Chapter 3

Air quality standards and objectives

At a glance

Air quality limits and thresholds are fundamental to effective air quality management. Ambient air quality limits serve to indicate what levels of exposure to pollution are generally safe for most people, including the very young and the elderly, over their lifetimes. While the World Health Organization (WHO) provides scientific guidance to all countries on the levels of pollution that adversely affect human health, its work does not take into consideration the socio-economic conditions prevalent within any country. As a result, the WHO produces guidelines that a country can then use to inform the development of its own standards. The pollutants for which South Africa has set air quality limits include particulate matter, sulphur dioxide, nitrogen dioxide, carbon monoxide, lead, ozone, benzene, and the deposition of dust. The health impacts of the criteria pollutants, for which limits have been set, are briefly described.



Air quality limits and thresholds are fundamental to effective air quality management, as they link the potential source of atmospheric emissions with the user of that air at the downwind receptor site[1]. Ambient air quality limits serve to indicate what levels of exposure to pollution are generally safe for most people, including vulnerable groups, over their entire lifetimes. Such limits are typically set for common air pollutants that are usually emitted into the atmosphere, sometimes in large quantities, through various industrial and other processes, and for which health and environmental impacts are relatively well-known.

Suspended fine particulate matter, sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), lead (Pb), and ozone (O_3) are classified by most countries as 'criteria pollutants', and air quality limits are set for all of them (see §3.1 below). Such limits are not published for all possible air pollutants to which the public may be exposed, but are typically set only for common ones that are known to have detrimental effects. For constituents of air that are listed as pollutants but for which no limits are promulgated, dose-response thresholds have been published by public health bodies such as the WHO (see §3.2 below).

There is concern about PM_{10} and $PM_{2.5}$ because of the potential health risks that they pose, given that such fine particles are able to be deposited in, and cause damage to, the lower airways and gas-exchanging portions of the lungs

Air quality indexing systems are often used to communicate the extent and acceptability of air-pollution levels in a concise and readily understandable way, and are able to integrate information across a range of chemical compounds (specifically those relating to air pollution, such as SO_2) and averaging periods. The creation of bands, in the approach adopted by the UK, for example, helps to classify 24-hour periods into 'low', 'medium', 'high', and 'very high' air pollution days. Although various indexing systems are currently in use in different parts of South Africa, no single national air quality index had been adopted for national implementation by the end of 2004. The simple air quality classification system used in this report is outlined in §3.3.

3.1 AIR QUALITY LIMITS FOR CRITERIA POLLUTANTS

National air quality standards are given in Schedule 2 of the National Environmental Management: Air Quality Act (AQA) (Act no. 39 of 2004). They largely reflect the national air quality guideline values established in the 1990s, and have become dated and in need of revision.

The Department of Environmental Affairs and Tourism (DEAT) has been reviewing and revising the national air quality standards published in the AQA, to ensure that these limits adequately protect human health and welfare. The review process began with the gazetting of a new interim guideline for SO_2 in December 2001, and this revised level was then included in the AQA. Subsequently, the DEAT engaged the South African Bureau of Standards (SABS) to facilitate the development of further health-based ambient air quality standards. Two documents were compiled during this process: *SANS 69:2004 – South African National Standard – Framework for setting & implementing national ambient air quality standards*, and *SANS 1929:2005 – South African National Standard – Ambient Air Quality – Limits for common pollutants*. The latter includes limits for particulate matter less than 10 μm in aerodynamic diameter (PM_{10}), dust deposition, SO_2, NO_2, O_3, CO, Pb, and benzene (C_6H_6). These SANS documents were finalized and published in 2004 and 2005. The adoption of the air quality limits documented in SANS 1929:2005 is under consideration by the Department. Finalizing these standards and having them accepted as national standards requires permissible frequencies of exceedance and compliance time-frames to be established.

The health impacts of criteria pollutants are briefly discussed below, and national air quality limits published locally for such pollutants are compared to widely-referenced limits published by other countries and international organizations. (For further details on the health and ecological impacts of common pollutants, see DEAT, 2006c.)

3.1.1 Suspended particulate matter

The potential of particles to be inhaled and deposited in the lungs is a function of the aerodynamic characteristics of these particles in the air, and it is related to their size, shape, and density. Their impact on human health largely depends on (i) particle characteristics, especially particle size and chemical composition, and (ii) the duration, frequency, and magnitude of people's exposure to them.

1. A downwind receptor site is any site downwind of a source of pollution – sometimes specific receptor sites are identified as communities, or as buildings or areas (such as a school), where people (or specified ecosystems) are affected by that particular source of pollution.



The deposition of particles in different regions of the human respiratory system depends on their size. Nasal openings allow large dust particles to enter the nose, along with much finer airborne particulates. The larger particles are deposited on the hairs in the nose or at the bends of the nasal passages. Smaller particles (PM_{10}) pass through the nasal region and are deposited in the windpipe and lung (tracheobronchial and pulmonary) regions. As they hit the bronchial walls, particles are removed from the inhaled air. When the airflow decreases near the terminal bronchi, the smallest particles are removed by Brownian motion, which pushes them to the alveolar membrane[2] (CEPA/FPAC Working Group, 1998; Dockery & Pope, 1994). Such fine particles are able to be deposited in the lower airways and gas-exchanging portions of the lungs, and to cause damage there[3].

Air quality guidelines for particulates are given by various countries and organizations for various particle sizes, including total suspended particulates (TSP), *inhalable* particulates (PM_{10}), and *respirable* particulates ($PM_{2.5}$, defined as particulates with an aerodynamic diameter of less than 2.5 μm)[4]. Although the term TSP technically refers to all particulates with an aerodynamic diameter of less than 100 μm, it is normally applied to particulates with an upper aerodynamic diameter limit of 30 μm. There is concern about PM_{10} and $PM_{2.5}$ because of the potential health risks that they pose, given that such fine particles are able to be deposited in, and cause damage to, the lower airways and gas-exchanging portions of the lungs.

The PM_{10} limits and standards issued nationally and abroad are documented in Table 3.1. In addition to the PM_{10} standards published in Schedule 2 of the AQA, this act also includes standards for TSPs (namely, a 24-hour average maximum concentration of 300 $\mu g/m^3$ not to

Table 3.1: Air quality standard for inhalable particulates (PM_{10})

Authority	Maximum 24-hour concentration ($\mu g/m^3$)	Average annual concentration ($\mu g/m^3$)
SA standards (AQA)*	180[a]	60
SANS limits (SANS 1929:2005)	75[b] 50[c]	40[d] 30[e]
Australia	50[f]	–
EC	50[g]	30[h] 20[i]
World Bank (General Environmental Guidelines)	70[j]	50[j]
World Bank (Thermal Power Guidelines)	150[k]	50[k]
UK	50[l]	40[m]
US EPA	150[n]	50[o]
WHO	50 [p]	20 [p]

ABBREVIATIONS: EC, European Commission; SANS, South African National Standard; SA standards (AQA), South African standards (Air Quality Act); UK, United Kingdom; US EPA, United States Environmental Protection Agency; WHO, World Health Organization.

* On 9 June 2006, South Africa's Department of Environmental Affairs and Tourism gazetted new air quality standards for public comment (a 90-day comment period was given). The proposed PM_{10} standards were given as 75 $\mu g/m^3$ for highest daily (compared to the previous standard of 180 $\mu g/m^3$) and 40 $\mu g/m^3$ for annual averages (compared to 60 $\mu g/m^3$ previously) (*Government Gazette* No. 28899, 9 June 2006).

[a] Not to be exceeded more than three times in one year.

[b] Limit value. Permissible frequencies of exceedance, margin of tolerance, and date by which limit value should be complied with, to be determined through a complete standard-setting process through the SABS.

[c] Target value. Permissible frequencies of exceedance, and date by which limit value should be complied with, to be determined through a complete standard-setting process through the SABS.

[d] Limit value. Margin of tolerance, and date by which limit value should be complied with, to be determined through a complete standard-setting process through the SABS.

[e] Target value. Date by which limit value should be complied with to be determined through a complete standard-setting process through the SABS.

[f] Australian ambient air quality standards (www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more often than 5 days per year. Compliance by 2008.

[g] EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Compliance by 1 January 2005. Not to be exceeded more than 25 times per calendar year. (From 1 January 2010, no violations more often than 7 times per year will be permitted.)

[h] EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Compliance by 1 January 2005.

[i] EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Compliance by 1 January 2010.

[j] World Bank (1998), Pollution Prevention and Abatement Handbook (www.worldbank.org). Ambient air conditions at property boundary.

[k] World Bank (1998), Pollution Prevention and Abatement Handbook (www.worldbank.org). Ambient air quality in thermal power plants.

[l] UK Air Quality Objectives (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 35 times per year. Compliance by 31 December 2004.

[m] UK Air Quality Objectives (www.airquality.co.uk/archive/standards/php). Compliance by 31 December 2004.

[n] US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than once per year.

[o] US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). To attain this standard, the 3-year average of the weighted annual mean PM_{10} concentration at each monitor within an area must not exceed 50 $\mu g/m^3$.

[p] WHO (2000) issued linear dose-response relationships for PM_{10} concentrations and various health endpoints, with no specific guideline provided. WHO (2005), made available during early 2006, proposed several interim target levels (see following tables).

2. Brownian motion is the erratic random movement of microscopic particles in a fluid, as a result of continuous bombardment from molecules of the surrounding medium. The pollutant particles reach the alveolar membrane in the air that is breathed in.

3. The breathing process is a guide to understanding the way in which the damage is caused. As air enters the body through the nose or mouth, it passes the epiglottis and enters the trachea, continuing through the vocal cords in the larynx until it reaches the bronchi; from there it passes into each lung. Following narrower and narrower bronchioles, the air then reaches the alveoli. The oxygen concentration is high within each air sac, so oxygen passes or diffuses across the alveolar membrane into the pulmonary capillary. At the beginning of the pulmonary capillary, the haemoglobin in the red blood cells has CO_2 bound to it and very little oxygen. The oxygen binds to haemoglobin and the CO_2 is released – it is also released from sodium bicarbonate dissolved in the blood of the pulmonary capillary. The CO_2 concentration is high in the pulmonary capillary, so CO_2 leaves the blood and passes across the alveolar membrane into the air sac. This exchange of gases occurs rapidly (fractions of a second). When the person exhales, the CO_2 leaves the alveolus, and the oxygen-enriched blood returns to the heart. The purpose of breathing, therefore, is to keep the oxygen concentration high and the CO_2 concentration low in the alveoli, so that this gas exchange can occur.

4. In air quality, 'inhalable' refers to the depth in the lung to which PM_{10} particles penetrate, and 'respirable' refers to the level deeper down in the lung to which $PM_{2.5}$ particles penetrate.

be exceeded more than three times in one year, with an annual average limit of 100 μg/m³).

During the 1990s, the WHO stated that no safe thresholds could be determined for exposure to particulates, and responded to the problem by publishing linear dose-response relationships for PM_{10} and $PM_{2.5}$ concentrations (World Health Organization, 2005). Dose-response relationships refer to the relationship between human exposure to a pollutant and the resultant health response to that exposure. In this case the relationship is linear, but that is not always the case. Linear dose-response relationship graphs were published to illustrate the fact that the relationship between PM concentration and various health indicators were roughly 'linear' – that is, as PM concentration increases, the percentage increase in daily mortality increases linearly. Similarly, as PM concentration increases, the proportional change in hospital admissions assigned, specifically, to PM_{10}, $PM_{2.5}$, and sulphates, also increase linearly; and as PM concentration increases, the proportional change in various health end-points (such as peak expiratory flow, coughing, symptom exacerbation, and bronchodilator use) is also linear.

This approach was not well accepted by air quality managers and policy-makers, so the WHO Working Group of Air Quality Guidelines recommended that the updated WHO air quality guideline document define concentrations which, if achieved, would be expected to reduce the rates of adverse health effects. Such guidelines would provide air quality managers and policy-makers with explicit objectives when setting national air quality standards. Given that air pollution levels in developing countries frequently far exceed the recommended WHO Air Quality Guidelines (AQGs), the working group also proposed interim targets (IT), higher than the WHO's AQG levels, to promote steady progress towards meeting the AQG objectives (World Health Organization, 2005). (See Tables 3.2 and 3.3 for the air quality guidelines and interim targets issued by the WHO in 2005 for particulate matter.)

Table 3.2: WHO Air Quality Guideline and interim targets for particulate matter (annual mean) (World Health Organization, 2005)

Annual WHO mean level	PM_{10} (μg/m³)	$PM_{2.5}$ (μg/m³)	Basis for the selected level
Interim target-1 (IT-1)	70	35	These levels were estimated to be associated with long-term mortality, which is about 15% higher than at AQG levels
Interim target-2 (IT-2)	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% (2–11%) compared with IT-1
Interim target-3 (IT-3)	30	15	In addition to other health benefits, these levels reduce mortality risks by a further approximately 6% (2–11%) compared with IT-2 levels
WHO AQG	20	10	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase (with more than 95% confidence) in response to exposure to $PM_{2.5}$ (as demonstrated in the American Cancer Society study, Pope *et al*., 2002, as cited in WHO, 2005)

ABBREVIATIONS: WHO, World Health Organization; WHO AQG, WHO Air Quality Guideline.

Table 3.3: WHO Air Quality Guideline and interim targets for particulate matter (daily mean) (World Health Organization, 2005)

Annual WHO mean level	PM_{10} (μg/m³)	$PM_{2.5}$ (μg/m³)	Basis for the selected level
Interim target-1 (IT-1)	150	75	Published risk coefficients from multi-centre studies and meta-analyses (about 5% increase of short-term mortality over AQG)
Interim target-2 (IT-2)*	100	50	Published risk coefficients from multi-centre studies and meta-analyses (about 2.5% increase of short-term mortality over AQG)
Interim target-3 (IT-3)†	75	37.5	Published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase of short-term mortality over AQG)
WHO AQG	50	25	Relation between 24-hour and annual levels

ABBREVIATIONS: See Table 3.2.

* 99th percentile (3 days/year)

† For management purposes, based on annual average guideline values; precise value to be determined on the basis of local frequency distribution of daily means

Air quality standards for $PM_{2.5}$ had (by the end of 2006) been set by various countries such as the USA, Canada, and Australia (see Table 3.4). The EC is still in the process of developing its $PM_{2.5}$ limit. No air quality limits have yet been published in South Africa for this particulate size.

3.1.2 Sulphur dioxide

Sulphur dioxide is an irritant gas, which is absorbed in the nose and aqueous surfaces of the upper respiratory tract, and is associated with reduced lung function and increased risk of mortality and morbidity. Adverse health effects of SO_2 include coughing, phlegm, chest discomfort, and bronchitis. Ambient air quality guidelines and standards for SO_2 have been issued for various countries and organizations (see Table 3.5).

The WHO AQGs published in 2000 for SO_2 were revised a few years later (World Health Organization, 2005). Although the 10-minute AQG of 500 μg/m³ remained unchanged, the previously published daily

Table 3.4: Air quality standard for $PM_{2.5}$

Authority	Maximum 24-hour concentration ($\mu g/m^3$)	Average annual concentration ($\mu g/m^3$)
Australia	25[a]	8[a]
US EPA	35[b]	15
Canada[c]	30	–

ABBREVIATIONS: US EPA, United States Environmental Protection Agency.

[a] Advisory reporting standards and goal for particles as $PM_{2.5}$. Measure schedule commenced in 2005 (www.deh.gov.au/atmosphere/airquality/standards.html).

[b] To attain this standard, the 3-year average of the 98th percentile of the 24-hour concentrations at each population-oriented monitor within an area must not exceed 35 $\mu g/m^3$ (www.epa.gov/air/criteria.html).

[c] Canada-Wide Standards issued by the Canadian Council of Ministers of the Environment.

Table 3.5: Ambient air quality guidelines and standards for SO_2 for various countries and organizations

Authority	Maximum 10-minute average ($\mu g/m^3$)	Maximum 1-hour average ($\mu g/m^3$)	Maximum 24-hour average ($\mu g/m^3$)	Annual average concentration ($\mu g/m^3$)
SA standards (AQA)	500[a]	–	125[a]	50
SANS limits (SANS 1929:2005)	500[b]	–	125[b]	50
Proposed SA standards (*Government Gazette* No. 28899, 9 June 2006)	500[a]	350[a]	125[a]	50
Australia	–	524[c]	209[c]	52
EC	–	350[d]	125[e]	20[f]
World Bank (General Environmental Guidelines)	–	–	125[g]	50[g]
World Bank (Thermal Power Guidelines)	–	–	150[h]	80[h]
UK	266[i]	350[j]	125[k]	20[l]
US EPA	–	–	365[m]	80
WHO (2000)	500[n]	–	125[n]	50[n] 10–30[o]
WHO (2005)	500[p]	–	20[p]	–[p]

ABBREVIATIONS: See Table 3.1.

[a] No permissible frequencies of exceedance specified.

[b] Limit value. Permissible frequencies of exceedance, margin of tolerance, and date by which limit value should be complied with, to be determined through a complete standard-setting process through the SABS.

[c] Australian ambient air quality standards. (http://www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more often than 1 day per year. Compliance by 2008.

[d] EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Limit to protect health, to be complied with by 1 January 2005 (not to be exceeded more than 24 times per calendar year).

[e] EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Limit to protect health, to be complied with by 1 January 2005 (not to be exceeded more than 3 times per calendar year).

[f] EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Limited value to protect ecosystems. Applicable two years from entry into force (date of publication) of the Air Quality Framework Directive 96/62/EC.

[g] World Bank, 1998. Pollution Prevention and Abatement Handbook (www.worldbank.org). Ambient air conditions at property boundary.

[h] World Bank, 1998. Pollution Prevention and Abatement Handbook (www.worldbank.org). Ambient air quality in thermal power plants.

[i] UK Air Quality Objective for 15-minute averaging period (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 35 times per year. Compliance by 31 December 2005.

[j] UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 24 times per year. Compliance by 31 December 2004.

[k] UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Not to be exceeded more than 3 times per year. Compliance by 31 December 2004.

[l] UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Compliance by 31 December 2000.

[m] US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than once per year.

[n] WHO Guidelines for the protection of human health (World Health Organization, 2000).

[o] Represents the critical level of ecotoxic effects (issued by WHO for Europe); a range is given to account for the different sensitivities of various vegetation types (World Health Organization, 2000).

[p] The new WHO guidelines (World Health Organization, 2005) are documented primarily for the protection of human health. The 10-minute guideline of 500 $\mu g/m^3$ published in 2000 remains unchanged, but the daily guideline is significantly reduced from 125 $\mu g/m^3$ to 20 $\mu g/m^3$ (in line with the precautionary principle). An annual guideline is not deemed necessary, since "compliance with the 24-hour level will assure lower levels for the annual average".

guideline (which was based on epidemiological studies) was significantly reduced from 125 μg/m³ to 20 μg/m³. More recent evidence (cited in World Health Organization, 2005) suggested the occurrence of health risks at lower concentrations. Considerable uncertainty is acknowledged in WHO (2005) as to the extent to which SO_2 is the pollutant responsible for the observed adverse effects (these could also be due to ultra-fine particles or other correlated substances), but, nevertheless, in line with the precautionary

Table 3.6: WHO Air Quality Guidelines and interim guidelines for SO_2 (World Health Organization, 2005)

WHO mean levels	24-hour average SO_2 (μg/m³)	10-minute average SO_2 (μg/m³)
Interim target-1 (IT-1) (2000 AQG level)	125	
Interim target-2 (IT-2)	50*	
WHO AQG	20	500

ABBREVIATIONS: See Table 3.2.

* Intermediate goal based on controlling (i) motor vehicle emissions; (ii) industrial emissions; and/or (iii) power production: this would be a reasonable and feasible goal to be achieved within a few years for some developing countries, and lead to significant health improvements that would justify further improvements (such as aiming for the guideline).

Table 3.7: Ambient air quality guidelines and standards for NO_2 for various countries and organizations

Authority	Instantaneous peak (μg/m³)	Maximum 1-hourly average (μg/m³)	Maximum 24-hour average (μg/m³)	Maximum 1-month average (μg/m³)	Annual average concentration (μg/m³)
SA standards (AQA)*	940[a]	376[a]	188[a]	150[a]	94
SANS limits (SANS 1929:2005)	–	200[b]	–	–	40[b]
Australia	–	226[c]	–	–	56
EC	–	200[d]	–	–	40[e]
World Bank (General Environmental Guidelines)	–	–	150 (as NO_X)[f]	–	–
World Bank (Thermal Power Guidelines)	–	–	150[g]	–	100[g]
UK	–	200[h]	–	–	40[i] 30[j]
US EPA	–	–	–	–	100(k)
WHO (2000, 2005)	–	200[l]	–	–	40[l]

ABBREVIATIONS: See Table 3.1.

* On 9 June 2006, South Africa's Department of Environmental Affairs and Tourism gazetted new air quality standards for public comment (a 90-day comment period was given). The proposed NO_2 standards were given as 200 μg/m³ for highest daily and 40 μg/m³ for annual averages (in line with the SANS limits). See Government Gazette No. 28899, 9 June 2006.

The standards and guidelines of most countries and organizations are given exclusively for NO_2 concentrations. South Africa's NO_2 standards are compared with various widely referenced foreign standards and guidelines in this table.

[a] No permissible frequencies of exceedance specified.

[b] Limit value. Permissible frequencies of exceedance, margin of tolerance, and date by which limit value should be complied with, to be determined through a complete standard-setting process through the SABS.

[c] Australian ambient air quality standards (www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more often than 1 day per year. Compliance by 2008.

[d] EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Not to be exceeded more often than 18 times per year. This limit is to be complied with by 1 January 2010.

[e] EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Annual limit value for the protection of human health, to be complied with by 1 January 2010.

[f] World Bank, 1998. Pollution Prevention and Abatement Handbook (www.worldbank.org). Ambient air conditions at property boundary.

[g] World Bank, 1998. Pollution Prevention and Abatement Handbook (www.worldbank.org). Ambient air quality in thermal power plants.

[h] UK Air Quality Provisional Objective for NO_2 (www.airquality.co.uk/archive/standards/php). Not to be exceeded more often than 18 times per year. Compliance by 31 December 2005.

[i] UK Air Quality Provisional Objective for NO_2 (www.airquality.co.uk/archive/standards/php). Compliance by 31 December 2005.

[j] UK Air Quality Objective for NO_X for the protection of vegetation (www.airquality.co.uk/archive/standards/php). Compliance by 31 December 2000.

[k] US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html).

[l] WHO Guidelines for the protection of human health (World Health Organization, 2000). AQGs remain unchanged according to WHO (2005).



principle, the WHO decided to publish a stringent daily guideline. An annual guideline was thought not to be needed for protecting human health, since compliance with the 24-hour level would assure sufficiently lower levels to reduce the annual average. Given that the 24-hour WHO AQG of 20 $\mu g/m^3$ was anticipated to be difficult for some countries to achieve in the short term, the WHO (2005) recommended a step-by-step approach using interim goals (see Table 3.6).

3.1.3 Oxides of nitrogen

Oxides of nitrogen, primarily in the form of nitric oxide (NO), comprise a primary pollutant emitted during combustion. Nitrogen dioxide (NO_2) is formed through oxidation of these oxides once they are released into the air, and is an irritant gas, which is absorbed by the mucous membrane of the respiratory tract. The worst health effect occurs at the junction of the conducting airway and the gas exchange region of the lungs. The upper-airways are less affected, because NO_2 is relatively insoluble in aqueous surfaces. Exposure to NO_2 is linked with increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and reduced pulmonary function.

3.1.4 Carbon monoxide

Carbon monoxide absorbed through the lungs reduces the blood's capacity to transport available oxygen to the tissues. This is because approximately 80–90% of the absorbed CO binds with haemoglobin to form carboxyhaemoglobin (COHb), lowering the oxygen level in blood, and, as a result, the heart needs to work harder to supply sufficient oxygen to the organs. This process is the main cause of tissue hypoxia (that is, deficiency in the amount of oxygen delivered to the body tissues) due to CO at low exposure levels. At higher concentrations, the rest of the absorbed CO binds with other haem proteins such as myoglobin and with cytochrome oxidase and cytochrome P-450. Taking in CO impairs perception and thinking, slows reflexes, and can cause drowsiness, angina, unconsciousness, or even death. (For the ambient air quality guidelines and other standards issued for various countries and organizations for CO, see Table 3.8.)

3.1.5 Ozone

Ozone is one of the most toxic pollutants regulated under ambient air quality guidelines and standards. Exposure to sufficient quantities can cause severe damage to lung tissue and weaken the body's defences against bacteria and viruses. Changes in lung function depend on the concentrations of ozone, and these increase with deeper breathing. Chronic exposures to ozone can result in the premature ageing of the lungs. Health effects associated with ozone exposures include increased incidence and severity of asthma attacks and increased pulmonary resistance. High exposure

Table 3.8: Ambient air quality guidelines and standards for CO for various countries and organizations

Authority	Maximum 1-hour CO average ($\mu g/m^3$)	Maximum 8-hour CO average ($\mu g/m^3$)
SA guidelines[a]	40 000[a]	10 000[a]
SANS limits (SANS 1929:2005)	30 000[b]	10 000[b]
Australia	–	10 000[c]
EC	–	10 000[d]
World Bank	–	–
UK	–	10 000[d]
US EPA	40 000[f]	10 000[f]
WHO	30 000[g]	10 000[g]

ABBREVIATIONS: See Table 3.1.

[a] Issued in the 1990s by the Chief Air Pollution Control Officer (CAPCO). No air quality standards for CO were included in South Africa's National Environmental Management: Air Quality Act.

[b] Limit value. Permissible frequencies of exceedance, margin of tolerance, and date by which limit value should be complied with, to be determined through a complete standard-setting process through the SABS.

[c] Australian ambient air quality standards (www.deh.gov.au/atmosphere/airquality/standards.html). Not to be exceeded more often than 1 day per year. Compliance by 2008.

[d] EC Second Daughter Directive, 2000/69/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Annual limit value to be complied with by 1 January 2005.

[e] UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Maximum daily running 8-hourly mean. Compliance by 31 December 2003.

[f] US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html). Not to be exceeded more than once per year.

[g] WHO Guidelines for the protection of human health (World Health Organization, 2000).

Venting of pollution from a low-rise building.

Photography: Zies van Zyl

levels are associated with an impaired capacity to diffuse carbon monoxide, headaches, and possible acute bronchiolitis (the inflammation of the bronchioles, the smallest air passages of the lungs). (For air quality guidelines and standards for ozone, see Table 3.9.)

The WHO (2005) published interim targets in addition to the AQG it stipulated for ozone (see Table 3.10). In addition to the target value for the protection of human health, the EC published a target value for ozone, to protect vegetation, which was given as 18 000 μg/m³ per hour averaged over five years (referred to as AOT40, calculated from 1-hour values from May to July, where AOT40 means the sum of the difference between hourly concentrations greater than 80 μg/m³ and 80 μg/m³ over a given period, using only the 1-hour values measured between 08h00 and 20h00 Central European Time each day).

3.1.6 Benzene

Benzene has been classified as a known human carcinogen, having been linked to increases in the incidence of leukemia in humans. Acute neurological effects after people have been inhaling benzene include drowsiness, dizziness, headaches, convulsions, and even death. Exposure to vapour can irritate the skin, eyes, and upper respiratory tract. Chronic exposures cause disorders in the blood in humans and specifically affect bone marrow. Other effects that may occur include aplastic anemia, excessive bleeding, and damage to the immune system, due to changes in blood levels of antibodies and loss of white blood cells.

Table 3.9: Ambient air quality guidelines and standards for ozone for various countries and organizations

Authority	Instantaneous peak (μg/m³)	Maximum 1-hour average (μg/m³)	Maximum 8-hour average (μg/m³)
SA standards (AQA)*	472 (0.25 ppm)	226 (0.12 ppm)	
SANS target values (SANS 1929:2005)		200[a]	120[a, b]
Australia[c]		189 (0.1 pm) (maximum 1-hour average) 151 (0.08 ppm) (maximum 4-hour average)	
WHO (2005)			100[d]
UK			100[e]
EC[f]			100[g]

ABBREVIATIONS: See Table 3.1.

* On 9 June 2006, South Africa's Department of Environmental Affairs and Tourism gazetted new air quality standards for public comment (a 90-day comment period was given). The proposed standards for ozone concentrations were the same as those issued by the SANS (Government Gazette No. 28899, 9 June 2006).

[a] SANS 1929:2005 target values. Permissible frequencies of exceedance, margin of tolerance, and date by which limit value should be complied with, to be determined through a complete standard-setting process through the SABS.

[b] This is an 8-hourly running average calculated on hourly averages; designed to protect human health.

[c] Australian ambient air quality standards (http://www.deh.gov.au/atmosphere/airquality/standards.html). Goal to be achieved by 2008, with a maximum allowable exceedance of 1 day per year.

[d] WHO (2005), value set for daily maximum 8-hour mean.

[e] UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Maximum daily running 8-hourly mean. Compliance by 31 December 2005. Not to be exceeded more often than 10 times per year.

[f] EC Directive, 2002/3/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Target value for the protection of human health.

[g] Maximum daily 8-hour mean, not to be exceeded on more than 25 days per calendar year averaged over three years. Compliance with target values to be assessed as of this value. Data for the year 2010 will be the first to be used in calculating compliance over the following three or five years, as appropriate.

Table 3.10: WHO (2005) Air Quality Guidelines and interim guidelines for ozone

WHO mean levels	Daily maximum 8-hour mean ($\mu g/m^3$)	Effects at selected ozone level
High level	240	Significant health effects, with a substantial proportion of the vulnerable human population affected.
Interim target-1 (IT-1)	160	Important health effects: this is an intermediate target for populations exposed to ozone concentrations above this level; it does not provide adequate public health protection*.
WHO AQG	100	This concentration level gives adequate public health protection, though some adverse health effects may occur at levels below it†.

* The rationale for this level is based on the following evidence: (i) it is the lower level of 6.6-hour chamber exposures to ozone by healthy exercising young adults at which physiological and inflammatory effects on the lungs are revealed; (ii) it is the ambient level of ozone at various summer camp studies at which there are effects on children's health; (iii) it is the level at which there is an estimated 3–5% increase in daily mortality* (based on findings of daily time-series studies). Human deaths attributable to ozone concentrations above estimated baseline of 70 $\mu g/m^3$, based on range of 0.3–0.5% increase in daily mortality for 10 $\mu g/m^3$ 8-hour ozone.

† The rationale for this level is based on the following evidence: (i) estimated 1–3% increase in mortality (based on findings of daily time-series studies); (ii) extrapolation from chamber and field studies based on the likelihood that real-life exposure tends to be repetitive and chamber studies do not study highly sensitive or clinically compromised subjects or children; (iii) the likelihood that ambient ozone is a marker for related oxidants.

South Africa's published air quality limit for benzene (SANS 1929:2005) is given as 5 $\mu g/m^3$ averaged over any 12-month period, in line with the EC limit value for benzene which is also 5 $\mu g/m^3$, to be met by 1 January 2010. The EC limit starts at 10 $\mu g/m^3$ on 1 January 2006, decreasing by 1 $\mu g/m^3$ each year (for example, down to 9 $\mu g/m^3$ on 1 January 2007) until 2010, when the EC limit of 5 $\mu g/m^3$ comes into effect.

3.1.7 Dust deposition

Dust deposition has been evaluated according to the following categories:

Slight – less than 250 mg/m^2 per day
Moderate – 250–500 mg/m^2 per day
Heavy – 500–1 200 mg/m^2 per day
Very heavy – more than 1 200 mg/m^2 per day

Emissions from large veld fires result in local and regional haze.
Photography: Janet Peace


Table 3.11: Bands of dustfall rates proposed for adoption in South Africa (SANS 1929:2005)

Band number	Band description label	Dustfall rate (D) (30-day average; mg/m^2 per day)	Comment
1	Residential	D<600	Permissible for residential and light commercial areas
2	Industrial	600<D<1 200	Permissible for heavy commercial and industrial areas
3	Action	1 200<D<2 400	Requires investigation and remediation if two sequential months lie in this band, or if there are more than three occurrences in any 12-month period
4	Alert	2 400<D	Immediate action and remediation required following the first exceedance, with an incident report to be submitted to the relevant authority

Table 3.12: Target, action and alert thresholds for ambient dustfall in South Africa (SANS 1929:2005)

Level	Dustfall rate (D) (mg/m^2 per day, 30-day average)	Averaging period	Permitted frequency of exceedances
Target	300	Annual	
Action residential	600	30 days	Three within any 12-month period; not in two sequential months
Action industrial	1 200	30 days	Three within any 12-month period; not in sequential months
Alert threshold	2 400	30 days	None. First exceedance requires remediation and compulsory report to authorities

Table 3.13: Ambient air quality guidelines and standards for lead for various countries and organizations

Authority	Maximum 1-month/quarterly average (µg/m^3)	Annual average (µg/m^3)
SA standard (AQA)	2.5 (1-month)	–
SANS limits (SANS 1929:2005)	–	0.5[a] 0.25[b]
Ekurhuleni Local Objective	–	0.5[c]
EC	–	0.5[d]
World Bank	–	–
UK	–	0.5[e] 0.25[f]
US EPA	1.5 (quarterly)[g]	–
WHO	–	0.5[h]

ABBREVIATIONS: See Table 3.1.

[a] Limit value. Compliance date to be determined through a complete standard-setting process through the SABS.
[b] Target value. Compliance date to be determined through a complete standard-setting process through the SABS.
[c] Local objective listed in Ekurhuleni Metropolitan Municipality Air Quality Management Plan AQMP (2005).
[d] EC First Daughter Directive, 1999/30/EC (http://europa.eu.int/comm/environment/air/ambient.htm). Annual limit value to be complied with by 1 January 2010.
[e] UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Compliance by 31 December 2004.
[f] UK Air Quality Objective (www.airquality.co.uk/archive/standards/php). Compliance by 31 December 2008.
[g] US National Ambient Air Quality Standards (www.epa.gov/air/criteria.html).
[h] WHO Guidelines for the protection of human health (World Health Organization, 2000).

The 1 200-mg/m^2 per day threshold level has typically been used in practice to indicate what (if any) action is required. Exceedance of this dustfall rate indicates the need to investigate the specific cause(s) of high dustfall and to take remedial steps. "Slight" dustfall is barely visible to the naked eye; "heavy" dustfall indicates a fine layer of dust on a surface; and "very heavy" dustfall is easily visible when a surface is not cleaned for a few days. Dustfall levels of >2 000 mg/m^2 per day are characterized by a layer of dust thick enough to allow a person to 'write' words in the dust with their fingers.

A perceived weakness of these dustfall guidelines is that they are purely descriptive, without specific guidance for action or remediation made explicit in the guidelines. It is stipulated in SANS 1929:2005 that dustfall rates should be evaluated against a four-band scale, as presented in Table 3.11. Target, action, and alert thresholds for ambient dust deposition are given in Table 3.12.

In terms of the proposed dustfall limits, an enterprise may submit a request to the authorities to operate within the "Band 3 Action" range for a limited period, provided that this is essential for the practical operation of the enterprise (for example, to accommodate the final removal of a tailings deposit), and provided that the best available control technology is applied for the duration. No margin of tolerance is to be granted for operations that result in dustfall rates in the "Band 4 Alert" range.

3.1.8 Metals

Lead is a toxic element, with a variety of effects at low dose levels. In people, brain damage, kidney damage, and gastrointestinal distress result from acute exposure to high levels of lead. Chronic exposure to lead in humans affects the blood, central nervous system (CNS), blood pressure, kidneys, and vitamin D metabolism. Children are particularly sensitive to chronic exposure to lead, with reported effects including slowed cognitive development and reduced growth (IRIS, 1998). Air quality guidelines and standards are issued by various countries including South Africa for lead (see Table 3.13).

Internationally, there is an increasing trend towards specifying air quality limits for certain metals. The limits published by the EC for arsenic, nickel, and cadmium, all of which are carcinogenic, are



summarized in Table 3.14. No air quality limits have been set for such metals in South Africa.

3.2 AIR QUALITY THRESHOLDS FOR NON-CRITERIA POLLUTANTS

3.2.1 Health-based air quality thresholds

Health thresholds for non-criteria pollutants are published by various sources. (The most widely-referenced of these are documented in Table 3.15.)

WHO guideline values are based on the no observed adverse effect level (NOAEL) and the lowest observed adverse effect level (LOAEL). Although most guideline values are based on NOAELs and/or LOAELs related to human health endpoints, certain of the guidelines given for 30-minute averaging periods are related to odour thresholds. The short-term effect screening levels (ESLs) issued by the Toxicology and Risk Assessment (TARA) Division of the Texan Natural Resource Conservation Commission for certain odourous compounds are similarly intended to be used for screening purposes, to assess potential nuisance impacts related to bad smell (malodour).

Inhalation reference concentrations (RfCs) related to inhalation exposures are published in the US EPA's Integrated Risk Information System (IRIS) database. These RfCs are used to estimate non-carcinogenic effects, representing a level of environmental exposure at or below which no adverse effect is expected to occur. An RfC is defined as "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive sub-groups) that is likely to be without appreciable risk of deleterious effects during a lifetime" (IRIS, 1998). Non-carcinogenic effects are evaluated by calculating the ratio, or hazard index, between a dose (in this case the dosage) and the pollutant-specific inhalation RfC. In the current study, reference is made to the chronic inhalation toxicity values published by the US EPA (IRIS, 1998)[5].

The RfCs are based on an assumption of lifetime exposure, so they provide a conservative estimate when applied to shorter-than-lifetime exposure situations. The RfC is not a direct or absolute estimator of risk, but rather a reference point for gauging potential effects. Doses at or below the RfC are not likely to be associated with any adverse health effects, and exceedance of the RfC does not imply that an adverse health effect will necessarily occur. As the amount and frequency of exposures exceeding the RfC increase, however, so does the probability that adverse effects may be observed in the human population. The US EPA has therefore specified that although doses below the RfC are acceptable, doses above the RfC are not necessarily unsafe.

Table 3.14: Ambient air quality target values issued by the EC for metals (EC Fourth Daughter Directive, 2004/107/EC)

Pollutant	Target value (for the total content in the PM_{10} fraction averaged over a calendar year) (ng/m^3)
Arsenic	6
Cadmium	5
Nickel	20

Table 3.15: Widely-referenced sources of health threshold information for non-criteria pollutants

Widely-referenced information sources of health thresholds	Threshold type	Averaging period	Website
US EPA (IRIS)	Sub-chronic inhalation reference concentrations	Sub-chronic – weeks to months	www.epa.gov/iris
	Chronic inhalation reference concentrations	Chronic – 1-year average or longer	www.epa.gov/iris
	Cancer unit risk factors	Chronic – 1-year average or longer (assuming exposures over a 70-year lifetime)	www.epa.gov/iris
California Environmental Protection Agency – Office of Environmental Health Hazard Assessment	Acute RELs	Acute – typically 1-hour average ranging to 8-hourly average, depending on pollutant	www.oehha.ca.gov
	Chronic RELs	Chronic – 1-year average or longer	www.oehha.ca.gov
ATSDR	MRLs		www.atsdr.cdc.gov/mrls.html
WHO	Guideline values and tolerable concentrations	Various averaging periods, including: 30-minutes; 1-hour; 24-hour; annual average	www.who.int/en/
	Cancer unit risks	Chronic – 1-year average or longer (assuming exposures over a 70-year lifetime)	www.who.int/en/

ABBREVIATIONS: ATSDR, US Federal Agency for Toxic Substances and Disease Registry; IRIS, Integrated Risk Information System; MRL, minimal risk level; REL, reference exposure level; US EPA, United States Environmental Protection Agency; WHO, World Health Organization.

5. The Integrated Risk Information System (IRIS), prepared and maintained by the US Environmental Protection Agency (US EPA), is an electronic database containing information on human health effects that may result from exposure to various chemicals in the environment. This database was initially developed for EPA staff in response to a growing demand for consistent information on chemical substances for use in risk assessments, decision-making, and regulatory activities. The information in IRIS is intended for those without extensive training in toxicology, but with some knowledge of health sciences.

Table 3.16: Inhalation-based health thresholds for selected non-criteria pollutants (μg/m³)

Constituent	WHO Guidelines (2000)		US EPA (IRIS) inhalation reference concentrations	California OEHHA (first adopted as of August 2003)	
	Acute and sub-acute guideline value (average period)	Chronic guidelines (exposure for longer than 1 year)	Chronic inhalation RfCs	Acute RELs (average period, hours)	Chronic RELs
Benzene			30	1 300 (6)	60
Cadmium		0.005 (GV)			0.02
Carbon tetrachloride		6.1 (TC)		1 900 (7)	40
Chloroform				150 (7)	300
Chromium (VI) compounds			0.1		0.2
Copper				100 (1)	
Ethylbenzene		22 000 (GV)	1 000		2 000
Hydrogen sulphide	7 (30 min)[a]; 150 (24 h)		2	42 (1)	10
Toluene	1 000 (30 min)[a]; 260 (1 week)		400	37 000 (1)	300
Xylene	4 800 (24 h)	870 (GV)	100	22 000 (1)	700

ABBREVIATIONS: ATSDR, US Federal Agency for Toxic Substances and Disease Registry; ESL, effect screening level; GV, guideline value; IRIS, Integrated Risk Information System; MRL, maximum risk level; OEHHA, Office of Environmental Health Hazard Assessment; REL, reference exposure level; RfC, inhalation reference concentration; TARA, Texas Natural Resource Conservation Commission Toxicology and Risk Assessment Division; TC, tolerable concentration; WHO, World Health Organization.

[a] Given for odour.

The US Federal Agency for Toxic Substances and Disease Registry (ATSDR) uses the no-observed-adverse-effect-level/uncertainty factor (NOAEL/UF) approach to derive minimal risk levels (MRLs) for hazardous substances. They are set below levels that, based on information current at the time, might cause adverse health effects in the people most sensitive to such substance-induced effects. The MRLs are derived for acute (1–14 days), intermediate (>14–364 days), and chronic (365 days and longer) exposure durations, and for oral as well as inhaled exposure. These levels are generally based on the most sensitive substance-induced end point considered relevant to humans. The ATSDR does not use serious health effects (such as irreparable damage to the liver or kidneys, or birth defects) as a basis for establishing MRLs. Exposure to a level above the MRL does not mean that adverse health effects will necessarily occur.

The intention of MRLs is to serve as a screening tool that helps public health professionals decide where to look more closely. They are also a mechanism for identifying hazardous waste sites that are not expected to cause adverse health effects. Most MRLs contain some degree of uncertainty because of the lack of precise toxicological information about the people who might be most sensitive to effects of hazardous substances (for example, infants, the elderly, and those who are nutritionally or immunologically compromised). The ATSDR uses a conservative (that is, protective) approach to address these uncertainties, consistent with the public health principle of prevention. Although human data are preferred, MRLs often have to be based on animal studies because relevant studies on people are lacking. In the absence of evidence to the contrary, the ATSDR assumes that humans are more sensitive than animals to the effects of hazardous substances, and that certain people or groups may be particularly sensitive. The resulting MRL, therefore, may be as much as a hundredfold below levels shown to be nontoxic in laboratory animals. When adequate information is available, physiologically based pharmacokinetic (PBPK) modelling and benchmark dose (BMD) modelling have also been used as an adjunct to the NOAEL/UF approach in deriving MRLs.

Proposed MRLs undergo a rigorous assessment process. They are reviewed by the Health Effects/MRL Workgroup within the Division of Toxicology of the US Federal Agency for Toxic Substances and Disease Registry (ATSDR); an expert panel of external peer reviewers; the agency-wide MRL Workgroup, with participation from other federal agencies, including EPA. They are also submitted

Table 3.17: Odour threshold values for common sources of odour (μg/m³)

Pollutant	Odour recognition thresholds		Other odour thresholds	WHO guideline value (30 min)
	100% recognition	50% recognition		
Ammonia			500[a]	
Hydrogen sulphide	1 430	11.2	4.29[b]	7

[a] Odour threshold concentration (Verschueren, 1996)

[b] South African guideline (personal communication, M. Lloyd, 8 October 1998)

for public comment through the toxicological profile public comment period. Each MRL is subject to change as new information becomes available, which results in the updating of the toxicological profile of the substance. The MRLs in most recent toxicological profiles supersede previous published levels. (For a synopsis of the health-based air quality criteria extracted for use in the current study, see Table 3.16.)

3.2.2 Odour thresholds

Odour thresholds are defined in several ways, including absolute perception thresholds, recognition thresholds, and objectionability thresholds. At the perception threshold, one is certain that an odour is detected but it is too faint to identify further. Recognition thresholds are normally given for 50% and 100% recognition by an odour panel. (For various odour thresholds published in the literature for odorous compounds of interest in the current study, see Table 3.17.)

Reported odour threshold data vary considerably, as much as by four orders of magnitude for certain chemicals. Reasons for this variability include differences in experimental methods used, and in human responses to smell.

3.3 DEFINITION OF HIGH POLLUTION DAYS

A comprehensive overview of international best practice and local developments in the use of air pollution indices for the purpose of communicating air quality information is given in the *Technical Compilation Document to Inform the State of Air Report* (DEAT, 2006a), reproduced in the Appendix. Pending the national adoption in South Africa of an air quality indexing system for the routine reporting of air pollution levels in the country, the following approach was employed in this report to define "low", "moderate", and "high" pollution days.

Poorly managed waste may result in malodorous emissions.

Photography: Ignatius Gerber

Air pollution data for PM_{10}, SO_2, NO_2, CO, O_3, and hydrogen sulphide (H_2S) were selected for use in calculating high pollution days. Hourly- and daily-averaged air pollution data were analyzed, with hours and days initially classified into pollutant-specific categories based on health-related thresholds.

All days with one or more exceedances of the hourly-average threshold given for "high" gaseous pollution concentrations, or of the daily-average threshold given for "high" PM_{10} concentrations, were classified as "high pollution days", and the pollutants resulting in this classification noted.

Table 3.18: Pollutant thresholds

Pollutant*	PM_{10}	SO_2	NO_2	CO	O^3	H_2S
Units	µg/m³	µg/m³	µg/m³	mg/m³	µg/m³	µg/m³
Low	<50	<245	<140	<21	<140	<30
Moderate	50–75	245–350	140–200	21–30	140–200	30–42
High	>75	>350	>200	>30	>200	>42

* Each entry corresponds to an hourly averaging period