the risk assessment paradigm are then applied to derive an ambient air quality goal in a generic exposure scenario that would be adequate to protect the health of the population against a particular air pollutant according to the target risk level.

In setting the ambient air quality goal, the relevance of international guidelines and standards is considered. These should be used to provide a broader perspective on the interpretations, but should not dictate the decision on the ambient air quality goal.

1.1.2 Air quality standards

An ambient air quality standard is a description of a level of air quality that is adopted by a regulatory authority as enforceable (WHO, 2000a). In its simplest form, an ambient air quality standard should be defined in terms of one or more concentrations and averaging times. In addition, an implementation plan and management strategy should be developed. These would include the schedule of implementation, monitoring that is relevant in assessing compliance with the standard, methods of data analysis, quality assurance protocols, and procedures for dealing with non-attainment.

1.1.3 Developing guidelines into standards

In moving from guidelines to standards, prevailing exposure levels and environmental, social, economic and cultural conditions in a nation or region should be taken into account. In certain circumstances there may be valid reasons to pursue policies that will result in pollutant concentrations above or below the guideline values. Ideally, guideline values should represent concentrations of chemical compounds in air that would not pose any hazard to the human population. However, the realistic assessment of human health hazards necessitates a distinction between absolute safety and acceptable risk. In setting standards, the definition of acceptable risk is related to risk perception and economic and social circumstances. Data on environmental contaminants are not always comprehensive and conclusive enough to aim at achieving absolute safety, therefore scientific judgement and consensus play an important role in establishing acceptable levels of population exposure (WHO, 2000a).

In setting air quality standards on the basis of air quality guidelines, it is necessary to define from which effects the population is to be protected. Health effects range from death and acute illness, through chronic and lingering diseases, to temporary physiological or psychological changes. The distinction between *adverse* and *non-adverse* effects sometimes poses considerable difficulties. An adverse effect has been defined as "any change in morphology, physiology, growth, development or life span of an organism which results in impairment of functional capacity, or impairment of capacity to compensate for additional stress, or increase in susceptibility to the harmful effects of other environmental influences" (WHO, 1994a). Judgements as to whether the health effects are adverse may differ between countries, because of factors including different cultural backgrounds and different levels of health status.

Figure 1.1 on page 3 illustrates the process of developing and setting standards.

This document describes all the elements that were considered in deriving a national ambient air quality guideline for sulphur dioxide. It provides the technical basis for developing a national ambient air quality standard for sulphur dioxide.

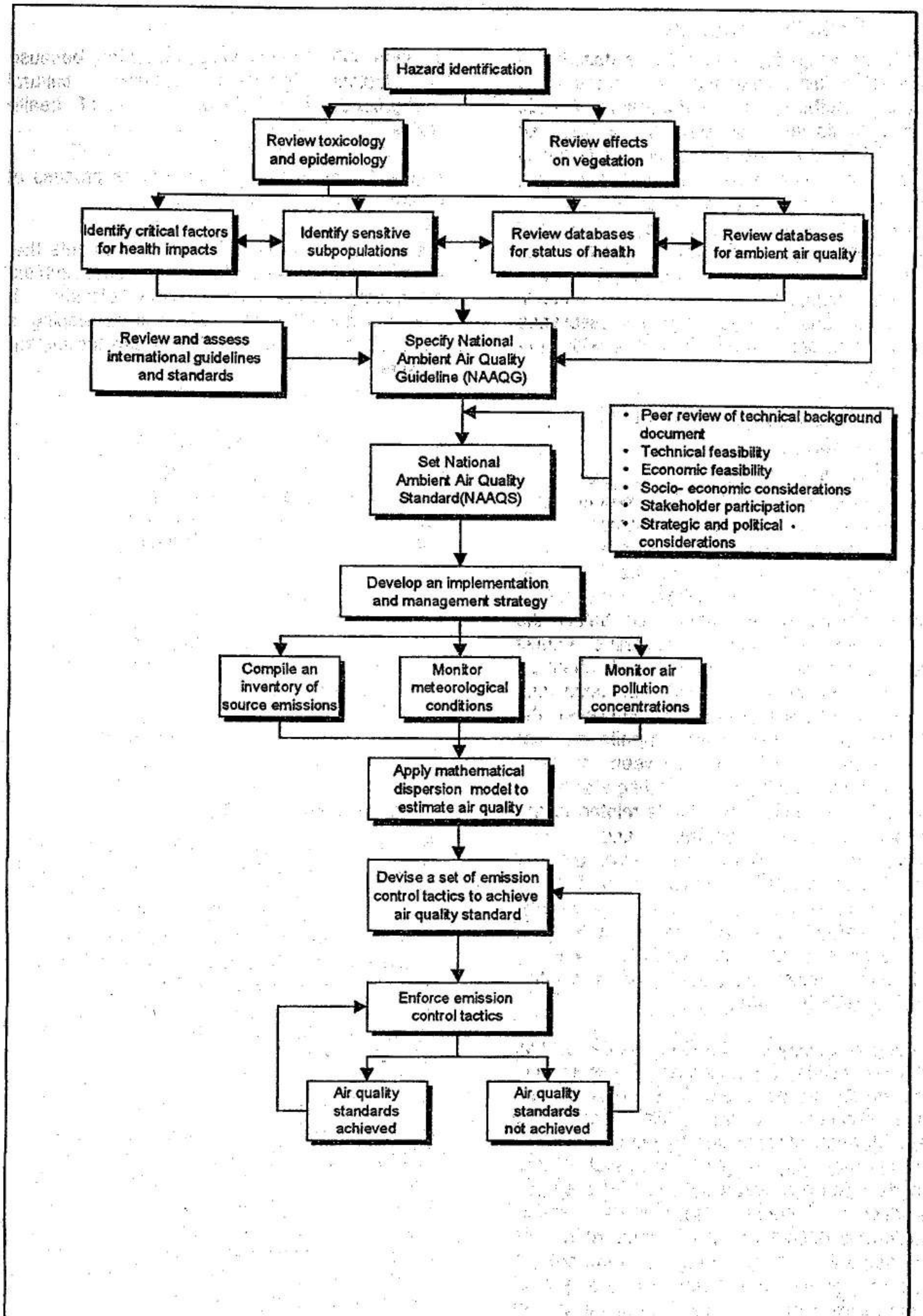


Figure 1.1.3: Diagram of the standard-setting process.

Section 2

Hazard assessment for sulphur dioxide

2.1 Physical and chemical information

Synonyms:
Bisulphite
Sulphurous oxide
Sulphur oxide
Sulphur dioxide

Hazard rating:	3 (highly toxic)
CAS registry number:	7446-09-5
Molecular formula:	SO_2
Molecular weight:	64.06

Properties:
Colourless, pungent, non-flammable, water soluble and reactive gas or liquid under pressure (Lewis, 1996).

Odour threshold:
1 175 μg SO_2/m^3 or 0.5 ppm. The threshold where 50 per cent of the exposed individuals would notice the odour (Ruth, 1986).

Conversion factors (at 0 °C, 101.3 kPa):
1 ppm = 2860 μg SO_2/m^3
1 mg/m^3 = 0.35 ppm

2.2 Hazard profile

SO_2 is a poisonous gas. Human systemic effects by inhalation include pulmonary vascular resistance, respiratory depression and other pulmonary changes. It chiefly affects the upper respiratory tract and the bronchi. It may cause oedema of the lungs or glottis, and can produce respiratory paralysis. It is a corrosive irritant to eyes, skin, and mucous membranes. This material is so irritating that it provides its own warning of toxic concentration. Levels of 400–500 ppm are immediately dangerous to life. However, less than fatal concentrations can be borne for fair periods of time with no apparent permanent damage. It is a common air contaminant (Lewis, 1996).

2.3 Sources

Sulphur dioxide (SO_2) and particles derived from the combustion of fossil fuels are major air pollutants in urban areas of the world (WHO, 1987a). Natural sources of SO_2, such as volcanic action and forest fires, exceed anthropogenic sources on a global scale. However, when considering the effects of air pollutants on health, especially in urban areas where population densities are high, anthropogenic sources are very important and are those to which attention is usually directed with a view to control. In most countries, motor vehicles, industrial activity and the generation of electricity account for a large percentage of the anthropogenic production of sulphur oxides (WHO, 2000a).

2.4 Sulphur dioxide in ambient air

Sulphur oxides (SO_x) and particulate matter are parts of a complex pollutant mixture. For a more holistic view of the pollutant profile, a division into three categories is appropriate:

- Sulphur dioxide;
- Acid aerosols that may result from the oxidation of sulphur dioxide in the atmosphere, and
- Sulphur dioxide in combination with particulates.

2.4.1 Sulphur dioxide

Sulphur in fuel gives rise to both primary and secondary pollutants. SO_2 is formed by oxidation during the combustion of sulphur-containing fossil fuels, the smelting of sulphur-containing ores and other industrial processes. Domestic fires can also produce emissions containing SO_2 (WHO, 1987a). It is soluble in airborne water droplets, within which it can be oxidised to sulphate, bisulphite and sulphite ions (Manahan, 1994).

2.4.2 Acid aerosol

Further oxidation of SO_2 leads to SO_3, which rapidly undergoes hydration to sulphuric acid and this, in turn, is neutralised by NH_3 to ammonium bisulphate and ammonium sulphate. These compounds make an important contribution to the ambient fine particle aerosol (WHO, 2000a). Sulphuric acid (H_2SO_4) is a strong acid that is strongly hygroscopic. In the atmosphere, it is present as an aerosol, often associated with other pollutants in droplets or solid particles extending over a wide range of sizes. Most of the sulphuric acid in ambient air results from SO_2 emitted by combustion. Other direct or primary point sources of sulphuric acid include acid manufacturing plants and consuming industries, such as fertilizer and pigment factories. Sulphuric acid and ammonium bisulphate represent almost all of the strong acid content in the ambient aerosol. Acidic aerosol concentrations can be expressed as µmoles of H^+/m^3 or as sulphuric acid equivalent in µg/m^3 (WHO, 1987a).

2.4.3 SO_2 and particulate matter

Airborne particulate matter represents a complex mixture of organic and inorganic substances. SO_2 can only reach the gas-exchange region of the lungs after sorption onto fine particles. (See Section 3.1.1.1 below.) Particulate matter of less than 10 µm aerodynamic diameter (PM_{10}) is regarded as a better indicator of health-related effects than total suspended particulates (WHO, 1987a). PM_{10} particulate matter is divided into two principal groups: particles larger than 2.5 µm in aerodynamic diameter, and fine particles smaller than 2.5 µm in aerodynamic diameter ($PM_{2.5}$) (WHO, 2000a). The acid component of particulate matter is generally contained in the fine fraction, although in fog some coarser acid droplets are also present.

Section 3

The effects of sulphur dioxide on human systems and vegetation

3.1 Review of toxicology and epidemiology: How sulphur dioxide reacts in the human body

Inhalation is the only route of exposure that is of interest in relation to the effects of sulphur dioxide, acidic aerosol and suspended particulate matter on human health; therefore only health effects on the respiratory tract are considered. Essential parts of the human respiratory system are illustrated in Figure 3.1. More detail of the components of the respiratory system is listed in the glossary of terms.

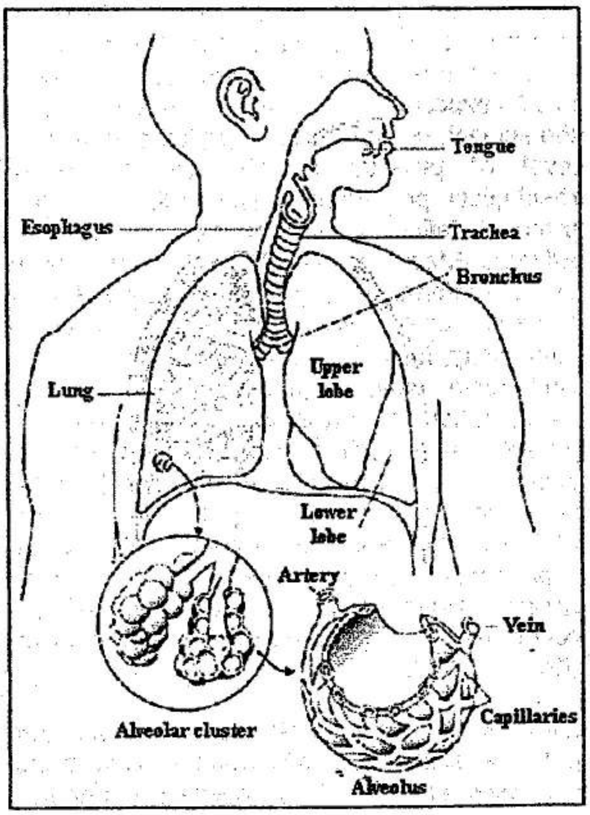


Figure 3.1: Illustration of the human respiratory system (after Scorgi, 2001).

3.1.1 Sulphur dioxide

SO_2 has a highly non-uniform dose distribution along the conductive airways of the respiratory tract (WHO, 2000a). Absorption in the mucous membranes of the nose and upper respiratory tract occurs as a result of its solubility in aqueous media. Absorption is concentration-dependent, with 85 per cent absorption in the nose at 4 to 6 mg/m^3, and about 99 per cent at 46 mg/m^3 (WHO, 1987a). For low-to-moderate tidal volumes and nasal breathing, the penetration into the lungs is negligible. For larger tidal volumes and oral inhalation, doses of interest may extend into segmental bronchi (WHO, 2000a). From the respiratory tract, sulphur dioxide enters the blood. Elimination occurs (after biotransformation to sulphate in the liver), mainly by the urinary route (WHO, 1987a). The biological half-life of sulphur dioxide is less than 10 minutes (Roach, 1992). On exposure, trigeminal nerve endings in the nasal mucosa are stimulated, leading to a stinging or burning sensation. Coughing is excited by even slight irritation of the larynx from stimulation of laryngeal nerve endings. The protective reflexes are coughing, constriction of the larynx and bronchi, closure of the glottis, and inhibition of respiration. On continued exposure, the irritation effects may seem to become less pronounced. This reflects the development of a tolerance or desensitisation, which happens rapidly with SO_2 (Roach, 1992).

3.1.2 Acid aerosol

The deposition pattern within the respiratory tract is dependent on the size distribution of the ambient droplets and humidity. Acidic ambient aerosol typically has a mass median aerodynamic diameter of 0.3 to 0.6 µm. Thus, particles remain within the fine-particle range and deposit preferentially in the distal lung airways and airspaces. Some neutralisation of the droplets can occur before deposition, due to the normal excretion of endogenous ammonia into the airways. Deposited free H^+ reacts with components of the mucus of the respiratory tract, changing its viscosity. The unreacted part of H^+ diffuses into surrounding tissues. The capacity of the mucus to react with H^+ is dependent on the H^+ absorption capacity, which is reduced in acidic saturated mucus as found, for example, in asthmatics (WHO, 1987a). Persons having asthma or atopy can be about 10 times more susceptible to a bronchoconstrictive response than healthy subjects (WHO, 2000a).

Under fog conditions the ambient acid is incorporated into droplets, with average droplet sizes in the range of 10 to 15 μm. Such droplets can also contain dissolved nitric acid and other acidic vapours. Inhaled fog droplets will deposit primarily in the upper respiratory tract; very little will penetrate to the deeper lung airways, where most of the fine acidic aerosol will deposit (WHO, 1987a).

3.1.3 Particulate matter

In inhalation toxicology, the term "deposition" refers to removal from inspired air of inhaled particles, by contact with airway surfaces. "Clearance" refers to the subsequent removal of deposited material from the respiratory tract. Deposition of inhaled particles in the respiratory tract depends mainly on breathing pattern and particle size (aerodynamic diameter) (WHO, 1987a). With normal nasal breathing, coarse particles (10 μm and above) are mainly deposited in the upper respiratory tract (above the epiglottis) and fine particles are transported to the lower respiratory tract (WHO, 2000a). SO_2 can only reach the gas-exchange region of the lungs after sorption onto fine particles; and the available particle surface is limited except when very large mass concentrations of fine particles are present (WHO, 1994b). Current techniques used to measure the mass concentration of particles in air make use of size-specific sampling devices. Thus the mass of particles less than 10 μm diameter may be determined (PM_{10}) as an index of the mass concentration of particles that can penetrate into the human thorax (WHO, 2000a).

With mouth breathing, the regional deposition pattern changes markedly, extrathoracic deposition being reduced and tracheobronchial and pulmonary deposition enhanced. The proportion of mouth breathing to nose breathing increases with exercise and conversation. During mouth breathing, fine particles ($PM_{2.5}$) deposit primarily in the pulmonary region; 3 to 5 μm diameter particles deposit in significant amounts in both the pulmonary and tracheobronchial regions, and at 7 to 15 μm deposition is predominantly in the tracheobronchial as opposed to the pulmonary Walters *et al*, 1994, and Anderson *et al*, 1998region (WHO, 1987a).

3.2 Health effects

3.2.1 Acute effects

The effects of concern in relation to short-term exposures are those on the respiratory tract. Acute responses occur within the first few minutes after commencement of inhalation. Effects include reductions in lung function parameters 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 (WHO, 2000a). There is an extremely large variability of sensitivity to SO_2 exposure, both among normal individuals and those with asthma, but people with asthma are the most sensitive group in the community. High concentrations of SO_2 can give rise to severe effects in the form of bronchioconstriction and chemical bronchitis and tracheitis, as seen in occupational exposures to more than 10 000 μg/m^3. Concentrations of SO_2 in the range 2 600 to 2 700 μg/m^3 give rise to bronchospasms in asthmatics (WHO, 1987a).

3.2.2 Effects of repeated and/or long-term exposures

The occurrence of pulmonary effects in communities is often associated with combined exposure to SO_2 and particulates. The response to SO_2 exposure is a function of the sensitivity of the subject, concentration, duration of exposure, level of physical activity, and of mucus rheological properties (WHO, 1987a). More precise definition of the Lowest-Observed-Adverse-Effect Level (LOAEL) also depends on detailed information regarding the proportion of asthmatic or otherwise sensitive people in the community, for which estimates of around 5 per cent have been suggested (WHO, 1987a). Exacerbation of symptoms among sensitive patients arises when concentrations of SO_2 exceeds 250 μg/m^3 (24-hour average) in the presence of suspended particulate matter. Children exposed to sulphur dioxide at concentrations in the range 250 to 500 μg/m^3 (24-hour averages) were shown to have more cough than children living in other communities (Dodge, 1983).

Even at low daily levels 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 however been demonstrated (WHO, 2000a; Walters *et al*, 1994, and Anderson *et al*, 1998). These aspects are discussed in more detail in Section 3.3 below.

3.2.3 Sensory effects

At concentrations of 10 000 μg/m^3, SO_2 has a pungent, irritating odour. The odour in itself is not critical in relation to public health (WHO, 1987a).

3.2.4 Long-term health effects

There is no evidence in the literature that brief exposures to SO_2 at concentrations in the low parts-per-million range (around 10 ppm and lower) would cause long-term health effects. Concentrations higher than 50 ppm may result in damage to the larynx, trachea, distal airways, and alveoli. There is a risk in such cases that a second phase of respiratory symptoms may develop typically 2 to 3 weeks after the initial exposure. During this phase patients may develop respiratory failure with diffuse pulmonary infiltrates (Weiss *et al*, 1994). Persistent airflow obstruction occurs in some individuals after acute exposure to SO_2. It has been shown that after exposure to high levels of SO_2 in accident scenarios, those individuals who survive the exposures experience obstructive impairment of ventilatory function and permanent bronchial hyperreactivity (Piirila *et al*, 1996; Rabinovitch *et al*, 1989).

3.2.5 How to consider the SO_2, acid aerosol, and particulate matter mixture

In early health criteria work of the WHO, guidelines for sulphur dioxide were based on observations in scenarios where populations were exposed to a mixture of SO_2 and smoke or total suspended particulates. Epidemiological and experimental studies indicated effects of these constituents on respiratory health and they were previously included in guidelines on ambient SO_2 in the environment (WHO, 1987a). It was inferred that the guidelines might overestimate risk in situations where only SO_2 would be present (WHO, 1979). Current guidelines of WHO however consider exposure to SO_2 as a separate issue, not referring to the presence of other pollutants. In developing an ambient air quality guideline for South Africa, a similar approach was followed.

3.3 The public health gain of air pollutant regulation

3.3.1 Decreases in hospital admissions as a measure of health benefits

It has been demonstrated that there is a link between respiratory hospital admission rates and SO_2 concentrations. This is usually described as a percentage increase in the baseline respiratory hospital admission rate for an incremental increase in SO_2 concentration. Conversely, a decrease in SO_2 concentration in air would relate to a decrease in hospital admissions, which would reflect health benefits. Care should be taken in the interpretation, because several pollutants may contribute to the same symptoms. Some of the more prominent research findings in this field are reviewed below.

- Dab *et al.* (1996) assessed daily pollution levels in Paris for the period 1987 to 1992, as part of a multi city European Project (*Air Pollution and health: A European Approach (APHEA)*). The relative risk of a concentration of 100 □g/m^3 above the 24-hour and 1-hour reference values were reported for daily mortality as a result of respiratory conditions, and for the daily counts of hospital admissions for chronic obstructive pulmonary disease (COPD), asthma and all respiratory causes together (ICD-9 460-519; ICD-10 J00-J99) (Medicode 1996 and WHO 1992, respectively). The greatest relative risk was observed with the 24-hour index, showing an increase in admissions for COPD of almost 10 per cent. For asthma, an increase of 7 per cent in hospital admissions was associated with an increase of 100 □g/m^3 above the 5th percentile concentration for 24-hour data.

- Anderson *et al.* (1998) investigated the situation in London. They found that an increase of 10 □g SO_2/m^3 (daily average) was significantly associated with hospital admissions in the life stage 0 to 14 years.

- Schwartz *et al.* (1996) reviewed hospital admissions for all respiratory disease in persons aged 65 and older in Cayahoga County, Ohio. The relative risk for hospital admissions for respiratory disease as a result of exposure to sulphur dioxide was 1.03, calculated for each 100-□g SO_2/m^3 increase (as an average per day). A relative risk of 1.03 implies that the increase in SO_2/m^3 was associated with an increase of 3 hospital admissions per 1 000 admissions.

- In Barcelona, it was shown that 100-□g/m^3 increases in the daily average of SO_2 in summer were associated with a 15 per cent increase in cardiovascular mortality (Saez, 1993). In these studies, 24-hour averages never exceeded 160 □g/m^3.

- Associations were also found between admissions for chronic pulmonary obstructive disease and low levels of SO_2 (Sunyer *et al.* 1991; Sunyer *et al.*, 1993).

- In the UK, a figure of 0.5 per cent increase in respiratory hospital admissions for each 10 μg SO_2/m^3 increase in SO_2 concentration (based on the 24-hour mean concentration) has been documented (Stedman *et al*, 1999).

Because several pollutants are normally present, it is not simplistic to determine the effects of individual toxicants, and the evidence of the cause-effect relationship in some cases is not conclusive. Overall, however, the studies conducted under the APHEA are well documented and supported, and provide a good basis for assessment of damages and health benefits associated with variations in pollutant levels.

3.4 Effects of sulphur dioxide on vegetation

3.4.1 Exposure levels and effects

Evaluation of the ecotoxic effects of SO_2 on vegetation (crops, forests) should include evaluation of deposition effects and the contribution of SO_2 to total acidity. Critical levels and critical loads are derived to describe effects. Critical levels are concentrations of pollutants in the atmosphere above which direct adverse effects on receptors such as plants, ecosystems or materials may occur. Critical loads represent quantitative estimates of exposure, in the form of deposition, to one or more pollutants, below which significant harmful effects on specified sensitive elements of the environment will not occur (WHO, 2000a).

In view of its degree of phytotoxicity and its wide distribution, for many years SO_2 has been regarded in many parts of Europe as the most important air pollutant as far as plant damage is concerned (WHO, 1987b). Acute visible injury symptoms can be caused by episodes of relatively high concentrations of SO_2 and are usually observed on broadleaved plants as relatively large bleached (necrotic) areas. Chronic exposure of plants to SO_2 causes early ageing and chlorosis, a bleaching or yellowing of the normally green portions of the leaf. This visible injury may decrease the market value of certain crops and lower productivity of plants. Plant injury increases with increasing relative humidity (Smith, 1990, Botha & Olbrich, 1997).

SO_2 impairs stomatal functioning, which leads to a decrease in photosynthetic rates, which in turn causes a decrease in plant growth. Long-term, low-level exposure to SO_2 can reduce the yields of grain crops, such as wheat or barley, even in the absence of visible foliar symptoms (Mudd & Kozlowski, 1975). Damage to forest and plantation trees is also of concern. SO_2 has been shown to reduce net photosynthesis, increase dark respiration, and to increase transpiration rates. It also affects plant metabolism and has been shown to inhibit pollen germination (Smith, 1990, Botha & Olbrich, 1997).

Species that are sensitive to SO_2, for example spinach, cucumber and oats, may show decreases in growth at concentrations of 0.01 to 0.5 ppm SO_2. Green beans have shown significant reductions in plant growth, even in the absence of typical injury symptoms. Visible SO_2 injury to some crops can occur at dosages ranging from 0.05 to 0.50 ppm for 8 hours or more (Botha & Olbrich, 1997). Other crops such as maize, celery and citrus show much less damage at these low concentrations (Mudd & Kozlowski, 1975). Examples of sensitive plants include alfalfa, barley, cotton, squash and wheat, while resistant plants include cantaloupe, celery and corn (Botha & Olbrich, 1997).

The following threshold levels for injury due to SO_2 exposure have been described in sensitive plants:

- 0.5 to 1.05 ppm for 1 hour;
- 0.3 to 0.6 ppm for 3 hours, and
- 0.2 to 0.26 ppm for 6 to 8 hours.

Resistant species were found to have threshold levels for the development of visible symptoms at three times these concentrations.

Threshold concentrations for yield reductions were found to be:

- 0.2 ppm for recurrent short-term fumigations (equal to a 0.2 ppm monthly mean), and
- 0.08 ppm for long term continues exposures (equal to 0.08 ppm annual mean).

The growth of conifers and the yield of fruit trees can be reduced by:

- 0.10 ppm exposure over several weeks (equal to a 0.1 ppm monthly mean), and
- 0.05 ppm exposure over a three year period (equal to a 0.05 ppm annual mean).

The threshold concentration is lower for longer term exposures due to the cumulative effect of a reduced growth rate on yield (Botha & Olbrich, 1997).

SO_2 in the atmosphere is converted to sulphuric acid; therefore in areas with high levels of SO_2 pollution, SO_2 acid aerosols may damage plants (Smith, 1990). The effect of wet deposition (acid rain) on vegetation appears to be largely indirect and may be a consequence of chemical changes in the soil. Direct impacts of acidic precipitation on the foliage of plants have been shown to occur at acidities below pH 3. Although most rainfall is above this level, mists of pH 3 and below could occur. Acid precipitation has been implicated in increased erosion of cuticular waxes on the surfaces of leaves, leaching of essential nutrients from the soil and/or leaves, and the mobilisation of aluminium in the soil, which has been shown to damage root systems. Plant growth may also be reduced by factors such as an imbalance in the availability of essential nutrients such as calcium, magnesium and potassium (Botha & Olbrich, 1997).

3.4.2 Critical ambient air levels for vegetation

The International Union of Forest Research Organisations (IUFRO) recommends a SO_2 annual mean of 25 µg/m^3 (0.009 ppm) as maximum level for environmental protection against erosion and avalanches and to ensure full production in areas where growth is poor owing to other environmental stresses. A 24-hour average of 50 µg/m^3 (0.018 ppm) is recommended, which may not be exceeded more than 12 times in a period of 6 months (WHO, 1987b). The United Nations Economic Commission for Europe (UN/ECE) recommends critical levels, as annual means, of 30 µg/m^3 (0.010 ppm) for the protection of crops and 20 µg/m^3 (0.007 ppm) for the protection of forest trees, natural and semi-natural vegetation. A daily mean of 70 µg/m^3 (0.024 ppm) is recommended for the protection of crops, forest trees, natural and semi-natural vegetation (Botha & Olbrich, 1997) (Table 3.4).

Table 3.4. Critical levels for the protection of vegetation against the detrimental effects of SO_2.

Guideline	Agricultural crops		Forest trees		Natural and semi-natural vegetation	
	µg/m^3	ppm	µg/m^3	ppm	µg/m^3	ppm
IUFRO annual mean	25	0.009	25	0.009		
24 hour mean*	50	0.018	50	0.018		
UN/ECE annual mean	30	0.010	20	0.007	20	0.007
24 hour mean	70	0.024	70	0.024	70	0.024

IUFRO: International Union of Forest Research Organisations (WHO, 1987b)
UN/ECE: United Nations Economic Commission for Europe (Botha & Olbrich, 1997)
* May be exceeded 12 times in a period of 6 months.

3.5 Overview of the effects of sulphur dioxide on humans and vegetation

Figures 3.5.1 and 3.5.2 illustrate the effects of sulphur dioxide on human health and vegetation at different levels of environmental exposure. The enhanced vulnerability of asthmatics and respiratory compromised individuals is clearly shown. It is also indicated that effects on plants may occur at ambient air concentrations below ambient air quality guidelines based on human health.

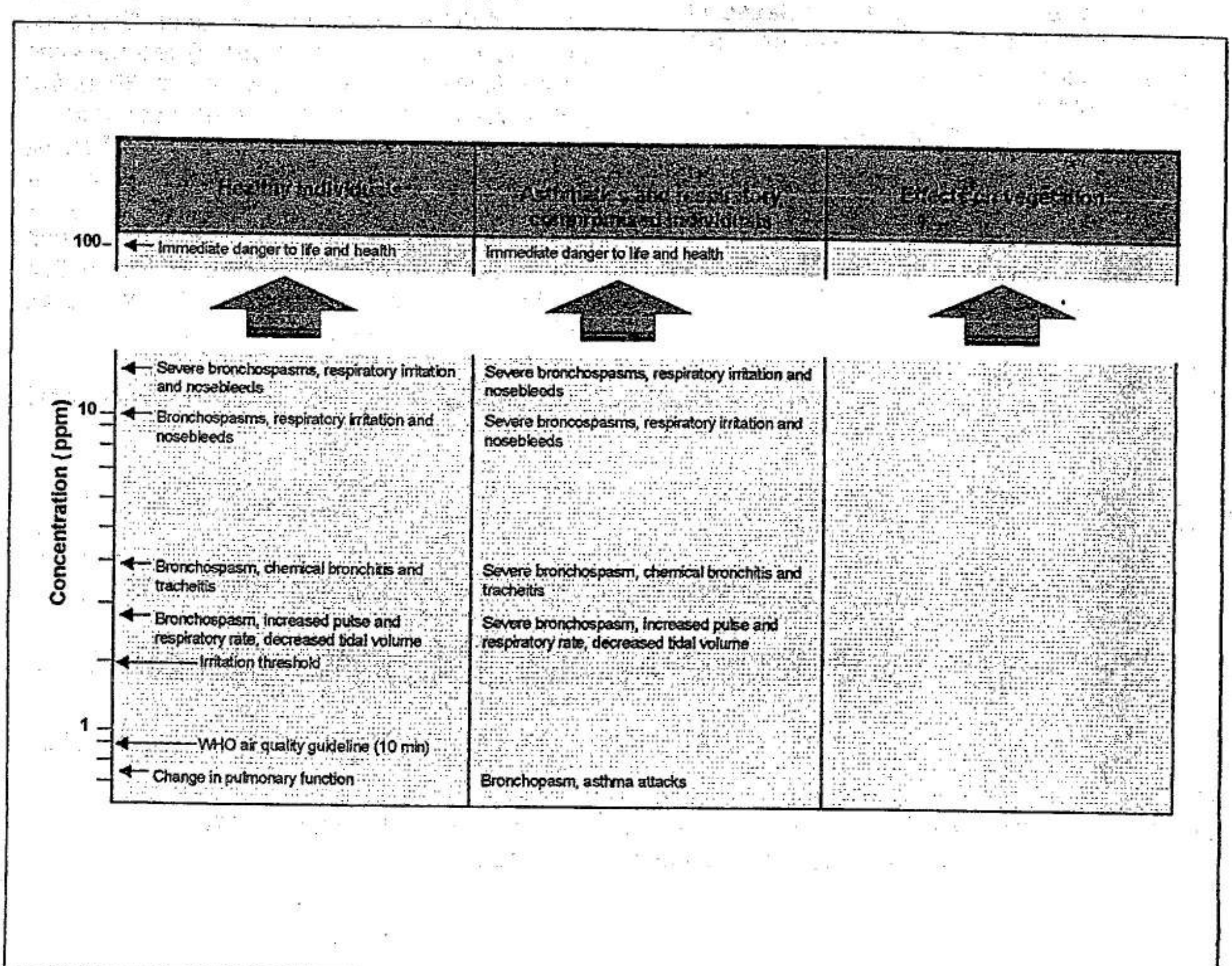


Figure 3.5.1: Impacts of sulphur dioxide on human health and vegetation at different levels in ambient air (high concentration range). Note the logarithmic scale.

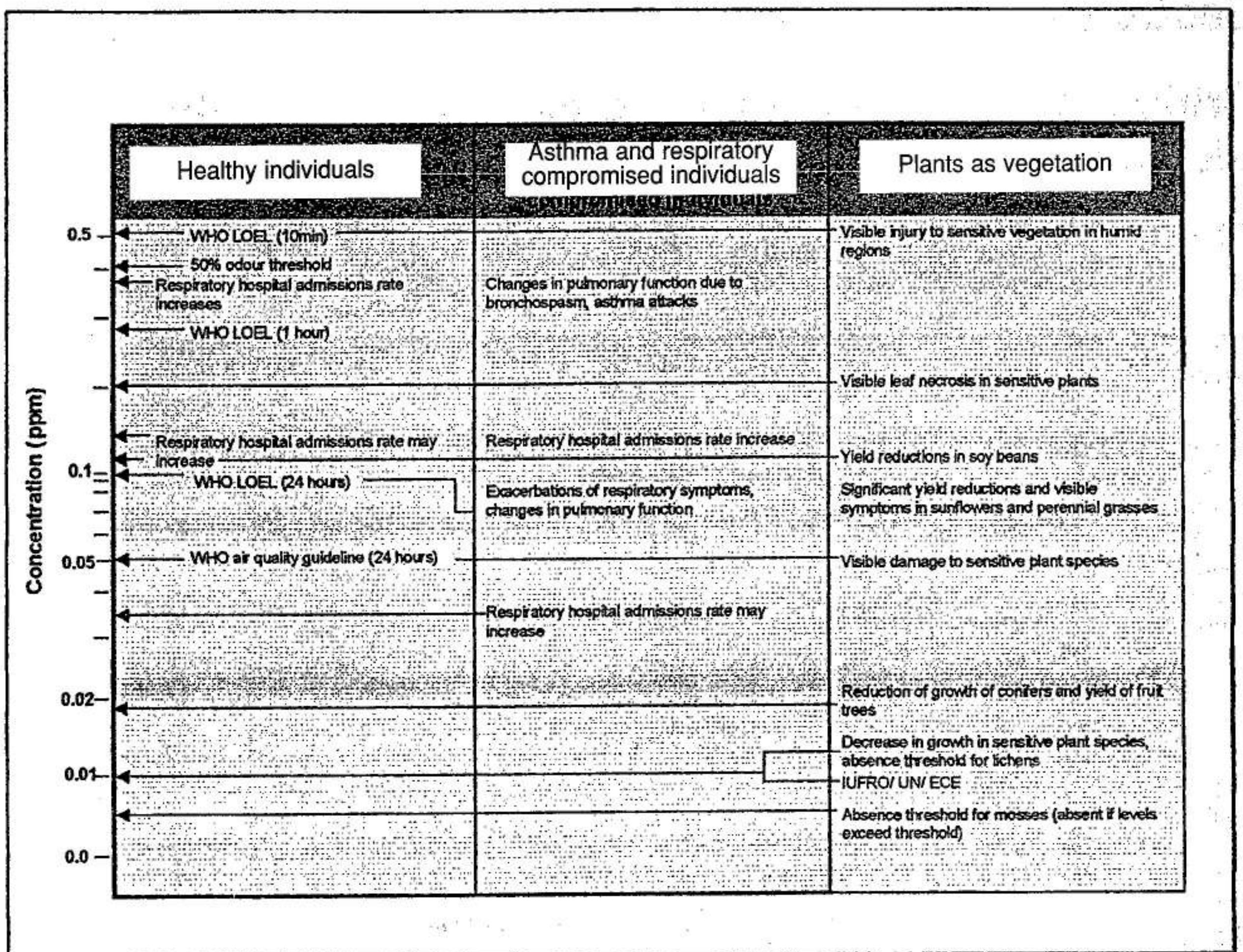


Figure 3.5.2: Impacts of sulphur dioxide on human health and vegetation at different levels in ambient air (low concentration range). Note the logarithmic scale.

Section 4

Critical factors for assessing exposure to sulphur dioxide

4.1 Critical factors for health impacts

4.1.1 Asthma

Asthma (ICD-9 code 493 (Medicode 1996); ICD-10 code J45 (WHO 1992)) is a disorder of breathing characterised by narrowing of airways within the lung. It is a disease caused by increased responsiveness of the tracheobronchial tree to various stimuli, which results in paroxysmal constriction of the bronchial airways (WHO, 2000a). The main symptom is breathlessness. Recent research has emphasised the importance of inflammation in the wall of the airways. Inflammation produces swelling in the airway wall, which narrows the lumen, and there is also contraction of the smooth muscle in the airway wall. The resultant narrowing of the airways in the lung causes great difficulty in breathing. The inflamed airways are unusually sensitive to a wide range of non-specific stimuli, including inhaled irritants and allergens. This results in obstruction to airflow, which is episodic (at least in individuals with early or mild asthma) and which causes symptoms of tightness and wheeziness in the chest (Macpherson, 1995).

4.1.2 Chronic obstructive pulmonary disease (COPD)

COPD (ICD-9 categories 490-496 except 493; ICD-10 categories J20, J40-44, J47) is a disease process that decreases the ability of the lungs to perform ventilation. Diagnostic criteria include a history of persistent dyspnea and exertion, with or without chronic cough, and less than half of normal predicted maximum breathing capacity. Diseases that cause this condition are chronic brônchitis, pulmonary emphysema, chronic asthma, and chronic bronchiolitis (WHO, 2000a). Obstructive diseases are always characterised by prolongation of airflow on expiration. They are most readily demonstrated by lung function parameters, including a reduction of the forced expiratory volume in one second (FEV_1), reduced maximum expiratory flow volume curve, and elevated residual volume as a proportion of the total lung capacity (RV/TLC%) (Douglas, 1984). The three major sites of chronic airflow obstruction are the large airways or bronchi, the small airways or bronchioles, and the gas-exchanging part of the lung, known as the acinus (Thurlbeck, 1991).

4.1.3 Cardiovascular disease

The cardiovascular system refers to the whole circulatory system: the heart, the systemic circulation (the arteries and veins of the body), and the pulmonary circulation (the arteries and veins of the lungs). Cardiovascular disease affects any of these structures and more than one at a time (Macpherson, 1995).

4.1.4 Socio-economic deprivation

Material deprivation or affluence and occupational class are most valuable in explaining inequalities of health. Social class is often regarded as *the* social concept that is fundamental to the explanation of the distribution of the quality of health (Townsend *et al.*, 1988). The World Health Report 2000, stating that inequalities in life expectancy are strongly associated with socio-economic class, confirmed the consequences of socio-economic deprivation in this regard. Furthermore, the gap between rich and poor widens when life expectancy is divided into years in good health and years of disability. In effect, the poor not only have a shorter life expectancy than the non-poor, a bigger part of their lifetime is surrendered to disability (WHO 2000b).

The health sector that was in place in South Africa in 1994 mirrored the inequalities existing in society. A long-established and well-developed private health care industry accounted for 61 per cent of health care financial resources, while providing for the needs of only the affluent 20 per cent of the population (WHO, 2000b). Today, the health concerns of the non-affluent 80 per cent of the population must be carefully protected by government regulations, also regarding the potential impacts of air pollutants on human health.

4.2 Sensitive subpopulations and the status of health in South Africa

Factors such as background pollutant concentrations and nutritional status of a community could influence the health outcomes of a population during incidents of air pollution. Elderly people and very young children tend to show increased susceptibility to air pollution and may be at increased risk (WHO, 2000a). People with a poor standard of living suffer from nutritional deficiencies, from infectious diseases due to poor sanitation and overcrowding, and tend to be provided with a poor standard of medical care. Each of these factors may render individuals more susceptible to the effects of air pollution (WHO, 2000a). Socio-economic deprivation is also strongly associated with hospitalisation rates for respiratory conditions, especially for asthma in children (Walters *et al*, 1995). In addition, in developing countries, poor air quality may be more closely associated with the incidence of infectious diseases (WHO, 2000a).

The World Health Report 2000 (WHO 2000b) contains a recent comparison of the burden of disease, estimated in disability-adjusted life years (DALYs), for the six WHO regions. The DALY consists of the loss of healthy life years due to either premature mortality or morbidity. The DALY integrates several dimensions of the public health impact, such as the number of affected persons and the severity and duration of adverse health effects, using time as a unit of measurement. It is superior to comparisons based on annual mortality rates, because it also includes non-lethal endpoints and addresses quality and quantity of life expectancy (Havelaar *et al.*, 2000).

In comparison to other regions, Africa's situation regarding COPD and cardiovascular disease does not appear excessive, both if DALYs (Table 4.2.1) and mortality rates (Table 4.2.2) are considered. The uncertainties of underreporting in a region notorious for its poor infrastructure should however still be kept in mind. The question may arise whether South Africa is not considerably different from the rest of Africa regarding the health status of the population, but the comparative life expectancy at birth reveals that South Africa is still clearly aligned with Africa as apposed to Europe or the Americas (Table 4.2.3).

The ratio of DALYs per 1000 people for asthma in Africa is clearly elevated compared to other regions. Any consideration of sensitive subpopulations in the development of guidelines for South Africa will therefore need to take the asthmatic population into account.

4.2.1 Asthma

It was reported recently that the asthma prevalence as a percentage of adults aged 15 years and older are 7 per cent in men and 9 per cent in women (Department of Health, 1999b). Although there is wide agreement that asthma in childhood is very common, its true incidence is quite difficult to determine. Surveys in Scotland (Ninan *et al*, 1992) showed that 10 per cent of children reported asthma at some time in their life, and 20 per cent reported regular wheezing. In Australia, Peat *et al.* (1994) reported 23 to 28 per cent rates of current wheezing and 9 to 12 per cent of children were diagnosed as asthmatics. A study in Nottingham, UK, found that of 11.5 per cent of children had had episodes of wheezing in the previous year and 5.9 per cent had been diagnosed as asthmatics (Hill *et al*, 1989). Godfrey (1997) studied asthmatics in Israel, and reported rates of 9.6 per cent in boys and 6 per cent in girls.

Van Niekerk *et al* (1979) found a 3.17 per cent prevalence of asthma in black children from Guguletu. Although this is an older study, the current prevalence should be higher rather than lower, since hospital admissions for acute childhood asthma showed a sharp upward trend from 1978 to 1984, followed by a slower increase until 1987, after which rates remained stable until 1990, when these comparisons were last done (Ehrlich & Weinberg, 1994). Landau (1993) reported that 30 to 50 per cent of children in South Africa will wheeze during early childhood, and that 10 to 20 per cent will have clinically diagnosed asthma in later childhood. Ehrlich *et al* (1996) concluded that 38 per cent of child asthmatics in South Africa were not reported as asthma sufferers by their parents.

4.2.2 Infections

The burden of disease in South African communities has been the subject of many studies (World Bank, 1998, World Bank Series, 1999, and Department of Health SA, 1999a), reporting high incidences of infectious diseases, notably childhood diarrhoea, measles, pneumonia, middle ear infections, tuberculosis, HIV/Aids, and malaria. This burden of disease leaves communities highly vulnerable in cases of exposure to environmental pollutants.

4.2.3 Other disease

Chronic and debilitating diseases make people more vulnerable to pollutants. Diseases with high rates in South African communities include conditions associated with the cardiovascular, endocrine (diabetes mellitus) and respiratory systems, and cancer, to name a few.

Table 4.2.1. Comparative burden of disease in disability-adjusted life years (DALYs) in WHO Regions: chronic obstructive pulmonary disease, asthma, and cardiovascular disease. Estimates are for 1999 (WHO, 2000b).

Africa		The Americas			Eastern Mediterranean		Europe			South-East Asia	
Mortality Stratum*											
High child, high adult	High child, very high adult	Very low child, very low adult	Low child, low adult	High child, high adult	Low child, low adult	High child, high adult	Very low child, very low adult	Low child, low adult	Low child, high adult	Low child, low adult	High child, high adult
Chronic obstructive pulmonary disease: Ratio of DALYs per 1000 people											
2.83	2.70	3.98	2.05	1.23	3.36	3.41	3.51	3.20	5.37	3.36	4.42
Asthma: Ratio of DALYs per 1000 people											
3.39	3.42	1.55	1.60	2.06	2.37	2.44	1.43	1.72	1.78	3.49	1.88
Total cardiovascular disease: Ratio of DALYs per 1000 people											
20.01	18.78	22.85	18.57	14.32	31.92	29.67	25.0	40.53	60.93	16.68	35.01

The matrix for six WHO Regions (Western Pacific Region not shown) and 5 mortality strata leads to 14 subregions, since not every mortality stratum is represented in every Region. Four mortality strata and 12 subregions are presented (WHO, 2000b).

- Mortality stratum: Because of the increasing heterogeneity of patterns of adult and child mortality, member states of the WHO have been divided into 5 mortality strata on the basis of their level of child and adult male mortality. Four of these strata are represented:

- Very low child, very low adult

- Low child, low adult

- High child, high adult

- High child, very high adult

Mortality strata are demographic indicators of differences in the age distribution of deaths, as a measure of health status. African countries are typically high-mortality countries, with just over half of all deaths among the poor occurring before 15 years of age, compared to only 4 per cent amongst the rich. High childhood mortality is usually associated with a high birth rat

Table 4.2.2. **Comparative mortality in WHO Regions: chronic obstructive pulmonary disease, asthma, and cardiovascular disease. Estimates are for 1999 (WHO, 2000b).**

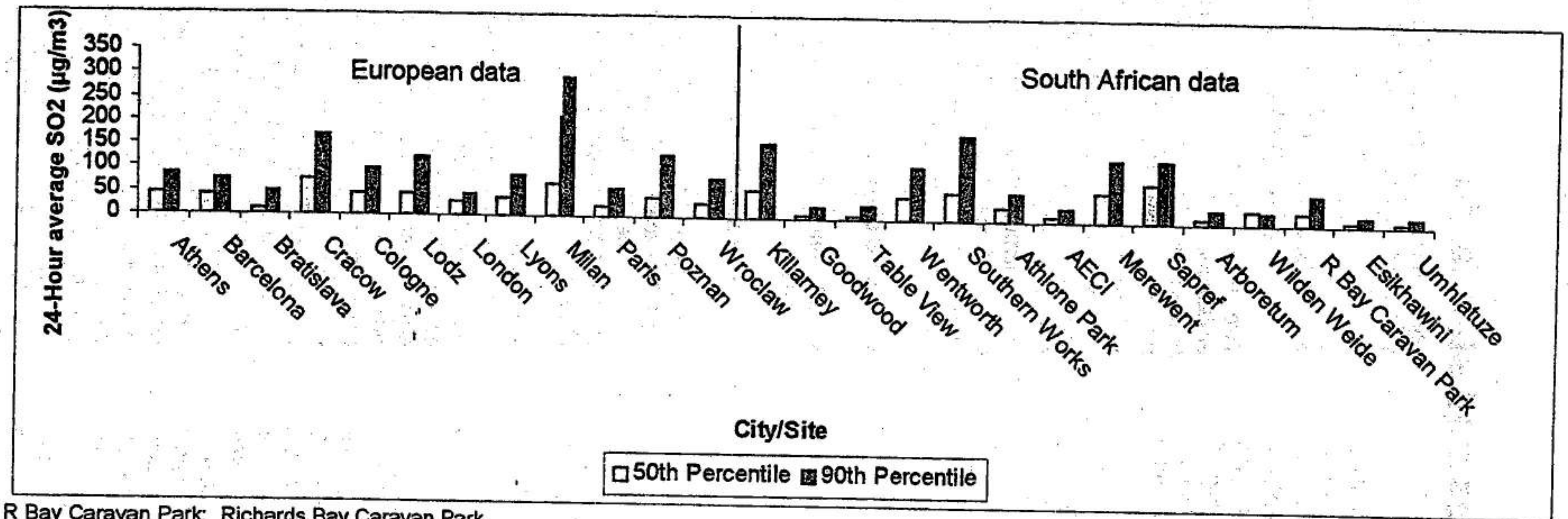
Africa		The Americas			Eastern Mediterranean		Europe			South-East Asia	
Mortality Stratum											
High child, high adult	High child, very high adult	Very low child, very low adult	Low child, low adult	High child, high adult	Low child, low adult	High child, high adult	Very low child, very low adult	Low child, low adult	Low child, high adult	Low child, low adult	High child, high adult
Chronic obstructive pulmonary disease: Ratio of deaths per 1000 people											
0.17	0.18	0.37	0.09	0.07	0.20	0.18	0.35	0.19	0.37	0.16	0.20
Asthma: Ratio of deaths per 1000 people											
0.03	0.03	0.02	0.01	0.03	0.03	0.03	0.03	0.02	0.04	0.07	0.03
Total cardiovascular disease: Ratio of deaths per 1000 people											
1.56	1.36	3.41	1.79	1.37	3.38	2.60	4.39	4.56	7.47	1.48	3.08

Table 4.2.3. **Comparative life expectancy at birth in selected African, European and North-American countries. Estimates are for 1999 (WHO, 2000b).**

Life expectancy at birth (years)		
Country	Male	Female
Angola	46.3	49.1
Botswana	39.5	39.3
Denmark	72.9	78.1
France	74.9	83.6
Lesotho	44.1	45.1
Mozambique	41.8	44.0
South Africa	47.3	49.7
United Kingdom	74.7	79.7
United States of America	73.8	79.7

4.3 Database for ambient air quality

Ambient SO_2 concentrations in cities of developed countries have mostly decreased in the last two or three decades due to tighter emissions control, increased use of low sulphur fuels, and industrial restructuring. However, the situation is more complex in developing countries. In cities, the annual mean concentrations of SO_2 in ambient air may range from very low levels up to 300 µg/m^3. Peak concentrations may exceed 2 000 µg/m^3 under conditions of poor atmospheric dispersion such as inversions, or when emissions from a major source are carried to ground levels by certain atmospheric conditions (WHO, 1998). A graphical representation of 24-hour average ambient SO_2 levels recorded in Europe and South Africa is given in Figure 4.4. Daily averages are usually considered in relation to health effects, such as hospitalisation rates, since annual averages can mask high daily excursions above the threshold levels. A comparative database for South African and international sites is given in Annexure 1.



R Bay Caravan Park: Richards Bay Caravan Park

<u>Sources:</u>

European data: Katsouyanni *et al.*, 1997.

South African data: ECOSERV, 1999, 2000a, b, c & Ravenscroft, Personal communication, 2001.

Figure 4.4: Comparison of ambient SO_2 levels recorded in Europe and South Africa.

Section 5

International guidelines and standards

5.1 Introduction

This section provides a comparison between ambient air quality guidelines and standards that are currently applied in South Africa, USA, UK, and the WHO guidelines. In setting an ambient air quality goal, it is important to take cognisance of guidance values in some of the prominent countries in the world, and also to indicate how the new goal for South Africa may differ from current levels at which regulation is applied.

5.2 South Africa: Department of Environmental Affairs and Tourism (DEAT)

Currently, the maximum levels of SO_2 allowed by DEAT according to national guidelines are:

- Instant peak value 0.6 ppm;
- 1-Hour average 0.3 ppm;
- 24-Hour average 0.1 ppm;
- 1-Month average 0.050 ppm, and
- Annual average of 0.030 ppm.

The guidelines are not explicitly enforceable by law, but are applied in the discretion of the Chief Air Pollution Control Officer (CAPCO), in accordance with the Atmospheric Pollution Prevention Act (Act No. 45 of 1965).

5.3 WHO Guidelines

Based upon controlled studies with asthmatics exposed to SO_2 for short periods, WHO has recommended that a value of 500 µg/m^3 (0.175 ppm) should not be exceeded over averaging periods of 10 minutes. Guideline values for SO_2 have previously been linked with the simultaneous exposure to suspended particulate matter. This approach has led to the setting of a 24-hour average guideline value of 125 µg/m^3 (0.047 ppm) for SO_2. In more recent studies, adverse effects with significant public health importance have been observed at much lower levels of exposure. The current guideline values are no longer linked to particulate matter, but remain 125 µg/m^3 for an averaging period of 24 hours, and 50 µg/m^3 (0.019 ppm) as an annual mean (WHO, 2000a). With regard to acid aerosols, regular monitoring is recommended when levels of sulphuric acid or equivalent acidity of aerosol exceed 10 µg/m^3 (WHO, 1987a).

5.4 USA Environmental Protection Agency (USEPA) standards

Two measures of SO_2 are presented, viz. emissions, and concentration exceedances in ambient air. Emissions in this context refer to a release of a substance into the atmosphere. An exceedance occurs when emissions are concentrated in the air and exceed a set maximum standard. This concentration could be from increased emissions, or as a result of certain atmospheric conditions. Emissions are monitored and reported by dischargers, while monitoring stations collect air concentration data. The ambient standards for SO_2 are:

- Annual average 80 µg/m^3 (0.03 ppm);
- 24-Hour average 365 µg/m^3 (0.140 ppm), and
- 3-Hour average: 1 300 µg/m^3.

In the case of the annual average, if the mean for SO_2 exceeds 80 µg/m^3, it is considered an exceedance. The 24-hour and 3-hour standards are not to be exceeded more than once per year (Quarles & Lewis, 1990).

The USEPA's Clean Air Market Programs use "cap" and "trade" programs to address environmental issues. An emission cap is a limit on the total amount of a pollutant that can be emitted from all regulated sources (e.g. power plants). The cap is set lower than historical emissions to manage towards a reduction in emissions. The trade program is a market-based mechanism for reducing pollution using tradable emissions limitations. The type of emission trading approach used by the USEPA is called "allowance trading". An allowance is an authorisation to emit a fixed amount of a pollutant. Sources can choose how to reduce emissions, including whether to buy additional allowances from other sources that succeed in reducing their own emissions. At the end of each compliance period, each source must own at least as many allowances as its emissions (USEPA, 2000).

5.5 The United Kingdom

The UK government adopted National Air Quality Standards as part of the National Air Quality Strategy adopted in January 2000. A system of "banding" is applied in the management strategy. Pollutant concentrations for each band are set with reference to what is known about the health effects of each pollutant. The first threshold, called the "standard threshold" is defined by the UK National Air Quality Standard. The second and third thresholds are the "information" and "alert" levels that are in line with EC Directives on Air Quality.

5.6 Summary of guidelines and standards

Table 5.6 presents a summary of guidelines and standards applied by some of the most prominent agencies in the world, in comparison with current DEAT guidelines.

Table 5.5: UK National Air Quality Standard "banding": Criteria for classifying air pollution levels into bands (UK, 2000).

Air Quality Bands for sulphur dioxide*			
Severity of pollution	SO_2 (parts per million, 15 minute averages)	Description of air pollution	Threshold
	Less than 0.100	Low	
	0.100		Standard threshold level
	0.100–0.199	Moderate	
	0.200		Information threshold level
	0.200–0.399	High	
	0.400		Alert threshold level
	0.400 or more	Very high	

Table 5.6: International ambient air quality guidelines and standards for sulphur dioxide.

Maximum allowable concentrations of ambient SO_2										
Guideline*	Instantaneous		1 Hour average		3 Hour average		24 Hour average		Annual average	
	ppm	µg/m³	ppm	µg/m³	ppm	µg/m³	ppm	µg/m³	ppm	µg/m³
DEAT	0.600 (3 min average)	1 716	0.300	858			0.100	286	0.030	86
USEPA					0.450	1 300	0.140	365	0.030	80
					Not to be exceeded more than once per year					
WHO	0.175 (10 min average)	500					0.047	125	0.019	50
UK DETR	0.100	266	0.132	350			0.047	125	0.008	20
	(15 min average) Not to be exceeded more than 35 times a year		Not to be exceeded more than 24 times a year				Not to be exceeded more than 3 times a year		For the protection of vegetation and ecosystems	

* DEAT: Department of Environmental Affairs and Tourism (SA)
USEPA: US Environmental Protection Agency (Quarles & Lewis, 1990)
WHO: World Health Organisation (WHO, 2000a)
UK DETR: UK Department of the Environment, Transport and the Regions (UK, 2000)

Section 6

Setting the ambient air quality guideline

6.1 General considerations for an ambient air quality goal for South Africa

The effects of air pollutants on health depend on several factors, among others the level of exposure, and the susceptibility of the exposed population. The latter is affected by such factors as the number of young children and elderly people, as well as the proportion of the community that is suffering from asthma and other chronic respiratory conditions. In addition, sources and patterns of exposure, e.g. indoor and outdoor exposures, are likely to differ substantially from region to region. In part this is dependent on weather conditions. Response-concentration relationships derived from Western European or North American studies should therefore not simply be adopted for general use in South Africa. It has been the purpose of this technical background document to provide the necessary scientific perspectives for specifying the most appropriate health-risk based ambient air quality SO_2 guidelines for South Africa. The study considered critical factors for health impacts, sensitive subpopulations, the health status in South Africa in comparison with Africa and other parts of the world and current ambient SO_2 levels in South Africa in comparison with the rest of the world. In addition, effects of SO_2 on vegetation were also taken into account.

The WHO guidelines are purely health-risk based, whereas the USEPA and UK DETR have developed standards that are enforceable by law. These standards have been carried through the standard-setting process, and include country-specific considerations that might not be applicable in South Africa. It is therefore appropriate that any South African guideline be derived from the lowest-observed-adverse-effect level (LOAEL) associated with exposure to SO_2, and not directly from guidelines and standards adopted by other countries. Factors that might suggest that a different LOAEL would be more likely in South African communities, should be taken into account in setting the health-risk based goal. The health-risk based WHO ambient air quality guidelines provide a credible starting point for this process.

Recent progress in understanding the effects of sulphur dioxide on health suggests that all levels of exposure above zero may be associated with effects on health. The effects may be subtle at low concentrations, but a significant relationship between increases in ambient air concentration and the manifestation of respiratory and, to a lesser degree, cardiovascular effects, could be established in epidemiological studies. The fact that sulphur dioxide should be regarded as a non-threshold toxicant might seem toxicologically implausible, but such a conclusion is difficult to avoid, given the current time-series data (WHO, 2000a).

6.2 Specification of guidelines

In comparison to the current SA guidelines and USEPA standards, the WHO guidelines are relatively conservative

Table 6.2: The lowest-observed-adverse-effects levels for SO_2 and the WHO guidelines (WHO, 2000a).

Health endpoint	Observed effect level (µg/m³)	Uncertainty factor	Guideline value (µg/m³)	Averaging time
Changes in lung function in asthmatics	1 000	2	500	10 minutes
Exacerbations of respiratory symptoms in sensitive individuals	250	2	125	24 hours
	100	2	50	1 year

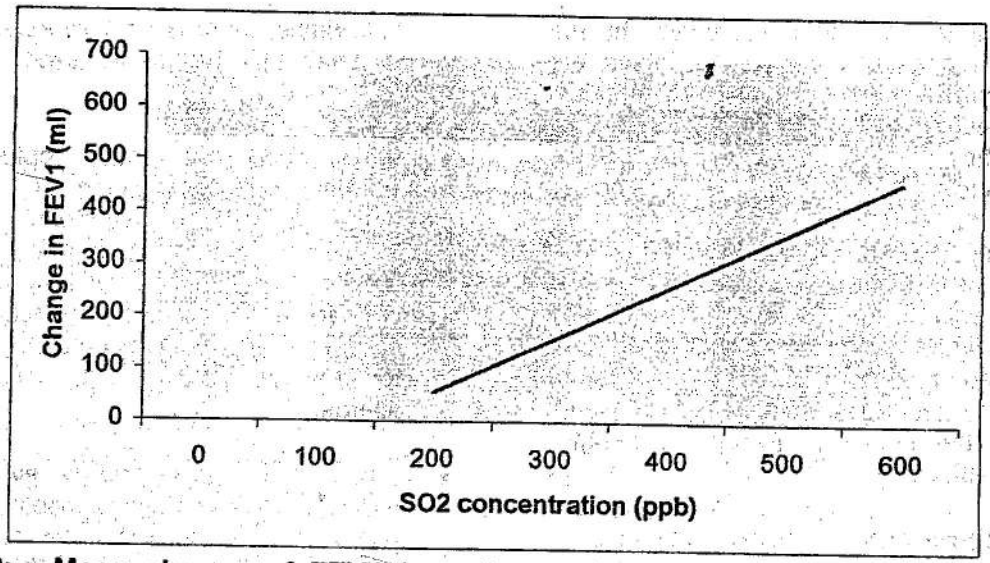


Figure 6.2: Mean change of FEV1 in asthmatics with changing SO_2 concentrations (WHO, 2000a).

To develop guideline values, WHO considered minimum concentrations associated with adverse effects over specified time periods. With respect to the 10-minute guideline, the mean change of FEV_1 (a measure of obstruction of respiratory airflow) in asthmatic patients, after an experimental 15-minute exposure to different levels of SO_2, was considered The minimum concentrations associated with adverse effects in these patients, who were exercising during exposure, was found to be 1 000 µg/m^3. 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 over a 24-hour period and 100 µg/m^3 over an annual period. In more recent epidemiological studies, adverse effects with significant public health importance have been observed at much lower levels of exposure. However, there is still uncertainty as to whether SO_2 is the pollutant responsible for the observed adverse effects, therefore it was decided to apply an uncertainty factor of 2 to the lowest-observed-adverse-effect level (WHO 2000a). The resultant guideline values are as represented in Table 6.2.

Having said that the sensitive-populations to be considered in the South African situation are the socio-economically deprived groups and, in a health context, mainly the asthmatic group, it is recommended that the WHO guidelines be used in the setting of standards. These factors are discussed in more detail below.

6.3 Evaluation of the critical factors for health impacts

6.3.1 Socio-economic deprivation, sensitive subpopulations, and the status of health in South Africa

It is appropriate that the significance of socio-economic deprivation be put into perspective before assessing the health status of South African communities with regard to the critical health factors that were identified for assessing effects of exposure to sulphur dioxide.

There is general agreement that a large proportion of the South African community would be more vulnerable to disease in many forms, because of socio-economic deprivation. Section 4.1.4 has outlined the scientific background for explaining inequalities of health on this basis. A local database is however not available to quantify the relationship between aspects relating to economic deprivation and the nature and incidence of disease in South Africa. The most useful information in this regard has been documented by the World Health Organisation in The World Health Report (WHO, 2000b). The overall impact of economic deprivation on the African Continent is reflected in figures for life expectancy at birth (Table 4.2.3). It is shown that estimates for South Africa are much lower than the life expectancy in first-world countries, but are representative of the average situation in Africa. The major contributing factors to mortality in Africa are communicable diseases, maternal and perinatal conditions, and nutritional deficiencies (WHO, 2000b).

South Africa is not listed separately in the burden of disease and mortality rate tables, but Africa as a whole is compared to the Americas, Eastern Mediterranean, Europe, South-East Asia, and the Western Pacific regions. Since the life expectancy at birth in South Africa is comparable to the rest of Africa, it is generally inferred that estimates for various disease categories in Africa should also reflect a reasonable estimate for the situation in South Africa. The figures published in the WHO report therefore also provide a basis for comparison of the incidence of respiratory disease in South Africa with the status in Europe and other developed nations.

6.3.2 Asthma and exposure to SO_2

Health impacts of asthma on populations in Africa appear to be worse than in other regions. (See Table 4.2.1 in Section 4.) Asthma is therefore the most important chronic respiratory disease to consider in setting an ambient air quality goal for South Africa. It should be noted, however, that asthma does not contribute significantly more to mortality in Africa compared to e.g. Europe and the Americas (Table 4.2.2).

To put the weight of evidence and relative severity of health impacts of SO_2 at levels close to ambient air quality guidelines into perspective, it is useful to refer to studies conducted in the UK. The UK Department of Health has published a report on the possible links between outdoor air pollution and asthma, excluding biological pollutants such as pollen. The following important observations were made:

- An increase of about 50 per cent occurred in the prevalence of childhood asthma over the period 1967 to 1997, which corresponded to an increase in atopic diseases. Atopic diseases are characterised by hypersensitivity of individuals to immunologically active substances, which could result in asthma, hay fever and eczema (Macpherson, 1995). There has also been at least a ten-fold increase in hospital admissions for asthma among children, which may partly reflect changes in medical practice.

- Over the period during which asthma increased, emissions of SO_2 had fallen markedly, while those of NOx and volatile organic compounds from motor vehicle emissions have increased.

- While there is laboratory evidence that air pollution could potentially play a role in the *initiation* of asthma in previously healthy individuals, there is no firm epidemiological evidence that this has occurred in the UK or elsewhere.

- While there is some epidemiological evidence that air pollution may *provoke or aggravate* asthma symptoms in existing asthmatics, the effect, if any, is generally small. Overall, the effect of air pollution appears to be relatively unimportant when compared with several other factors known to provoke asthma (e.g., infections and allergens).

- There is some laboratory evidence that exposure to the common gaseous pollutants can enhance the response of asthmatic patients to allergens, though the effect does not seem large. There is no direct evidence for such an interaction as a result of exposure to outdoor air pollution in the UK.

It was concluded that factors other than air pollution are influential with regard to the initiation and provocation of asthma and are likely to be more important than air pollution in both respects (COMAP, 1997).

Whilst the impact of SO_2 on asthmatics in the laboratory setting is indisputable, and several epidemiological studies have demonstrated a significant association between mortality rates and hospital admissions for respiratory conditions, accommodating the sensitive asthma population in South Africa does not have to translate into stricter considerations in the process of setting SO_2 guidelines. The WHO guidelines were already based on the LOAEL for asthmatics, with a safety factor of 2 built in to account for uncertainties.

6.3.3 Chronic obstructive pulmonary disease

Estimates for COPD in Africa do not compare unfavourably with other WHO regions. The ratio of DALYs lost per 1000 persons in the African population is estimated to be 2.83 and 2.70 in the high child, high adult and high child, very high adult mortality strata, respectively, while the ratio for the Europe is 3.51, 3.20 and 5.37, respectively, for the very low child, very low adult; low child, low adult and high child, high adult mortality strata. Furthermore, COPD does not contribute significantly more to mortality in Africa compared to e.g. Europe and the Americas (Table 4.2.2).

6.3.4 Cardiovascular disease

Epidemiological studies have shown an effect of ambient SO_2 on hospitalisation rates for cardiovascular diseases, but these are tentative findings that have not been investigated as precisely and exhaustively as is the case with respiratory diseases. In addition, cardiovascular diseases do not contribute significantly more to mortality in Africa compared to e.g. Europe and the Americas (Table 4.2.2).

6.3.5 Infections

Since the South Africa population suffers from the highest rates of HIV/Aids infection in the world, the protection of this sensitive subpopulation needs special consideration. Aids sufferers are prone to contracting secondary infections, particularly of the respiratory system, rendering them respiratory compromised. One of the results of such secondary respiratory infections is an irritable lung, which might be as sensitive to SO_2 as the asthmatic airway. Since the immune system is not directly involved in the protection of the respiratory system against the effects of exposure to SO_2, the HIV/Aids infected population should be adequately protected by measures designed for the protection of asthmatics.

Certain socio-economic groups in South Africa are also suffering from high rates of pulmonary tuberculosis and these groups deserve special consideration in the development of SO_2 guidelines. Untreated pulmonary tuberculosis severely damages the lung tissue, ultimately leaving the sufferer severely respiratory compromised. The formation of tubercles, as a result of multiplication of the infectious agent, *Mycobacterium tuberculosis*, results in areas of irritation in the lung tissue. These irritable areas in the lungs of the TB sufferer could be as sensitive to SO_2 exposure as the asthmatic airway. The TB infected population should be adequately protected by these guidelines derived from the lowest-observed-adverse-effects levels applicable to asthmatics.

6.4 Exceedances as measures of compliance

Assessment of compliance with an ambient air quality standard should be based on two considerations:

- A specified number of exceedances of a standard may be allowed in the averaging period, and
- A maximum ambient SO_2 level (cap) should be applicable to each exceedance.

The required level of attainment or compliance determines the number of allowable exceedances. Levels of attainment may be defined in terms of the fundamental units that define the standard. For example, if the unit defined by the standard is the daily average, then a requirement for 99 per cent compliance allows the standard to be exceeded by three days a year. The cost of meeting any standard is likely to depend on the degree of compliance required. Consequently, it would be appropriate to consider carefully the costs and benefits of different levels of compliance when deciding on the standard.

The maximum ambient SO_2 level applicable to each exceedance should aim to protect the population and the environment from adverse effects in all instances. In deciding on this level, the lowest-observed-adverse-effect levels and the respective uncertainty factors (Table 6.2) should be considered. The maximum ambient SO_2 level applicable to each exceedance, with the aim of safeguarding public health, should therefore not exceed the respective LOAEL. These are:

- 1 000 $\mu g/m^3$ over a 10 minute period;
- 250 $\mu g/m^3$ over 24-hours, and
- 100 $\mu g/m^3$ over one year.

The annual average guideline is set to limit daily exposures to levels that are well within the daily guideline.

With regard to the protection of vegetation, it should be noted that the guideline values for vegetation are well below those protecting human health (refer to Table 3.4) and are usually applicable to specific areas of agricultural, forestry or natural resource interest. Because of a lack of data, the UN/ECE is still in the process of determining the effects of exceedances and will only subsequently recommend regulation of exceedances. IUFRO does, however, recommend that the 24-hour means of 25 and 50 $\mu g/m^3$, applicable to agricultural crops and forest trees, respectively, may be exceeded 12 times in a period of 6 months (WHO, 1987b). Levels in Kennilworth (Cape Town), and at semi-industrial sites in Durban (Wentworth, Southworks, Athlone Park, Sapref and Merewent) are currently exceeding these guidance values.

In consideration of all the critical health and socio-economic factors listed and discussed above, a summary of the guideline values recommended for use in South Africa is represented in Table 6.4. Exceedances are not specifically mentioned as the setting of exceedances should be considered as part of the process of the development of a standard from the proposed guidelines. With regard to the protection of crops, forests and other vegetation, there is no reason to dispute the guidelines recommended by UN/ECE, and these are therefore recommended for the South African situation.

Table 6.4: Recommended South African national ambient air quality guidelines for sulphur dioxide.

Maximum allowable concentrations of ambient SO_2 (at 25 °C, 101.3 kPa)							
Guideline		Instantaneous		24 Hour average		Annual average	
		ppm	µg/m³	ppm	µg/m³	ppm	µg/m³
Health		0.191 (10 min average)	500	0.048	125	0.019	50
Vegetation:	Agricultural			0.027	70	0.011	30
	Forestry			0.027	70	0.007	20
	Natural and semi-natural			0.027	70	0.008	20

Please note that conversions between µg/m³ and ppm in this case were done at room temperature of 25 °C.

Section 7

Guidelines for implementation

7.1 Moving from the guideline to a standard

This section provides an overview of aspects that have to be considered in the standard-setting process, and outlines implementation and management strategies.

7.1.1 Peer review and consultation process

This technical background document serves as a source document to support decision-making in the development and implementation of a national ambient air quality standard for South Africa. The ambient air quality guidelines for sulphur dioxide that have been recommended in the document are based on considerations of human health. Effects on vegetation were also addressed in the recommendations. In moving from guidelines to a standard that is enforceable by law, it is essential that a world-class specialist in the field review the credibility of the proposed guidelines and the process employed in setting those guidelines. After confirmation of the validity of the technical background document, the national ambient air quality standard can be developed and implemented.

The technical and economic feasibility of implementation of the standard have to be assessed, taking into account also socio-economic factors, and strategic and political considerations. Stakeholder consultation is a key component in this process. Early and adequate involvement of all concerned stakeholders is important to increase the transparency of the process and to ensure the acceptability of the outcome.

7.1.2 Sequence of events

The following essential steps outline the standard-setting process:

- Drafting of the technical framework for air quality standard implementation;
- Tabling of the draft SO_2 standard, including thresholds, averaging periods and technical criteria, for stakeholder consultation;
- Assess the inventory of issues raised during the review period, and
- Finalisation of the sulphur dioxide standard by the Department of Environmental Affairs and Tourism.

7.2 The technical framework for implementation of a national ambient air quality standard

7.2.1 Introduction

Air quality standards comprise more than pollutant concentration thresholds and associated averaging periods. Key information linked to air quality standards include:

- Monitoring and data management protocols to assess and report compliance, including reference monitoring methods, quality assurance/quality control requirements, data analysis methods, and siting criteria for sampling stations;
- Time frames for establishing compliance monitoring;
- Time frames for achieving compliance in non-attainment areas and the setting of intermediate objectives;
- Incentives for standard achievement and penalties for non-compliance, and
- Recommendations regarding the review period for standards.

7.2.2 Compliance monitoring and quality assurance protocols

Air quality standards are designed to include harmonised requirements for air quality measurement, data management, and reporting. Such requirements should make provision for siting criteria for monitoring stations, and the definition of appropriate data quality objectives and a quality assurance programme.

Air quality measurement techniques must be accurate, specific for the pollutant in question, and must fit the purpose of the measurements with respect to sensitivity, measurement range, and averaging time. The credibility of air quality measurements depends on the following factors:

- The monitoring laboratory must operate within a formal quality assurance system, to demonstrate competence of persons undertaking the monitoring, ensure the traceability of standards and samples, calibration of equipment, and adequacy of supporting documentation.

- Only validated sampling and analytical methods must be used, and the laboratory must have documented proof of such validations. The laboratory must also be accredited by an appropriate authority to conduct the measurements;

- Sampling and analytical methods must be robust, allowing data to be reported in specified confidence intervals.

7.2.3 Time frames for establishing compliance monitoring

National Government needs to allow sufficient time, following the adoption of an SO_2 standard, for the provinces or metropols to monitor and determine their compliance status. Establishing monitoring networks and characterising baseline air quality and compliance assessment are time-consuming. Experience in the United States of America has shown that 3 years is a reasonable time frame for these objectives to be met. Following this time period, sufficient data should be available to allow National Government to establish whether an area is in non-compliance, and to estimate the magnitude of such non-compliance (Lents and Nikkala, 2001).

7.2.4 Time frames for the attainment of standards and the setting of intermediate objectives

National Government, *through a transparent consultative process*, will need to establish the maximum time period within which compliance with the SO_2 standard will need to be attained. The stipulation of shorter time frames for compliance attainment should be permitted within individual metropols or provinces, provided that such time frames have been established based on a local consultative process.

Time frames have been found to represent the drivers of air quality control efforts in the United States and Europe. The US currently classifies areas that do not meet the standards for a particular pollutant (non-attainment areas) as either marginal, moderate, serious, severe or extreme non-attainment areas for that pollutant. Short time frames for compliance demonstration are stipulated for marginal non-attainment areas, with increasingly longer time frames being permitted for the other classes. The USA experience is given as suggesting that annual reductions of pollutant emissions within the range of 5 per cent to 10 per cent are feasible. It is estimated that in an area found to exceed a standard by 50 per cent, the time frame for attainment of the standard may be established within the range of 5 to 10 years (Lents and Nikkala, 2001).

In certain non-compliance areas it may be necessary to establish intermediate air quality objectives. Whereas the SO_2 standard levels proposed are based exclusively on the protection of human health, objectives may reflect the costs and benefits and the feasibility and practicality of moving towards these standards. Such objectives are intended as an intermediate benchmark only, and not as an end. The establishment of intermediate air quality objectives should be based on a transparent consultative process.

7.2.5 Incentives for standard attainment and penalties for non-compliance

Given that the SO_2 standard is, by definition, mandatory and legally enforceable, it is necessary that National Government consider formal processes for undertaking enforcement actions. Such actions may take the form of penalties, shutdowns, and reduction agreements against the sources found to be responsible for non-compliance.

Incentives can be used to motivate local, metropolitan and provincial authorities in their undertakings to ensure compliance with air quality standards. Positive incentives, such as additional funding, or negative incentives, such as fund reduction or other sanctions, are used in the USA to ensure that provincial and local governments make sufficient efforts to achieve compliance with standards within the established time frames (Lents and Nikkala, 2001).

7.2.6 Standard-review process

Although South Africa's air quality guidelines have been submitted to *ad hoc* reviews in the past, no formal scientific review and public comment process has been established. It is recommended that the framework for regular scientific reviews be established for the planned SO_2 standard. This is required to ensure that new scientific evidence on the effects of a pollutant on public health and the environment, as well as international trends in guidelines and standards are taken into account.

In the stipulation of a review period attention should be paid to the experiences of other countries. The US Clean Air Act, for example, requires the USEPA to evaluate the potential health effects of criteria pollutants and to issue a criteria document every five years. The criteria documents detail the health studies and other scientific information evaluated in the process of setting the NAAQS at a level that protects the public health and welfare with an adequate margin of safety. Although the Act requires a new criteria document once every five years, in practice the USEPA usually takes about 10 years or more to issue new criteria documents and consider revising the standards (Erbes, 1996).

7.3 Implementation of an ambient air quality management strategy

7.3.1 Introduction

Air quality standards are only one of the components of an air quality management strategy. Air quality standards are of limited value unless such strategies are established to determine compliance with standards on an ongoing basis and to facilitate progress towards attainment in non-compliance areas. Air quality management systems typically comprise the following components:

- A regularly updated emissions inventory database;
- Air quality and meteorological monitoring and maintenance of air quality and meteorological databases;
- Mathematical atmospheric dispersion modelling capabilities;
- Defined air quality indicators and an air quality index for information reporting and trend analysis;
- A system of emission limits (via the permitting system);
- Accurate record-keeping (e.g. of violations);
- Information dissemination and public consultation; and
- Development and implementation of an air quality management plan in non-compliance areas.

7.3.2 Inventory of source emissions

An emission inventory is a comprehensive, accurate and current account of air pollutant emissions and associated data from specific sources over a specific time period. Site and emissions data from all source types, including stationary, mobile and area sources need to be included in the database. Such emissions inventories should preferably be established and maintained at provincial, and where feasible, metropolitan areas.

Effective emissions inventories serve to define problems in terms of which pollutants should be considered, which sources are important, and what control measures might be most effective in achieving and maintaining compliance with standards. In addition to containing information on present emission levels from the various source categories, an emission inventory should ideally indicate future levels of emissions. The potential for future non-compliance and the effectiveness of planned control strategies may then be evaluated. An emissions inventory also provides the basis for the planning of the ambient air monitoring network.

7.3.3 Ambient air quality modelling

Mathematical dispersion models calculate ambient air concentrations primarily as functions of source configurations, emission volumes, terrain features, and meteorological characteristics. Such models thus provide useful tools to predict the spatial and temporal patterns in ambient concentrations arising from the emissions of various sources. In Europe and elsewhere, there is a distinct trend towards the replacement of extensive and costly air quality monitoring networks by on-line dispersion modelling coupled with key monitoring sites for model calibration and validation.

Dispersion modelling may be used to determine the impact of potential strategies aimed at reducing emissions on ambient air concentrations. The effectiveness of various strategies may be evaluated prior to their implementation. It is also possible for a region to demonstrate attainment of ambient air quality standards subsequent to proposed intervention through dispersion modelling.

7.3.4 Monitoring of ambient air quality

The aim of air quality monitoring is to obtain information on ambient concentrations of pollutants and on the spatial and temporal changes of such concentrations. On-line, real-time monitoring is widely used in Europe and the USA, and is being used in various regions in South Africa for compliance monitoring, to calibrate dispersion models, and to provide early warnings during pollution episodes. Air quality monitoring also provides a good basis for determining whether air pollution reduction strategies to be undertaken will facilitate the achievement of compliance within the given time frame.

7.3.5 Definition air quality indicators and dissemination of information

The principal purpose of developing indicators and indices for air pollution is to condense and simplify monitoring information to make it suitable for public reporting and decision makers. The combination of several pollutant indicators to generate a normalised number can result in an air quality index, the purpose of which is to relate daily air pollution information for multiple pollutants to short-term air quality standards and turn the data from these multiple pollutants into a single index. Air quality indices have been used successfully in various other countries to report air pollution information to the general public.

Ongoing information dissemination to interested and affected parties may include e-mailed daily, weekly, monthly and annual reports, data presentation on the internet, presentation of results at committee meetings, and special reports and case studies, e.g. investigations into non-compliance episodes, periodic review of source contributions, and dispersion model validations.

7.3.6 Air quality management plans

Areas of non-compliance with air quality standards may be identified through the implementation of air quality management tools, including emissions inventories, dispersion modeling, and field monitoring. Such areas are typically termed pollution "hot-spots" (Europe) or "non-attainment areas" (USA). In non-attainment areas, air quality management plans need to be put in place to demonstrate how (*and when*) compliance with standards (or objectives) will be achieved. Such plans take the form of 'action plans' in Europe and 'state implementation plans' in the United States (Patrick, 1994).

The comprehensive structure of the State Implementation Plans (SIPs) developed and implemented in the USA is outlined in Table 7.3.6.

It is noted that such SIPs, due to their comprehensive nature, require considerable time, money and expertise to develop and implement. In South Africa it may not be appropriate to follow exactly the structure of SIPs, but it is recommended that such plan outlines be used as the starting point for discussions regarding the potential contents of local air quality management plans (AQMPs).

The need for consultation with interested and affected parties and the facilitation of public participation in the air quality management plan development process cannot be over emphasised. The process of public participation may be facilitated through public workshops, organised to inform the public of developments, to answer questions, and to record public comments. Once an AQMP has been drafted, a public hearing process may be implemented following which the AQMP may be revised and finalised. The public hearing process should, however, not signal an end to public involvement in the AQMP process. Public participation should be extended to include an opportunity to monitor the implementation of the AQMP and the progress made in reaching the targets set within the time frames agreed upon.

In addition to the implementation plan of which the essential elements are outlined in Table 7.3.6, emphasis should be placed on application of the Major Hazardous Installations Regulations promulgated under the Occupational Health and Safety Act (No. 85 of 1993), to prevent accidental releases of sulphur dioxide and to minimise the consequences of such releases.

Table 7.3.6: Outline of steps in state implementation plans (SIPs) for management of atmospheric pollution in the USA.

US State Implementation Plan Outline
1 Identification of pollutants to be controlled.
2 Identification of all sources of each pollutant. For each source determine: a) quantity of emissions (including temporal patterns in extent of emissions). b) percentage contribution to total emissions of a pollutant. c) the height of emission, e.g. ground, medium-elevated or high-elevated source. d) likelihood of human exposure to emissions (exposure index), e.g. emissions near population concentrations.
3 Identification of air pollution reduction strategies: a) list and description of possible strategies for each source. b) explanation of implementation of each control measure. c) quantification of reduction of ambient concentrations as a result of implementation of each strategy through use of dispersion model analysis. d) cost-benefit analysis of controlling each source with each strategy. Cost-benefit analyses should include the consideration of: i. source characteristics to select the sources to be controlled (i.e. percentage contribution, height of emission, and exposure index). ii. reduction of ambient concentrations as a result of implementation of each strategy. Identify most effective strategies for ambient pollution abatement. iii. technical feasibility of each strategy. iv. socio-economic impacts of each strategy. Determine the feasibility of strategies within the socio-economic context.
4 Following final evaluation of strategies, recommend the most cost-effective strategies that may be adopted to minimise emissions.
5 Use dispersion model analysis to demonstrate how and when standards may be attained should the recommended strategies be undertaken.
6 Indicate the effect of future emissions from growth and development (industry, transport, population growth) on ambient air quality and demonstrate how compliance will be maintained.
7 Contingency measures may have to be included in the air quality management plan. These measures need only be implemented should the recommended control strategies not be successful in achieving and maintaining compliance within a required time period.
8 The plan may also include a comprehensive long-range air quality management plan.

7.3.7 Multiple levels of air quality criteria

Internationally, there has been a shift away from the implementation of solitary, uniform standards throughout a country, towards the adoption of a system of multiple levels of air quality standards, limit values and/or objectives. In Europe, three air quality criteria have been defined, viz.:

- *Limit values* of pollution concentrations. Such values are based on scientific knowledge, with the aim of avoiding, preventing or reducing harmful effects on human health and the environment as a whole. Limit values are to be attained within a given period and are not to be exceeded once attained.
- *Target values*. In order to avoid harmful long-term effects on human health and the environment, target levels are to be attained where possible over a given period. Such levels represent a long-term goal to be pursued through cost-effective progressive methods, and are frequently termed *long-term acceptable thresholds*. At these levels pollutants are either harmless to health and the environment, or unlikely to be reduced through expending further reasonable cost

on abatement due to background sources or other factors.

- *Alert thresholds* refer to levels beyond which there is a risk to human health from brief exposure. The exceedance of such thresholds necessitates immediate steps.

Standards outlined in the UK legislation are essentially the same as those given in the European Union Directive (DETR, 2000). Levels of ambient standards referred to include:

Alarm thresholds, referring to the level of a pollutant or combination of pollutants where there is a potential risk of immediate serious damage, and immediate response is required.

Long-term acceptable thresholds represent a long-term goal to be pursued through cost-effective progressive methods. At these levels pollutants are either harmless to health and the environment, or unlikely to be reduced through expending further reasonable cost on abatement due to background sources or other factors.

Background thresholds reflect the impact of background, non-anthropogenic sources of pollutants.

The various air quality criteria outlined in the European Union Directive and the UK legislation explicitly link air pollution concentrations to appropriate remedial action over suitable time scales. Such multiple levels serve to emphasise that changes in ambient air quality take place over extensive periods, and that long term planning is more effective than corrective action aimed at instantaneous improvements in air quality. The USEPA has also placed increasing emphasis on the importance of multiple levels of standards. In addition to primary and secondary national ambient air quality standards (NAAQS), prevention of significant deterioration (PSD) increments have been determined to protect pristine environments (Patrick, 1994).

The geographical diversity within South Africa suggests the rationale for implementation of multiple air quality thresholds defined on a regional basis, in addition to national air quality standards that are designed primarily to protect human health. In polluted environments within which non-compliance with national standards occurs, for example, alarm or alert thresholds can be defined. Whereas the requirement of attaining compliance with the national standard will take the form of steady, cost-effective progress towards the reductions necessary, the exceedance of alarm thresholds will trigger a rapid (and hence potentially costly) response. In pristine or protected natural environments, air quality thresholds that are more stringent than the national standards may be set to ensure the protection of ecosystems. Alternatively, a limit may be placed on the maximum deterioration in air quality permissible in such environments.

Section 8

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Section 9

Annexure 1

Table A1: Ambient SO_2 levels reported in South Africa and other international sites

Country	Site	Year	Measure	Air concentration	Number of exceedances	Reference
Chile	Industrial area	?	Annual mean	101–145 μg/m^3		Sanchez-Cortez, 1997
Chile	Industrial area	?	Maximum daily mean	405-1230 μg/m^3		Sanchez-Cortez, 1997
Chile	?	?	Annual mean over 3 years	70 μg/m^3		Sanchez-Cortez, 1997
Chile	?	?	Annual mean over 3 years	130 μg/m^3		Sanchez-Cortez, 1997
Japan	Urban area	1981-1983	Annual mean	26.8-30.9 μg/m^3		WHO, 2000
Japan	Suburban area	1981-1983	Annual mean	20.5-23.9 μg/m^3		WHO, 2000
China	Chongqing	1994	Annual mean	330 μg/m^3		WHO, 2000
China	Beijing	1994	Annual mean	100 μg/m^3		WHO, 2000
China	Residential	1993	Annual mean	140 μg/m^3		Chen, Hong and Tao, 1993
Nepal	Residential area, Kathmandu	1993	Daily mean	273-350 μg/m^3		WHO, 2000
Nepal	Main roads, Kathmandu	1993	Daily mean	310-875 μg/m^3		WHO, 2000
Mexico	Mexico City	1995-1996	Annual mean	32-37 μg/m^3		WHO, 2000
India	Bombay	1988-1989	Maximum daily mean	584 μg/m^3		Kamat et al., 1992
Germany	Weimar	1990-1992	Daily mean	153-236 μg/m^3	105-145 times per winter (WHO guidelines)	Peters et al., 1996
Germany	Erfurt	1990-1992	Daily mean	96-125 μg/m^3	52-82 times per winter (WHO guidelines)	Peters et al., 1996
Czech Republic	Sokolov	1990-1992	Daily mean	71-90 μg/m^3	35-49 times per winter (WHO guidelines)	Peters et al., 1996
South Africa	Durban	1998	Instantaneous peak (3 min average)	0.870 ppm	9 per year (DEAT guidelines)	ECOSERV Report, 1999

Country	Site	Year	Measure	Air concentration	Number of exceedances	Reference
South Africa	Durban	1998	Hourly average	0.001-0.366 ppm	12 per year (DEAT guidelines)	ECOSERV Report, 1999
South Africa	Durban	1998	Daily average	0.003-0.169 ppm	11 per year (DEAT guidelines)	ECOSERV Report, 1999
South Africa	Durban	1998	Monthly average	0.001-0.042 ppm		ECOSERV Report, 1999
South Africa	Durban	1998	Annual average	0.004-0.034 ppm	1 per year (DEAT guidelines)	ECOSERV Report, 1999
South Africa	Durban	1999	Instantaneous peak (3 min average)	> 0.600 ppm	16 per year (DEAT guidelines)	ECOSERV Report, 2000a
South Africa	Durban	1999	Hourly average	0.001-0.400 ppm	20 per year (DEAT guidelines)	ECOSERV Report, 2000a
South Africa	Durban	1999	Daily average	0.009-0.142 ppm	6 per year (DEAT guidelines)	ECOSERV Report, 2000a
South Africa	Durban	1999	Monthly average	0.001-0.038 ppm		ECOSERV Report, 1999
South Africa	Durban	1999	Annual average	0.005-0.029 ppm	2 per year (local guideline of 0.015ppm)	ECOSERV Report, 2000a
South Africa	Durban	2000	Instantaneous peak (3 min average)	> 0.267 ppm	29-180 per month (local guideline of 0.267 ppm)	ECOSERV Report, 2000b
South Africa	Durban	2000	Hourly average	> 0.130 ppm	10-66 per month (WHO guideline)	ECOSERV Report, 2000b
South Africa	Durban	2000	Daily average	0.043-0.125 ppm	2-6 per month (WHO guideline)	ECOSERV Report, 2000b
South Africa	Richards Bay	1999	Hourly average	0.001-0.031ppm	None (DEAT guidelines)	ECOSERV Report, 2000c
South Africa	Richards Bay	1999	Daily mean	0.000-0.040 ppm	None (DEAT guidelines)	ECOSERV Report, 2000c
South Africa	Richards Bay	1999	Monthly average	0.001-0.012 ppm	None (DEAT guidelines)	ECOSERV Report, 2000c
South Africa	Richards Bay	1999	Annual average	0.002-0.009 ppm	None (DEAT guidelines)	ECOSERV Report, 2000c
South Africa	Goodwood (residential)	2000	Daily average	12 µg/m^3		Ravenscroft, 2001
South Africa	Table View (residential)	2000	Daily average	13 µg/m^3		Ravenscroft, 2001
South Africa	Killarney (Semi-industrial)	2001	Daily average	74 µg/m^3		Ravenscroft, 2001


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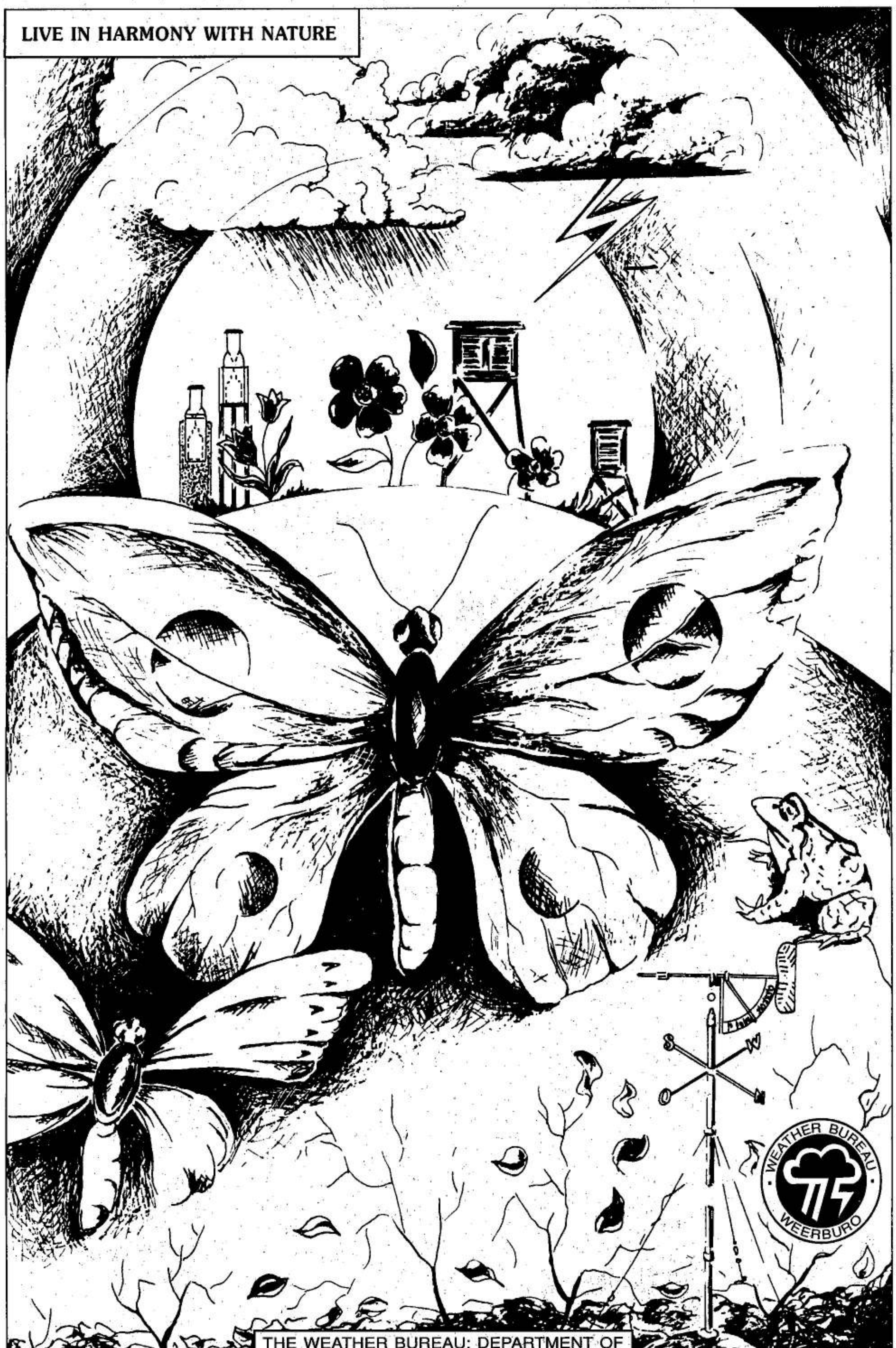
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