ANNEXURE F:

NOISE STUDY

JKA

JONGENS KEET ASSOCIATES

ACOUSTICAL ENGINEERING CONSULTANTS

Telephone: 021 – 7945643 Facsimile: 021 – 7945643 email: jongens@yebo.co.za

A.W.D. Jongens
8 Wingerd Avenue
7806 CONSTANTIA
Tel/Fax: 021 794 5643

D. Cosijn
207 Albert Street
0181 WATERKLOOF
Tel/Fax: 012 460 4481

Dr. W. de V. Keet
P.O. Box 236
7440 KERNKRAG
Tel/Fax: 021 553 2331

Architectural Acoustics Noise & Vibration Control Environmental Noise Traffic Noise Acoustical Material Research Underwater Sound Nonlinear Acoustics

ENVIRONMENTAL NOISE IMPACT ASSESSMENT FOR THE PROPOSED OPEN CYCLE GAS TURBINE POWER PLANT AT MOSSEL BAY

Prepared by

A.W.D. Jongens

for

Ninham Shand Consulting Services

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EXECUTIVE SUMMARY

A noise impact study was conducted into the potential impact of the proposed construction and operation of an Open Cycle Gas Turbine (OCGT) power station for peaking electrical capacity at a site west of the existing PetroSA refinery at Mossel Bay.

Siemens, the suppliers of the machinery, indicate that a sound pressure level of 45dBA will not be exceeded at 1100m from the outermost point of the plant installations. Calculations conducted in this study confirm this for the operation of one of three power generation units. Calculations predicted that, for continuous operation of all three power generation units, an equivalent continuous A-weighted sound pressure level of 45dBA would occur at 2000m from the centre or 1820m from the outermost point of the plant installations.

Assessment of noise in terms of SANS 10103 was based on comparing the predicted rating level, $L_{Req,T}$, of noise emanating from the plant with the prevailing, residual rating level of 43dBA measured on the adjacent farmland. For a total of two hours operation during daytime, an $L_{Req,d}$ of 43dBA due to noise emanating from the plant would occur at a distance of 1040m from the centre of the plant installations. This would result in areas of farmland within 860m of the boundaries closest to the plant being exposed to rating levels of noise in excess of acceptable levels. The anticipated intensity of noise impact would range from “low” at 860m from the farm boundary to “high” within 100m of the farm boundary. Were the site to be relocated at least 600m south and 600m east, intensity of noise impact on the area of affected farmland could be significantly reduced, if not eliminated.

Assessment of noise in terms of the Noise Control Regulations of the Province of the Western Cape indicated that noise emanating from the OCGT plant would be construed to be a disturbing noise on land within a radius of 1270m from the centre of the plant or within 1090m from the nearest farm boundaries. Relocating the plant 600m further south and east would reduce the farmland exposed to a disturbing noise to within 490m from the farm boundaries.

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1. INTRODUCTION

1.1. Background and brief

Jongens Keet Associates was commissioned to undertake a specialist study into the potential impact of noise of the proposed construction of an Open Cycle Gas Turbine (OCGT) Power Station for peaking electrical capacity at Mossel Bay.

2. METHODOLOGY

The study was conducted in accordance with procedures contained in South African National Standard (SANS) 10328, *Methods for environmental noise impact assessments* in terms of the National Environmental Management Act Nr 107 of 1998. These include the following:

1. Determine the land use zoning and identify all potential noise sensitive sites that could be impacted upon by activities relating to operation of the proposed Open Cycle Gas Turbine (OCGT) power plant at the proposed site.
2. Determine the existing ambient levels of noise at identified noise sensitive sites by conducting representative sound measurements.
3. Determine the acceptable rating level for noise at the identified noise sensitive sites.
4. Identify all noise sources relating to the activities of the plant during construction phase and operation phase that could potentially result in a noise impact at the identified noise sensitive sites.
5. Determine the sound emission, operating cycle and nature of the sound emission from each of the identified noise sources.

6. Calculate the combined sound power level due to the sound emissions of the individual noise sources.
7. Calculate the expected rating level of sound at the identified noise sensitive sites from the combined sound power level emanating from identified noise sources.
8. Calculate the noise impact at identified noise sensitive sites.
9. Assess the noise impact at identified noise sensitive sites in terms of SANS 10328; the Noise Control Regulations; the World Health Organsation; the World Bank.
10. Investigate alternative noise mitigation procedures, if relevant.
11. Prepare and submit an environmental impact report containing the procedures and findings of the investigation.

3. ASSESSMENT OF NOISE

The terminology used in South African National Standards for the measurement and assessment of noise is contained in Appendix A.

3.1. South African National Standards

In accordance with SANS 10328, the predicted impact that noise emanating from a proposed development would have on occupants of surrounding land is assessed by determining whether the rating level of the predicted ambient noise would exceed the residual noise or exceed the acceptable rating level of noise on that land as indicated in Table 2 of SANS 10103 and relating this excess to the probable response of a community to the noise as indicated in Table 5 of SANS 10103. Tables 2 and 5 of SANS 10103 are reproduced hereunder:

SANS 10103, Table 2 — Acceptable rating levels for noise in districts

1	2	3	4	5	6	7
Type of district	**Equivalent continuous rating level ($L_{Req,T}$) for noise,** dBA					
	Outdoors			**Indoors, with open windows**		
	Day-night $L_{R,dn}$ [a]	**Day-time** $L_{Req,d}$ [b]	**Night-time** $L_{Req,n}$ [b]	**Day-night** $L_{R,dn}$ [a]	**Day-time** $L_{Req,d}$ [b]	**Night-time** $L_{Req,n}$ [b]
RESIDENTIAL DISTRICTS						
a) Rural districts	45	45	35	35	35	25
b) Suburban districts with little road traffic	50	50	40	40	40	30
c) Urban districts	55	55	45	45	45	35
NON RESIDENTIAL DISTRICTS						
d) Urban districts with some workshops, with business premises, and with main roads	60	60	50	50	50	40
e) Central business districts	65	65	55	55	55	45
f) Industrial districts	70	70	60	60	60	50

NOTE 1 If the measurement or calculation time interval is considerably shorter than the reference time intervals, significant deviations from the values given in the table may result.

NOTE 2 If the spectrum of the sound contains significant low frequency components, or when an unbalanced spectrum towards the low frequencies is suspected, special precautions should be taken, and specialist attention is required. In this case the indoor sound levels may significantly differ from the values given in columns 5 to 7. See also annex B.

NOTE 3 Residential buildings, e.g. dormitories, hotel accommodation, residences etc. may only be allowed in non- residential districts on condition that the calculated or anticipated indoor $L_{Req,T}$ values given in column 3 of table 1 are not exceeded.

a The values given in columns 2 and 5 are equivalent continuous rating levels and include corrections for tonal character, impulsiveness of the noise and the time of day.

b The values given in columns 3, 4, 6 and 7 are equivalent continuous rating levels and include corrections for tonal character and impulsiveness of the noise.

SANS 10103, Table 5 — Categories of community/group response

1	2	3
Excess $\Delta L_{Req,T}$ [1)] dBA	**Estimated community/group response**	
	Category	**Description**
0 – 10	Little	Sporadic complaints
5 – 15	Medium	Widespread complaints
10 – 20	Strong	Threats of community/group action
>15	Very strong	Vigorous community/group action

a Calculate)$L_{Req,T}$ from the appropriate of the following:

1) $\Delta L_{Req,T}$ = $L_{Req,T}$ of ambient noise under investigation MINUS $L_{Req,T}$ of the residual noise (determined in the absence of the specific noise under investigation).

2) $\Delta L_{Req,T}$ = $L_{Req,T}$ of ambient noise under investigation MINUS the maximum rating level for the ambient noise given in table 1.

3) $\Delta L_{Req,T}$ = $L_{Req,T}$ of ambient noise under investigation MINUS the acceptable rating level for the applicable district as determined from table 2.

4) $\Delta L_{Req,T}$= Expected increase in $L_{Req,T}$ of ambient noise in an area because of a proposed development under investigation.

NOTE Overlapping ranges for the excess values are given because a spread in the community reaction may be anticipated

3.2. World Health Organisation

SANS 10103 contains the statement that the acceptable rating levels for ambient noise are essentially in line with the recommendations of the World Health Organisation (WHO) for community exposure.

3.3. World Bank

The World Bank has adopted the WHO recommendations on maximum L_{Aeq} in residential areas and schools. These recommendations apply to all World Bank Group funded projects.

The assessments of noise impact in this study therefore embody WHO and World Bank assessments.

3.4. Impact qualifiers

The **intensity** of a predicted noise impact was determined in relation to the categories of community response contained in Table 5 of SANS 10103 and are qualified as follows:

Negligible	Predicted $L_{Req,T}$ does not exceed the residual or acceptable $L_{Req,T}$
Low	Predicted $L_{Req,T}$ exceeds the residual or acceptable $L_{Req,T}$ by between 0 & 5 dB
Medium	Predicted $L_{Req,T}$ exceeds the residual or acceptable $L_{Req,T}$ by between 5 & 10 dB
High	Predicted $L_{Req,T}$ exceeds the residual or acceptable $L_{Req,T}$ by more than 10 dB

For a 16-hour daytime assessment, $L_{Req,d}$ replaces $L_{Aeq,T}$.
For an 8-hour night-time assessment, $L_{Req,n}$ replaces $L_{Aeq,T}$.

3.5. Noise Control Regulations

The control of noise in the Western Cape is legislated in the form of the Noise Control Regulations of the Environment Conservation Act No. 73 of 1989 applicable to the Province of the Western Cape, Provincial Gazette Number 5309 of 20 November 1998.

In terms of Clause 2 (d) of the Noise Control Regulations:

"*A local authority may, before changes are made to existing facilities or existing use of land or buildings, or before new buildings are erected, in writing require that noise impact assessments or tests be conducted to the satisfaction of the local authority by the owner, developer, tenant or occupant of the facilities, land or buildings and that reports or certificates relating to the noise impact be submitted to the local authority, to the satisfaction of the local authority, by the owner, developer, tenant or occupant.*"

In terms of Schedule 3 (c) of the Noise Control Regulations:

"No person shall make changes to existing facilities or existing use of land or buildings or erect new buildings, if these will house or cause activities that will, after such changes or erection, cause a disturbing noise, unless precautionary measures to prevent the disturbing noise have been taken to the satisfaction of the local authority."

In terms of Clause 4 of the Noise Control Regulations:

"No person shall make, produce or cause a disturbing noise, or allow it to be made, produced or caused by any person, animal, machine, device or apparatus or any combination thereof."

Ambient sound level means the reading on an integrating impulse sound level meter taken at a measuring point in the absence of any alleged disturbing noise at the end of a total period of at least 10 minutes after such meter was put into operation.

Disturbing noise means a noise level that exceeds the ambient sound level measured continuously at the same measuring point by 7 dB or more.

Noise level means the reading on an integrating impulse sound level meter taken at a measuring point in the presence of any alleged disturbing noise at the end of a total period of at least 10 minutes after such meter was put into operation, and, if the alleged disturbing noise has a discernible pitch, for example, a whistle, buzz, drone or music, to which 5 dBA is added.

Certain terminology used in the Noise Control Regulations and in the SANS 10103 have similar sounding, but not equal, meanings. Thus,

Noise Control Regulations:		SANS 10103:
Ambient sound level	is similar to	Residual noise level
Noise level	is similar to	Rating level of ambient noise

Cognisance needs to be taken of the fact that the National Noise Control Regulations, upon which the Provincial Noise Control Regulations are based, have undergone major revision to bring them in line with recommendations of the World Health Organisation, WHO. South Africa is a signatory of WHO and is thereby bound by its recommendations. Although the existing Noise Control Regulations remain in force until promulgation of the revised Noise Control Regulations, the draft revision has passed public comment stage and could be promulgated within the near future. Noise limits in the draft revision of the Noise Control Regulations are based on the acceptable rating levels of ambient noise contained in SANS 10103. Thus, in terms of the revised Regulations,

Disturbing noise means a specific noise level that exceeds either the outdoor equivalent continuous day/night rating level (L_{Rdn}), the outdoor equivalent continuous day rating level (L_{Rd}) and/or the outdoor equivalent continuous night rating level (L_{Rn}) for the particular neighbourhood indicated as the Outdoor ambient noise in various districts in SANS 10103.

4. STUDY AREA

The study area is shown in Figure 1. The proposed site is located approximately 1300m west of the existing PetroSA Refinery (Mossgas) bounded by a railway line to the north. The land to the north of the railway line and west of the proposed site is zoned rural containing several farms.

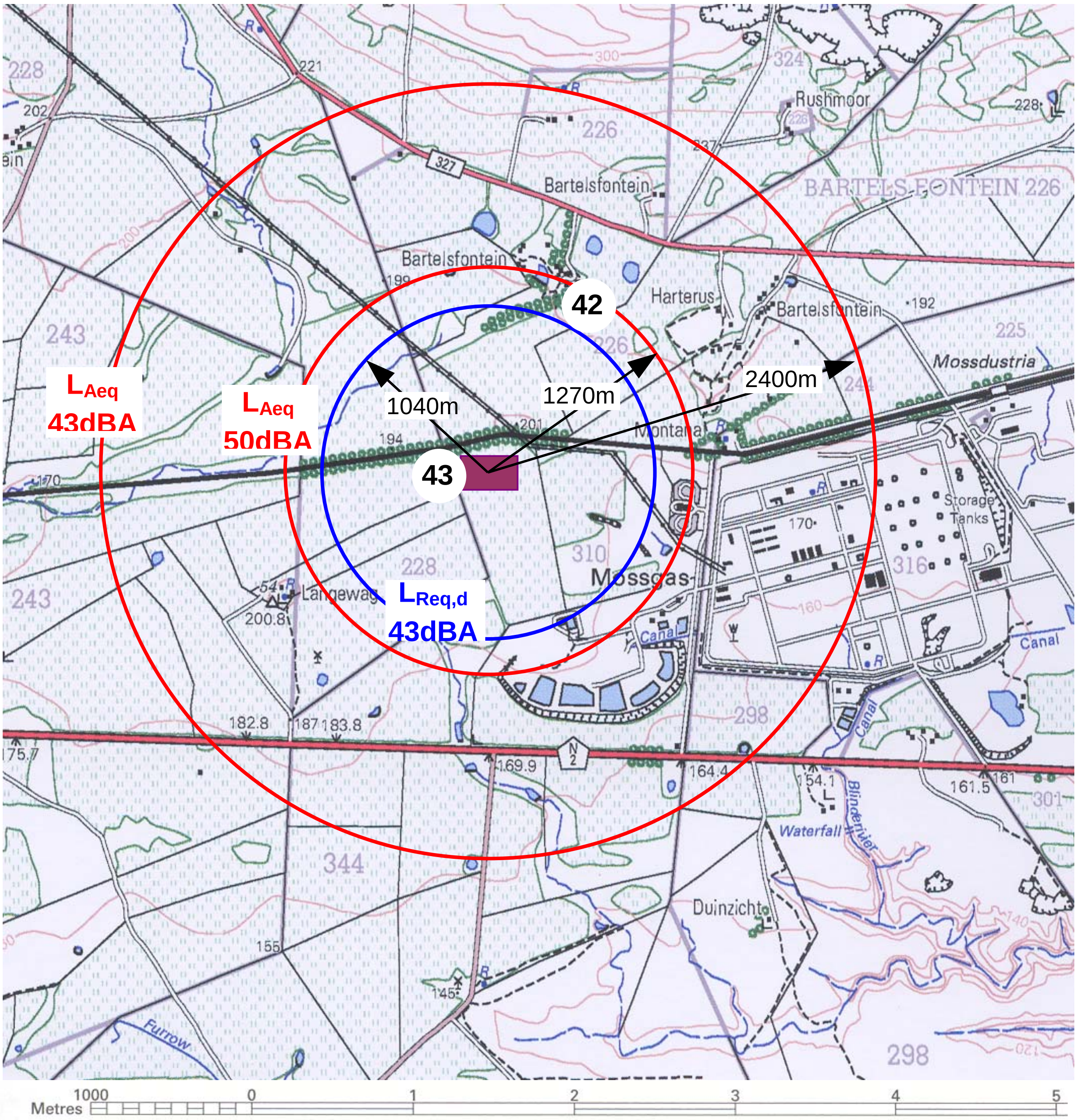

Figure 1 **Study area showing the proposed OCGT site location and the measured L_{Aeq} in black on a white background. The $L_{Req,d}$ contour of 43dBA is shown in blue. The L_{Aeq} contours of 43 and 50dBA are shown in red**

4.1. Measured ambient and acceptable rating levels for noise

Equivalent continuous A-weighted sound levels, L_{Aeq}, were measured on Wednesday 28 September 2005 between 11h00 and 12h00 at the NW corner of the proposed OCGT site. This was within a few metres of the boundary of the farm located west of the proposed site. Further measurements were conducted at a group of houses on Bartelfontein approximately 1100m WNW from the proposed site. The sky was partly overcast with a westerly wind of between 9 and 15km/hr blowing. Mr. J. Joubert of PetroSA was in attendance.

The L_{Aeq} recorded at the NW corner of the proposed OCGT site was 43dBA. Noise within the frequency band of 500Hz and 2000Hz originating from the safety flare blow-off stacks of the PetroSA plant was audible.

The L_{Aeq} recorded at the group of houses on Bartelfontein was 42dBA.

According to Mr Joubert the noise during the measurement periods was representative of that emanating from the PetroSA plant during normal operation.

In terms of SANS 10103 the measured 43dBA and 42dBA, respectively, were slightly lower than the acceptable daytime rating level of 45dBA for a rural residential district.

Analysis of the recorded sound spectra (not included in this report) showed that wind noise at frequencies below 500Hz contributed to the recorded L_{Aeq} values. It was estimated that, in the absence of wind noise, the L_{Aeq} values would be 2dB less than those recorded at the two sites.

The measured L_{Aeq} are displayed in black on a white background in Figure 1.

5. SOURCES OF NOISE RELATING TO THE PROPOSED OCGT PLANT

It is proposed to install three Siemens type SGT5-2000 OCGT power generation units. An example of two typical generation units, received from Siemens, is displayed in the photograph of Figure 2. Each unit comprises several major sources of noise. The photograph includes labels of some of the sources as interpreted by the author from a list of sources of noise received from Siemens. A plan and section of an OCGT power generation unit is displayed in Figure 3.

The linear-weighted sound power levels, in dB, in each octave frequency band from 31,5Hz to 8000Hz emitted by each noise source and the mean elevation of the source above ground level are recorded in Table 1. These were derived from a list of A-weighted octave band sound power levels provided by Siemens [1]. The list contained an "unidentified noise source" assumed to have a mean source height of 6m. A statement accompanying the data informed that the emission values supplied were not guaranteed and served for information only.

The data initially received was compared with a Table of emitted A-weighted sound power levels to the environment from the essential functional groups of the OCGT Eskom – Atlantis contained in Table 1 of Section 7 of a report provided subsequently by Siemens [3]. Section 7 of that report contained the following statement: "*Taking into account the assumed/recommended noise control installations the essential functional groups of the "OCGT Eskom – Atlantis", will emit the following sound power levels to the environment (see following Table 1) during steady-state base load operation of all Units of the gas turbine power plant.*" The A-weighted sound power levels of the latter report differed for a few of the noise sources compared to the initial data received. The A-weighted octave band sound power levels received initially were adjusted accordingly. The changes have been reflected in Table 1 of this report.

TABLE 1 Elevation & octave frequency band sound power levels of each source

Noise sources for each power generation unit	Source height, m	Octave frequency band, Hz								
		31.5	63	125	250	500	1000	2000	4000	8000
		Sound power levels, dB								
Gas turbine package UMB	6	123	121	112	107	100	95	92	87	83
Gas turbine filter house UMB	14	113	104	97	87	84	92	95	94	89
Gas turbine diffuser extension duct UHN	6	109	115	110	105	104	99	99	93	87
Exhaust stack	30	130	124	114	103	101	99	98	98	104
Lube oil coolers URC	4	96	98	100	101	96	92	90	88	87
Forced cooling water cooler URB	4	100	102	104	106	100	96	94	92	91
Transformers BAT/BBT/BFT	6	79	89	103	103	99	94	87	83	73
Unidentified noise source	6	121	121	116	112	103	97	91	85	81
Single noise source for all units:										
Fuel oil pump station UEL	3	82	95	103	101	99	98	96	94	88

FIGURE 2 Example of two OCGT power generation units

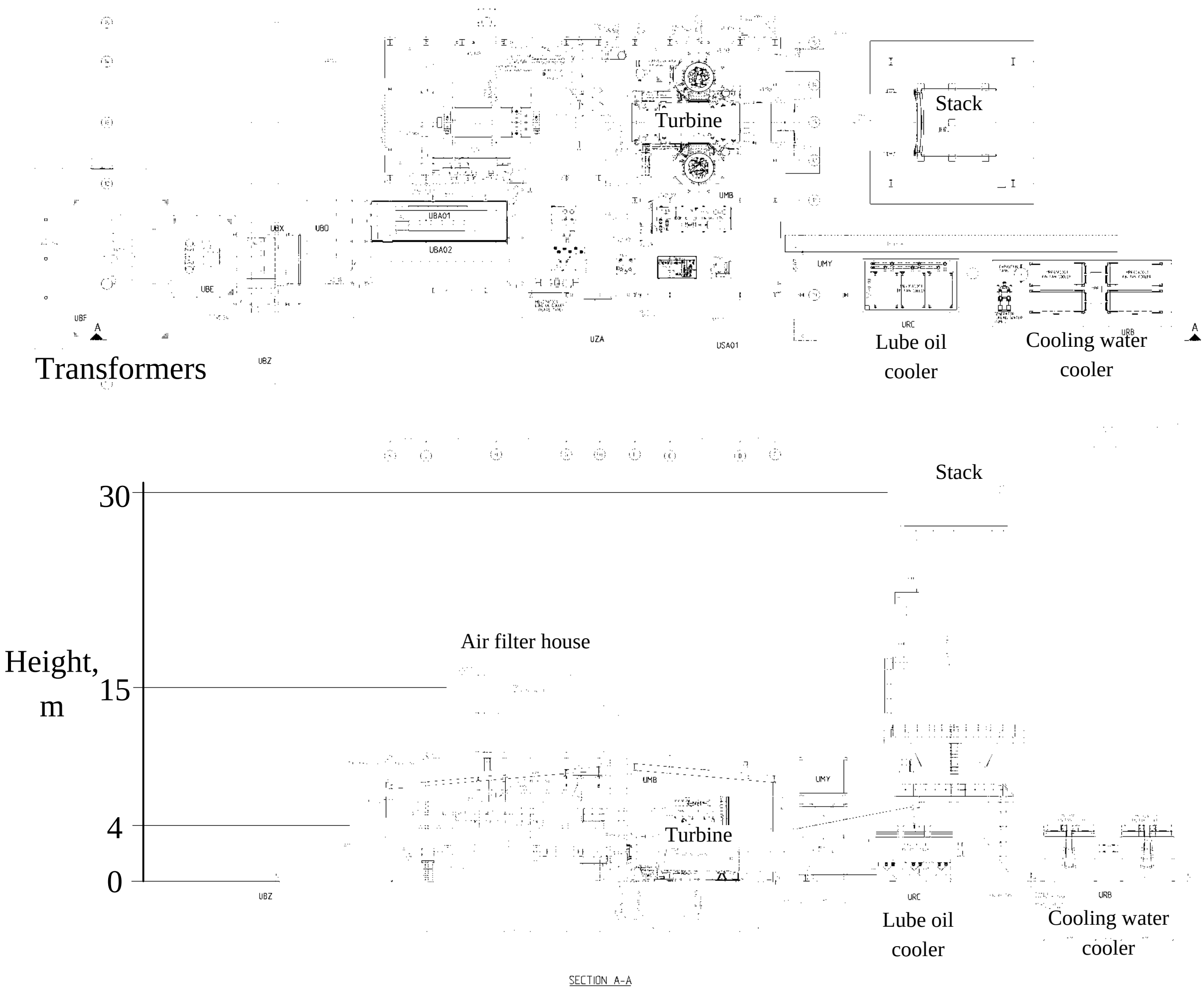

FIGURE 3 Plan and section of an OCGT power generation unit

Sections 9.2 and 10 of the Siemens report [3] indicated that impulsive types of noise, such as associated with steam blow-off systems and safety valves, do not exist in a gas turbine plant. Section 5.2.2 of the report [3], referring to noise mitigation procedures to be undertaken, contained the following statement: …. *Clearly audible tonal components shall be avoided.* From the information provided it was understood that adjustments for pure tones or impulsive nature of the noise were not applicable in deriving the rating level of noise.

Figure 4 shows the proposed site plan with the three OCGT power generation units contained within the circle. The fuel oil pump station is located at the south end of the site.

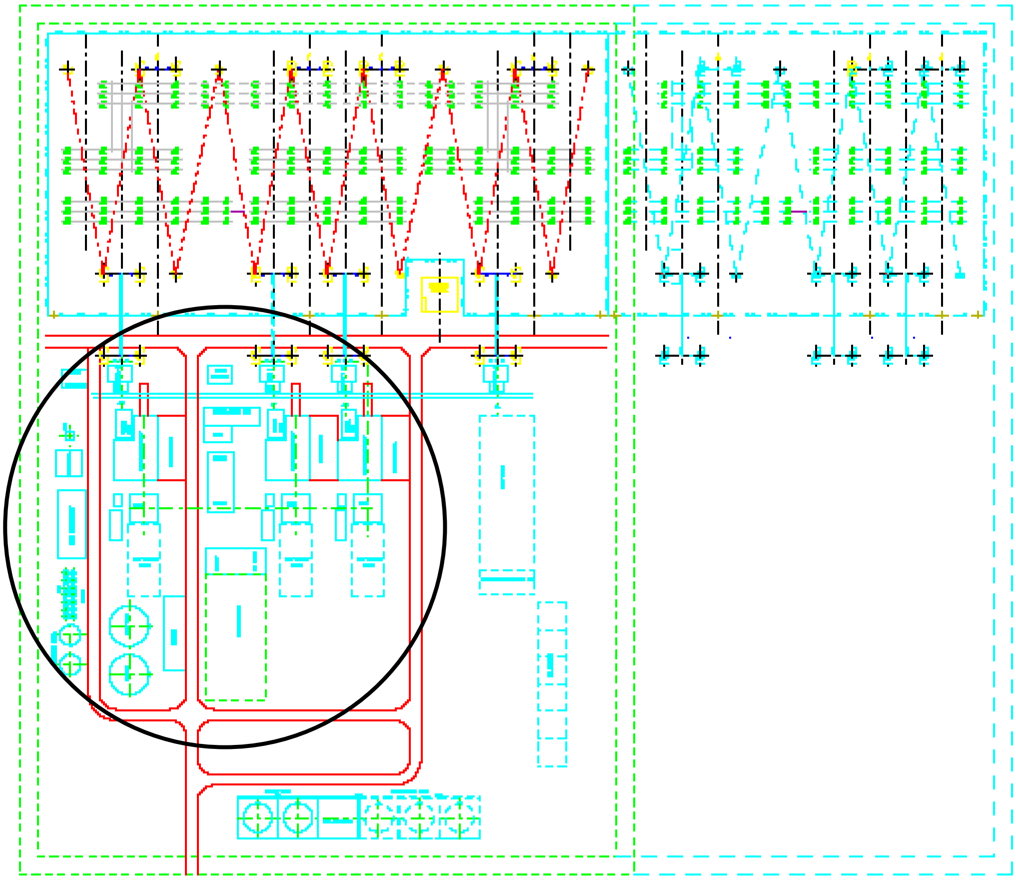

Figure 4 OCGT site plan with the three power generation units contained within the circle

6. IMPACT OF NOISE AT RECEIVER LOCATIONS – OPERATION PHASE

The linear-weighted sound power levels in Table 1 were used to calculate the A-weighted frequency octave band sound pressure levels at a receiver location due to the combined contribution due to each source of each of three power generation units, emanating from its respective height above ground level in accordance with procedures contained in SANS 10357, *The calculation of sound propagation by the Concawe method.* In view of the approximate information of the noise source data implied, it was assumed for calculation purposes that the noise originated from a geometrical mean source position in the horizontal plane. This was taken as the centre of the circle displayed in Figure 4. The mean elevation of each noise source above the ground was retained in the calculations.

According to information received from Eskom, the OCGT plant would primarily operate for one hour between 06:00 and 07:00hrs and for one hour between 19:00 and 20:00hrs. These times coincide with periods just before sunrise and after sunset during winter, respectively, when meteorological conditions favour the propagation of sound from a noise source to a receiver location. The appropriate meteorological conditions were applied in the calculation of sound propagation.

Results of calculations indicated that the equivalent continuous A-weighted sound pressure level, $L_{Aeq,T}$, due to noise emanating from the plant during each one-hour operation in the morning and evening (T = 1 hour) would be 43dBA and 50dBA when measured at distances of 2400m and 1270m, respectively, from the centre of the plant. This is depicted in Figure 1 by the red circles centred on the centre of the proposed plant. The $L_{Aeq,T}$ would increase with decreasing range from the centre of the proposed plant and would be approximately 65dBA at the boundary of the nearest farm.

For assessment purposes in accordance with SANS 10103, the sound energy occurring for the total of two hours of operation was averaged (on an energy basis) over the daytime period T = 16 hours assuming that both of the one-hour periods would occur during the daytime period from 06:00hrs to 22:00hrs. The result is termed the daytime rating level of noise, $L_{Req,d}$. The acceptable $L_{Req,d}$ for a rural residential district is 45dBA. The sound measurements indicated that the prevailing $L_{Req,d}$ near the boundary of the farm was 43dBA.

Results of calculations indicated that the $L_{Req,d}$ of 43dBA due to noise emanating from the OCGT plant would occur at a range of 860m from the centre of the plant. The 43dBA $L_{Req,d}$ contour is shown in blue in Figure 1.

Were the OCGT plant to operate continuously during the daytime or night time, the 43dBA rating level contour would equal the one-hour $L_{Aeq,T}$ occurring at a range of 2400m from the centre of the plant (red circle).

6.1. Assessment of the results

SANS 10103

The impact of noise due to the proposed development of the OCGT plant was assessed by determining the expected increase in $L_{Aeq,T}$ of ambient noise due to noise emanating from the operation of the plant. Refer to note 4 in Table 5 of SANS10103 reproduced in Section 3.1 of this report.

Study of Figure 1 indicates that the $L_{Req,d}$ = 43dBA (blue) contour would extend approximately 860m within the farmland to the north and to the west of the proposed site. The $L_{Req,d}$ due to noise from the OCGT plant would exceed the acceptable level on land within the 43dBA contour.

The anticipated intensity of noise impact within the $L_{Req,d}$ = 43dBA contour would range from "low" at 860m from the farm boundary to "high" within 100m of the farm boundary.

The assessment was based on the following assumptions:

- The OCGT noise emission data provided was representative of that to be constructed.
- Operation of the OCGT plant would be restricted to a total of two hours during the daytime period from 06:00hrs to 22:00hrs.
- The noise emanating from the plant did not contain pure tones and was not of an impulsive nature.

The red L_{Aeq} 43dBA contour would be applicable if the duration of operation of the OCGT was continuous during a daytime or night time period and would thus represent a worst case scenario. Increased duration of operation of the OCGT plant beyond two hours would result in the radius of the $L_{Req,T}$ contour to increase from that of the blue contour towards the red contour, depending on the total operating hours.

Noise Control Regulations

In terms of the existing Noise Control Regulations of the Province of the Western Cape, no cognisance is taken of the duration of the noise under investigation other than a minimum duration of ten minutes being required when the noise is being measured.

In terms of the existing Noise Control Regulations it might be interpreted that an assessment is made of a noise under investigation provided that the noise persists for more than ten minutes. Based on this interpretation, the noise emanating from the proposed OCGT plant, when operating for longer than ten minutes, would be construed to be a disturbing noise on land where the noise level would be 7dB higher than the ambient sound level of 43dBA. This would include all land within a radius of 1270m from the centre of the plant indicated by the red L_{Aeq} = 50dBA contour displayed in Figure 1.

The calculated noise contours depicted in Figure 1 were based on sound power noise emission levels contained in two reports provided by Siemens [1,3]. The latter report indicated that the sound power noise emission levels took into account the assumed/recommended noise control installations. Section 9 of the latter report states that "*…. a sound pressure level of 45dBA will be met at a distance of 1100m from the boundary of the plant*". The distance between centre and the nearest boundary of the plant shown in Figure 4 is approximately 180m. 45dBA would therefore be met at a distance of approximately 1280m from the centre of the plant.

Results of calculations conducted in the present study indicated that, for continuous operation, the equivalent continuous A-weighted sound pressure level due to noise emanating from one OCGT power generation unit would, to the nearest dB, be 45dBA at a distance of 1280m. This correlates closely with the information provided by Siemens for the noise emanating from one OCGT power generation unit.

7. IMPACT OF NOISE AT RECEIVER LOCATIONS – CONSTRUCTION PHASE

Table 2 contains information regarding noise emanating from operations and machinery during construction of the OCGT plant provided by Siemens [2].

TABLE 2 Noise data relating to construction operations and machinery

Equipment	Sound Power Level dB(A)	Sound Pressure Level at 100 m distance dB(A)
Bulldozer	112	64
Excavator	116	68
Tractor	108	60
Truck	120	72
Compactor	124	76
Grader	120	72
Range of noise levels during reclamation		**60 – 80**
Trailer	110	62
Truck	120	72
Lorry	106	58
Range of noise levels during transportation		**62 - 78**
Drop Hammer (precast concrete piles)	128	80
Vibratory System (sheet piles)	120	72
Screened Drop Hammer	95	47
Range of noise levels depending which equipment is used		**47 - 80**
Concrete Mixer	112	64
Concrete Truck	120	72
Crane (Boring & Placing Precast Concrete & Concrete	123	75
Pouring		
Generator Set for Welding	110	62
Generator Set for Power	120	72
Hammer Drill	112	64
Chipping Hammer	119	71
Air Compressor	119	71
Range of noise levels of all construction equipment		**62 - 80**
Boiler blow out without noise protection	165	117
Boiler blow out with silencer, silent steam blow	120	72

The results of approximate calculations, using the information provided, indicated that the instantaneous levels of noise originating from the noisiest sources would be 45dBA at a range of 2300m. Due to the highly varying nature of construction noise, it was anticipated that the $L_{Aeq,T}$ levels during a 16-hour day would be considerably less than the instantaneous levels.

According to information received from Siemens [2] it was considered unlikely that ground-borne vibration would be noticeable beyond the site boundary.

According to the information provided, it was anticipated that construction noise would be audible at the dwellings on Bartelfontein farm and at Langewag to the west of the proposed site. However, in terms of assessment in accordance with SANS 10103 it was anticipated that the intensity of impact of construction noise at these sites would vary between "negligible" and "low".

8. NOISE MITIGATION

Based on the noise emission data and operating conditions provided, the study found that the proposed location of the OCGT site would result in areas of farmland being exposed to rating levels of noise in excess of acceptable levels in terms of SANS10103. Were the site to be relocated at least 600m south and 600m east, the intensity of noise impact on the area of affected farmland could be significantly reduced, if not eliminated.

In terms of the Noise Control Regulations relocation of the site would reduce the land exposed to a disturbing noise to farmland within 490m from the farm boundaries closest to the plant. Noise mitigation procedures would still need to be implemented to reduce the combined noise emission of the plant by 7dB.

9. CONCLUSIONS

The results of the study into the potential impact of noise from the proposed OCGT power generation plant indicated that the proposed location of the site would result in areas of farmland being exposed to rating levels of noise in excess of acceptable levels in terms of SANS10103. Were the site to be relocated 600m further south and east the area of affected farmland could be reduced or even eliminated. However, in terms of the Noise Control Regulations, noise mitigation procedures would still need to be implemented to reduce the combined noise emission of the plant by 7dB

These findings were based on noise emission data received from Siemens and based on information received from Eskom that the plant would operate for a total of two hours during daytime hours defined in SANS 10103.

10. RECOMMENDATIONS

The following recommendations are made:

1. The site of the OCGT plant be moved at least 600m south and 600m east of the present proposed location.
2. Direct contact be arranged with the author of this assessment report and the author(s) of the reports received from Siemens to obtain clarification of the noise emission data supplied and of the sound propagation calculations.

REFERENCES

1.	Siemens power Generation	*Atlantis RSA800, Mossel Bay RSA801 Sound emission data for noise relevant functional groups of the power plants,* 4th Aug 2005. Received 12 August 2005
2.	Siemens	*Noise and Vibration during Civil and Construction Work,* undated
3.	Siemens	*Noise Protection Concept OCGT Eskom – Mossel Bay* Report number W7P/2005/034, 2 September 2005. Received 14 September 2005

APPENDIX A TERMINOLOGY USED IN THE MEASUREMENT AND ASSESSMENT OF SOUND

Certain of the terms used in SANS 10103 are listed hereunder. Their meanings are in certain instances loosely described to facilitate understanding. Formal definitions of these and additional terms are contained in SANS 10103.

Ambient noise

the totally encompassing sound in a given situation at a given time, and is usually composed of sound from many sources, both near and far. It includes the noise from the noise source(s) under investigation.

A-weighted sound pressure level (sound level), L_{pA}

the sound pressure level, in decibels, relative to a reference sound pressure, and incorporating an electrical filter network in the measuring instrument corresponding with the human ear's different sensitivity to sound at different frequencies.

A-weighted sound exposure level, $L_{AE,T}$

The value of the A-weighted sound pressure level of a single sound exposure that, within a reference time interval T, of one second, has the same mean-square sound pressure as a sound under consideration whose sound pressure level varies with time.

Equivalent continuous A-weighted sound pressure level, $L_{Aeq,T}$.

A formal definition is contained in SANS 10103. The term "equivalent continuous" may be understood to mean the "average" A-weighted sound level measured continuously, or calculated, over a period of time, T.

Equivalent continuous rating level, $L_{Req,T}$

the equivalent continuous A-weighted sound pressure level, $L_{Aeq,T}$, measured or calculated during a specified time interval T, to which is added adjustments for tonal character, impulsiveness of the sound and the time of day.

An adjustment of 5 dB is added for any tonal character, if present. If the noise is of an impulsive nature a further adjustment of either 5 or 12 dB, or a value derived in accordance with Section 5.1.6.1 of the Standard is added. Where neither is present, the $L_{Req,T}$ is equal to the $L_{Aeq,T}$.

Reference time interval

The time interval to which an equivalent continuous A-weighted sound pressure level, $L_{Aeq,T}$, or rating level of noise, $L_{Req,T}$, is referred. Unless otherwise indicated, the reference time interval is interpreted as follows:

– Day-time : 06:00 to 22:00 T = 16 hours

– Night-time: 22:00 to 06:00 T = 8 hours

Residual noise
The ambient noise that remains at a given position in a given situation when one or more specific noises (usually those under investigation) are suppressed.

ANNEXURE G:

AIR QUALITY STUDY

Project done on behalf of
Ninham Shand Consulting Services

AIR POLLUTION IMPACT ASSESSMENT FOR THE OCGT ESKOM POWER STATION NEAR MOSSEL BAY

Report No.: APP/05/SHA-01 Rev 1.0

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Authors: G Petzer
L W Burger

Airshed Planning Professionals (Pty) Ltd

PO Box 5260
Halfway House
1685

Tel : +27 (11) 254 4929
Fax : +27 (11) 805 7010
e-mail : mail@airshed.co.za

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AIR POLLUTION IMPACT ASSESSMENT FOR THE OCGT ESKOM POWER STATION NEAR MOSSEL BAY

1. INTRODUCTION

The proposed OCGT Eskom power station is located west of the Mossel Bay town just off the N2, near the PetroSA refinery. Both the proposed power station and the refinery are located in a rural area with low population density.

Airshed Planning Professionals (Pty) Ltd was contracted by Ninham Shand Consulting Services to conduct an air quality impact assessment study for the proposed OCGT Eskom Power Station.

The main aim of this investigation is to determine the impact from the proposed power station on the surrounding environment and human health. To accomplish this, a good understanding of the general and local climate of the area need to be established and subsequently all emission rates need to be quantified and atmospheric dispersion modelling executed.

1.1 Terms of Reference

The air quality investigation comprises two main components, viz. a baseline study and an impact assessment. The baseline study includes a review of the site-specific atmospheric dispersion potentials, and existing ambient air quality in the region, in addition to the identification of potentially sensitive receptors. Use was made of readily available information in addition to meteorological and air quality data recorded in the vicinity of the site in the characterisation of the baseline condition. In assessing the potential impacts associated with the proposed project, an emissions inventory needed to be compiled, atmospheric dispersion simulations undertaken and predicted concentrations evaluated.

The specific terms of reference are as follows:

- Collate and compile existing data for the ambient air pollution conditions emanating from the region (i.e. establishing the baseline conditions) and prepare dispersion simulations of baseline emissions;

- Prepare an emissions inventory of proposed sources at the power station, and prepare dispersion simulations of emissions for the following 4 scenarios:

- Plant operating 2 hours per day with NOx = 165 mg/Nm³, CO = 31.25 mg/Nm³, PM10 = 50 mg/Nm³ and SO_2 = 10.4 g/s;
- Plant operating 2 hours per day with NOx = 600 mg/Nm³;
- Plant operating 6 hours per day with NOx = 165 mg/Nm³, CO = 31.25 mg/Nm³, PM10 = 50 mg/Nm³ and SO_2 = 10.4 g/s;
- Plant operating 6 hours per day with NOx = 600 mg/Nm³.

- Dispersion simulation results of incremental impacts from the power station only, as well as cumulative impacts from both the power station and the refinery;

- Analyse predicted concentration levels (i.e. compliance checking with current and proposed legislation);

1.2 Methodological Overview

1.2.1 Baseline Conditions

Quantifying the baseline conditions requires an analysis of both ambient air quality data observations and predictive methods. A general description of the climate for the greater region can be found from historical records (e.g. Weather Bureau Reports). However, it is necessary to obtain local meteorological data to determine the conditions specifically applicable to the project.

Meteorological mechanisms govern the dispersion, transformation, and eventual removal of pollutants from the atmosphere. An analysis of the ventilation potential of prevailing synoptic systems, and of the nature and frequency of occurrence of weather perturbations, provides for an effective characterization of the macro-scale dispersion potential. Diurnal variations in dispersion potentials associated with meso-scale ventilation processes are most successfully evaluated on the basis of hourly average observations and estimations.

Use was made of data from the PetroSA weather station. Hourly average meteorological data, including wind speed, wind direction and temperature was used, and mixing heights were estimated for each hour, based on prognostic equations, while night-time boundary layers were calculated from various diagnostic approaches. Wind speed and solar radiation were used to calculate hourly stability classes.

For the completion of a baseline investigation, the data included both air quality and meteorological data. Air quality data included dispersion simulations showing predicted ground level concentrations from the PetroSA refinery. A comprehensive source inventory for PetroSA was completed by Harmse and Rowe of Ilitha (2004).

1.2.2 Impact Assessment

An emissions inventory was compiled and included emissions from the open cycle gas turbines (OCGT) at the power station. These emission rates were based on information supplied by Eskom.

Dispersion modelling of all emissions using hourly average meteorological data for the area was completed. The US EPA approved Industrial Source Complex (ISC) Model version 3 was used. Hourly, daily and annual average concentrations were calculated for comparison to and compliance with national air quality guidelines. The impact assessment was based on guidelines developed/adopted by institutions such as World Health Organisation (WHO), World Bank, United States Environmental Protection Agency (US EPA) and South Africa. The proposed South African limit values have been included for compliance with proposed legislation.

1.3 Outline of Report

The relevant air quality guidelines and standards are described in Section 2. The baseline environment including the atmospheric dispersion potential of the site, the emission inventory and the dispersion modelling results is included in Section 3. Section 4 covers the impact assessment, and the conclusions can be found in Section 5.

2. AMBIENT AIR QUALITY EVALUATION CRITERIA

Air quality guidelines and standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site. The ambient air quality guideline values indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Air quality guidelines and standards are normally given for specific averaging periods. These averaging periods refer to the time-span over which the air concentration of the pollutant was monitored at a location. Generally, five averaging periods are applicable, namely an instantaneous peak, 1-hour average, 24-hour average, 1-month average, and annual average.

The ambient air quality guidelines and standards for pollutants relevant to the current study are presented in Table 2-1 to Table 2-4. A detailed discussion on the health impacts and air quality standards is given in Appendix A. Air quality limits issued locally by the DEAT and SABS are reflected in the tables together with limits published by the WHO, EC and US-EPA.

The SABS was engaged to assist DEAT in the facilitation of the development of ambient air quality standards. A technical committee was established to oversee the development of standards. Three working groups were established by this committee for the drafting of ambient air quality standards for (i) sulphur dioxide, particulates, oxides of nitrogen and ozone, (ii) lead and (iii) volatile organic compounds, specifically benzene. Two documents were produced during the process, viz.:

> SANS 69 - South African National Standard - Framework for setting & implementing national ambient air quality standards
>
> SANS 1929 - South African National Standard - Ambient Air Quality - Limits for common pollutants

The latter document includes air quality limits for particulate matter less than 10 µm in aerodynamic diameter (PM10), dustfall, sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide, lead and benzene. The SANS documents were approved by the technical committee for gazetting for public comment. These draft documents were made available for public comment during the May/June 2004 period and were finalized and published during the last quarter of 2004. DEAT raised concerns regarding certain policy issues having been addressed in the documents. Although the SANS documents have been finalised, it is currently uncertain whether these standards will be adopted by DEAT. The current, primarily outdated DEAT air quality guidelines have been included in the new Air Quality Act. The Minister of Environmental Affairs and Tourism stated on 6 June 2005 that air quality standards would be in place by 1 September 2005[(1)]. Although the threshold levels to be selected for the proposed air quality standards are not currently known it is expected that

[1] http://www.deat.gov.za/NewsMedia/MedStat/2005Jun6/06062005_2.htm

such thresholds will be more stringent than the current DEAT guidelines and more in line with the SANS limits.

2.1 Criteria Pollutants

Table 2-1 to Table 2-4 provides guidelines/limits for the criteria pollutants (i.e. sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter.

Table 2-1: Ambient air quality guidelines and standards for sulphur dioxide for various countries and organisations

Averaging Period	South Africa (DEAT/SANS)	World Bank (2002)	World Health Organisation (1999)	US-EPA	European Community
	μg/m³	μg/m³	μg/m³	μg/m³	μg/m³
Annual Average	50(7)	50	50(3) 10-30(10)	80(1)	20(2)
Max. 24-hour Ave	125(7)	125	125(3)	365(4)	125(5)
Max 1-hour Ave	-	-	350(9)	-	350(6)
Instantaneous Peak	500(7)(8)	-	500(3)(8)	-	-

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

Table 2-2: Air quality standards for nitrogen dioxide (NO_2).

	Annual Average		Max 24-hour Average		Max 1-hour Average	
	μg/m³	ppm	μg/m³	ppm	μg/m³	ppm
DEAT guidelines	96	0.05	191	0.1	382	0.2
SANS limits (5)	40	0.021	-	-	200	0.10
United States EPA	100(1)	0.053(1)	-	-	-	-
European Community	40(2)	0.021(2)	-	-	200(3)	0.10(3)
World Health Organisation	40	0.021	150	0.08	200	0.1
Canada (4)	100	0.053	-	-	400	0.20

Notes:
(1) Annual arithmetic mean.
(2) Annual limit value for the protection of human health, to be complied with by 1 January 2010.
(3) Averaging times represent the 98th percentile of averaging periods; calculated from mean values per hour or per period of less than an hour taken throughout the year; not to be exceeded more than 8 times per year. This limit is to be complied with by 1 January 2010.
(4) Acceptable Canadian air quality objectives.
(5) SABS, 2004.

Table 2-3: Air quality standards for inhalable particulates (PM10)

	Maximum 24-hour Concentration ($\mu g/m^3$)	Annual Average Concentration ($\mu g/m^3$)
DEAT guidelines	180	60
SANS limits (9)	75	40
United States EPA	150(1)(2)	50(3)
European Union (EU)	130(4) 250(5)	80
European Community (EC)	50(6)	30(7) 20(8)
Canada	24	-

Reference: Chow and Watson, 1998; Cochran and Pielke, 1992.

Notes:

(1) Requires that the *three-year* annual average concentration be less than this limit;
(2) Not to be exceeded more than once per year;
(3) Represents the arithmetic mean;
(4) Median of daily means for the winter period (1 October to 31 March);
(5) Calculated from the 95th percentile of daily means for the year;
(6) Compliance by 1 January 2005. Not to be exceeded more than 25 times per calendar year. (By 1 January 2010, no violations of more than 7 times per year will be permitted.)
(7) Compliance by 1 January 2005;
(8) Compliance by 1 January 2010;
(9) SABS, 2004.

Table 2-4: Ambient air quality guidelines and standards for carbon monoxide (CO)

Averaging Period	South Africa		UK		World Health Organisation		US-EPA	
	$\mu g/m^3$	ppm	$\mu g/m^3$	ppm	$\mu g/m^3$	ppm	$\mu g/m^3$	ppm
Max. 8-hour Ave	10 000	9	11 600(1)	10(1)	10 000	9	10 000	9
Max. 1-hour Ave	40 000(2) 30 000(3)	35(2) 26(3)	-	-	30 000	26	40 000	35

Notes:
(1) Running 8-hour mean to be achieved by 31 December 2003.
(2) Current SA guidelines.
(3) SABS, 2004.

3. BASELINE CHARACTERISATION

The characterisation of existing air quality is crucial for assessing the potential for cumulative impacts due to the emissions from the proposed Eskom power station.

3.1 Regional atmospheric dispersion

The meteorological characteristics of a site govern the dispersion, transformations and eventual removal of pollutants from the atmosphere (Pasquill and Smith, 1983; Godish, 1990). A qualitative description of the synoptic climatology of the study region is provided in Appendix B, based on a review of the pertinent data.

Parameters, which needed to be taken into account includes wind speed, wind direction, extent of atmospheric turbulence, ambient air temperature and mixing depth. Hourly average wind speed, wind direction and air temperature data were available from PetroSA. Mixing depths and atmospheric stabilities were not measured and needed to be calculated. The parameterisation of the meso-scale ventilation potential of the site necessitates the analysis of meteorological data observed within the vicinity of the site.

3.1.1 Surface winds

Period, day-time and night-time average wind roses are depicted in Figure 3-1. Wind roses represent wind frequencies for the 16 cardinal wind directions. Frequencies are indicated by the length of the shaft when compared to the circles drawn to represent a 5% frequency of occurrence. The figure given in the centre of the circle described the frequency with which calms occurred, i.e. periods during which the wind speed was below 1 m/s.

Diurnal wind variations due to the influence of land-sea breeze circulations on the airflow of the region are clearly evident in the night-time and day-time wind fields. Land-sea breeze circulation arises due to the differential heating and cooling of land and water surfaces. During the day, the land is heated more rapidly than the sea surface, a horizontal pressure gradient develops with surface convergence and ascent over the land and descent and surface divergence over the sea. Sea breezes therefore characterise the daytime surface circulation. By night, land cools more quickly than the sea surface resulting in a reversal of the daytime sea breeze and upper air return currents and the onset of land breezes at the surface.

Night-times are characterised by an increase in the number of calms (13.1 %) as is typical of the night-time flow regime in most regions, and by the predominance of winds from the north-northwesterly sector.

During the day-time, winds from the northwestern and southeastern sectors predominates. Increased wind velocities are noted for day-time hours.

SE winds are predominant, especially in summer. The wind in winter (June to August) blows mainly from a north-westerly direction. The windiest season is mid-winter (July) to spring (September), which has an average wind speed of 20 km/hr. The average wind speed in summer is 15 km/hr.

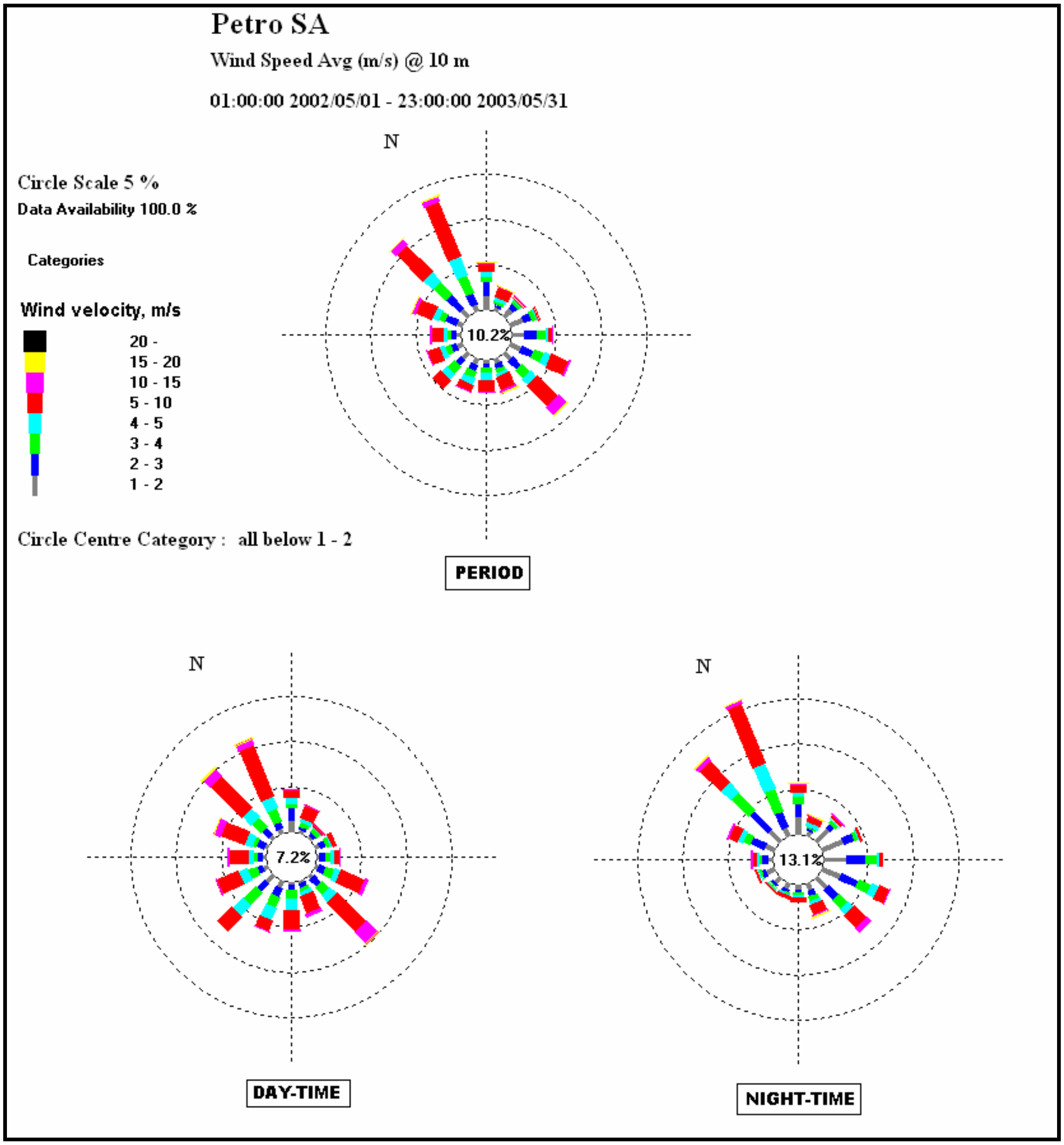

Figure 3-1: Wind roses for PetroSA for the period May 2002 – May 2003.

3.1.2 Temperature

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume is able to rise), and determining the development of the mixing and inversion layers. Long-term average maximum, mean and minimum temperatures for Mossel Bay for the period 1920-1984 is given in Table 3-1 (Schulze, 1986).

Table 3-1: Long-term minimum, maximum and mean temperature for Mossel Bay (Schulze, 1986).

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mossel Bay	Maximum	23.9	23.8	22.8	21.4	20.2	19.4	18.6	18.6	18.9	19.6	21.1	22.8
	Mean	21.0	21.0	20.0	18.3	16.8	15.7	14.9	14.9	15.4	16.5	18.1	19.9
	Minimum	18.0	18.2	17.1	15.1	13.3	12.0	11.1	11.1	12.1	13.5	15.2	16.9

A monthly-average diurnal ambient temperature trend, generated on the basis of measurements at PetroSA, is illustrated in Figure 3-2.

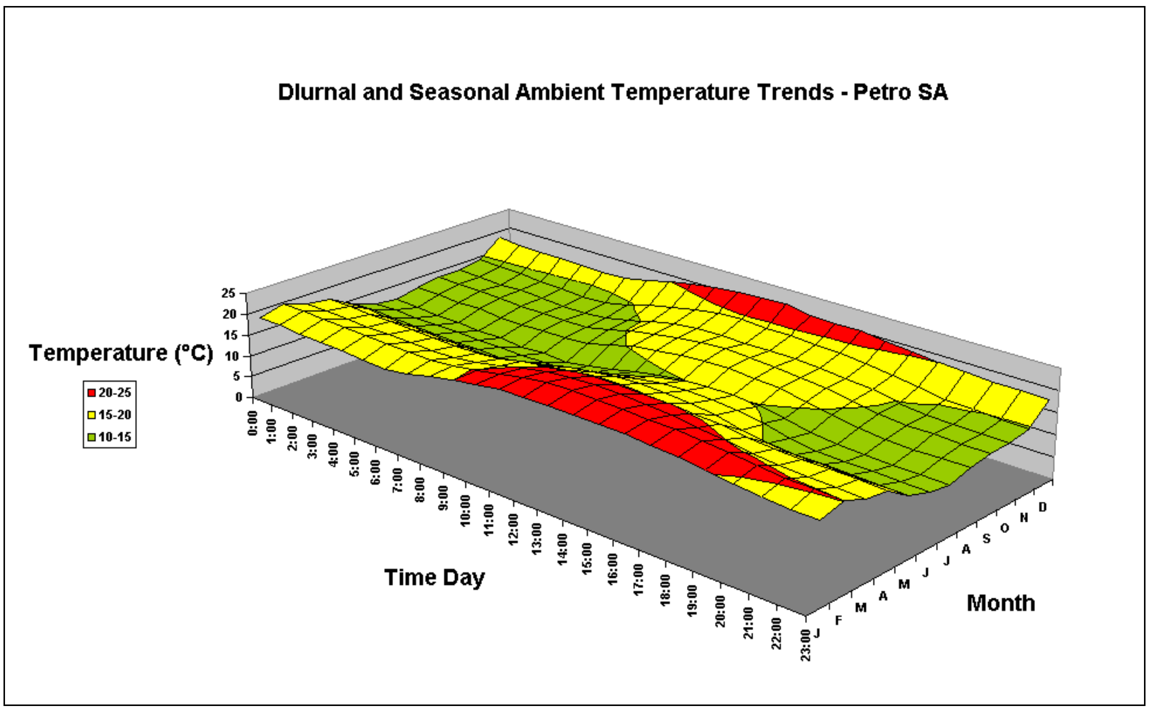

Figure 3-2: Monthly average diurnal temperature plot for PetroSA (2002 – 2003).

3.1.3 Precipitation

Precipitation represents an effective removal mechanism of atmospheric pollutants. The number of rainfall days (recorded when 0.1 mm or more is monitored) for Mossel Bay is 91.2 per annum. The long-term annual average rainfall for Mossel Bay for the period 1878-1984 is given in Table 3-2 (Schulze, 1986).

Table 3-2: Long-term average monthly rainfall for Mossel Bay (Schulze, 1986).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Ave rainfall (mm)	28	31	36	40	37	31	32	36	39	38	34	28	410
Ave no. of rain days	6.7	7.0	8.3	7.9	7.6	7.2	7.0	7.8	8.2	9.1	8.0	6.4	91.2

3.1.4 Mixing Height and Atmospheric Stability

The vertical component of dispersion is a function of the extent of thermal turbulence and the depth of the surface mixing layer. Day-time mixing heights were calculated with the prognostic equations of Batchvarova and Gryning (1990), while night-time boundary layer heights were calculated from various diagnostic approaches for stable and neutral conditions. Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table 3-3.

Table 3-3: Atmospheric stability classes.

A	very unstable	calm wind, clear skies, hot daytime conditions
B	moderately unstable	clear skies, daytime conditions
C	unstable	moderate wind, slightly overcast daytime conditions
D	neutral	high winds or cloudy days and nights
E	stable	moderate wind, slightly overcast night-time conditions
F	very stable	low winds, clear skies, cold night-time conditions

The atmospheric boundary layer is normally unstable during the day as a result of the turbulence due to the sun's heating effect on the earth's surface. The thickness of this mixing layer depends predominantly on the extent of solar radiation, growing gradually from sunrise to reach a maximum at about 5-6 hours after sunrise. This situation is more pronounced during the winter months due to strong night-time inversions and a slower developing mixing layer. During the night a stable layer, with limited vertical mixing, exists. During windy and/or cloudy conditions, the atmosphere is normally neutral.

3.2 Ambient Air Quality Data

The ambient air monitoring results from different locations at and around PetroSA for sulphur dioxide for the period 6 August 2002 to 19 August 2003 are shown in the graph below. No ambient data for oxides of nitrogen (NO_x), carbon monoxide (CO) and inhalable particulates (PM10) were available.

3.2.1 Sulphur Dioxide Concentrations (SO_2)

As shown in Figure 3-3 the SO_2 concentrations measured on and around PetroSA (range between 0.4 and 11.8 µg/m^3) and are low when compared to DEAT's annual average guideline of 50 µg/m^3.

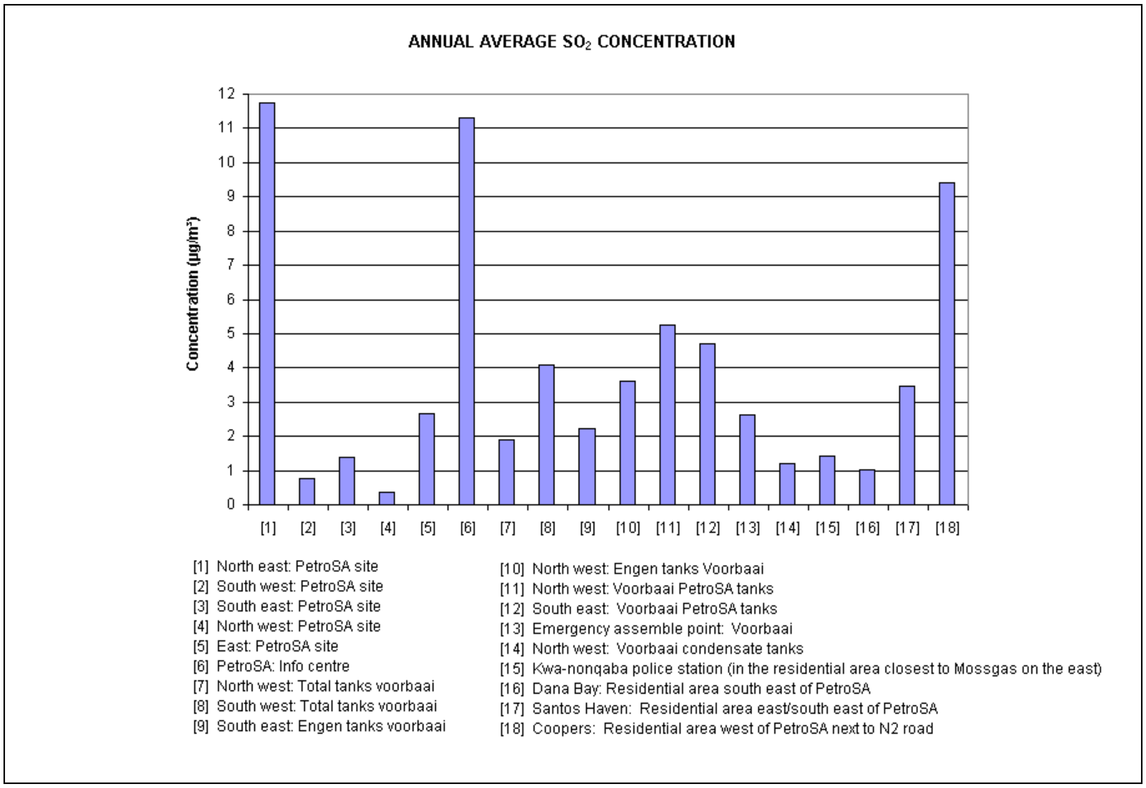

Figure 3-3 Annual average SO_2 concentrations measured at various locations at and around PetroSA.

3.2.2 Oxides of Nitrogen, Carbon Monoxide and Inhalable Particulate concentrations

No ambient data for oxides of nitrogen (NO_x), carbon monoxide (CO) and inhalable particulates (PM10) were available.

3.3 Emissions Inventory of Baseline Conditions

3.3.1 PetroSA refinery

Emissions produced by the PetroSA facilities were calculated by ILITHA (Background Emissions Study for the PetroSA Facilities at the Mossel Bay Refinery and Voorbaai Tank Farm, 2004).

Table 3-4 represents the total average annual PetroSA emissions used in the simulations. The instantaneous emissions represent the average emissions from a point or area source at any one time during operation. However, not all operations are continuous. For highest hourly concentrations, the instantaneous emissions were used. To simulate the highest daily and annual average concentrations, the average annual emissions were used.

SO_2 emissions from fired heaters and flares are negligible, as there is little or no sulphur present in the PetroSA fuel gas. Approximately 2771 tons of NO_2 gases are emitted from fired heaters and flares per annum, and 109 tons of particulate matter.

Nitrogen oxides (NOx) emitted from the refinery are expressed and simulated as nitrogen dioxide (NO_2). However, it is not understood exactly how much of the NOx is NO_2, perhaps only 10% of the total NOx emissions would be NO_2. The assumption that all NOx is NO_2 is therefore a conservative approach.

Table 3-4: Total average emissions per annum from PetroSA.

Source	CO	SO_2	NO_2	PM10
	tpa	tpa	tpa	tpa
Methane reformer	678		1534	61.35
Fired heater / boilers	258	0.47	617	22.82
Flares	274		620	24.80
TOTAL	1210	0.47	2771	109

3.4 Dispersion Simulations of Baseline Conditions

Air dispersion simulations were undertaken to determine inhalable particulate (PM10), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide.

Dispersion models compute ambient concentrations as a function of source configurations, emission strengths and meteorological characteristics, thus providing a useful tool to ascertain the spatial and temporal patterns in the ground level concentrations arising from the emissions of various sources. Increasing reliance has been placed on concentration estimates from models as the primary basis for environmental and health impact assessments, risk assessments and emission control requirements. It is therefore important to carefully select a dispersion model for the purpose.

For the purpose of the current study, it was decided to use the well-known US-EPA Industrial Source Complex Short Term model (ISCST3). The ISCST3 model is included in a suite of models used by the US-EPA for regulatory purposes. ISCST3 (EPA, 1995a and 1995b) is a steady state Gaussian Plume model, which is applicable to multiple point, area and volume sources. Gently rolling topography may be included to determine the depth of plume penetration by the underlying surface. A disadvantage of the model is that spatial varying wind fields, due to topography or other factors cannot be included. A further limitation of the model arises from the models treatment of low wind speeds. Wind speeds below 1 m/s produce unrealistically high concentrations when using the Gaussian plume model, and therefore all wind speeds below 1 m/s are simulated using 1 m/s.

The Industrial Source Complex model is perhaps the subject of most evaluation studies in the United States. Reported model accuracies vary from application to application. Typically, complex topography with a high incidence of calm wind conditions, produce predictions within a factor of 2 to 10 of the observed concentrations. When applied in flat or gently rolling terrain, the USA-EPA (EPA, 1986) considers the range of uncertainty to be -50% to 200%. The accuracy improves with fairly strong wind speeds and during neutral atmospheric conditions.

Input data types required for the ISCST3 model include: source data, meteorological data, terrain data and information on the nature of the receptor grid.

3.4.1 Meteorological Requirements

ISCST3 requires hourly average meteorological data as input, including wind speed, wind direction, a measure of atmospheric turbulence, ambient air temperature and mixing height. Meteorological information recorded at the meteorological station at PetroSA for the period, May 2002 to May 2003 was used.

The mixing height for each hour of the day was estimated for the simulated ambient temperature and solar radiation data. Daytime mixing heights were calculated with the prognostic equations of Batchvarova and Gryning (1990), while night-time boundary layer heights were calculated from various diagnostic approaches for stable and neutral conditions, as mentioned previously.

3.4.2 Source Data Requirements

The ISCST3 model is able to model point, area, volume and open pit sources. The PetroSA sources were modelled as point sources.

3.4.3 Receptor Grid

The dispersion of pollutants emanating from the site was modelled for an area covering ~30 km by ~30 km. The area was divided into a grid matrix with a resolution of 300 m by 300 m. The ISCST3 simulates ground-level concentrations for each of the receptor grid point.

Highest hourly, daily and period average concentration levels were simulated based on the emissions quantified for each source. These results represent interpolated values for each receptor grid point for the various averaging periods.

The ground level concentrations are displayed as isopleth plots indicating the baseline conditions. All predictions are compared to both local and international guidelines and standards. All the concentration plots are provided in Appendix C and a summary of the results in are given in Table 3-5.

It should be noted that the plots reflecting hourly and daily averaging periods contain only the highest predicted ground level concentrations, for those averaging periods, over the entire period for which simulations were undertaken. It is therefore possible that even though a high hourly or daily average concentration is predicted to occur at certain locations, that this may only be true for one hour or one day during the year.

Table 3-5: Maximum predicted concentrations at the PetroSA Refinery (Baseline conditions).

Pollutant	Impact Period	Guideline/ Standard (μg/m³) [1]	Maximum impact at the PetroSA refinery	
			Conc. (μg/m³)	% of Guideline/standard
PM10	Highest Daily	75[2]	1.21	1.6
	Annual	40[2]	0.18	<1
SO_2	Highest Hourly	350[3]	0.05	<1
	Highest Daily	125[2]	0.009	<1
	Annual	50[2]	0.001	<1
CO	Hourly	30 000[2]	75	<1
NO_2	Highest Hourly	200[2]	172	86
	Highest Daily	150[3]	30.76	21
	Annual	40[2]	4.66	12

<u>**Notes**</u>: [1] Although the threshold levels to be selected for the proposed South Africa air quality standards are not currently known it is expected that such thresholds will be more stringent than the current DEAT guidelines and more in line with the SANS limits. Therefore comparison was made to the stricter SANS limits as a conservative approach.
[2] South African limit values, reference: SANS 1929 - Ambient air quality - Limits for common pollutants.
[3] WHO 2000.

4. IMPACT ASSESSMENT

4.1 Emissions inventory

For the Eskom OCGT power station the following 4 scenarios were considered:

- Scenario 1: Plant operating 2 hours per day with NOx = 165 mg/Nm³, CO = 31.25 mg/Nm³, PM10 = 50 mg/Nm³ and SO_2 = 10.4 g/s;
- Scenario 2: Plant operating 2 hours per day with NOx = 600 mg/Nm³;
- Scenario 3: Plant operating 6 hours per day with NOx = 165 mg/Nm³, CO = 31.25 mg/Nm³, PM10 = 50 mg/Nm³ and SO_2 = 10.4 g/s;
- Scenario 4: Plant operating 6 hours per day with NOx = 600 mg/Nm³.

It was assumed that when the three turbines operate for two hours per day it would be between 6am-7am and 6pm-7pm, and for six hours per day between 6am-9am and 6pm-9pm. The stack parameters and emission rates used in the simulations are shown in Table 4-1 below.

Table 4-1: Emission rates and stack parameters for the OCGT Eskom power station stacks.

Parameter	Value	Units
Stack height	30	m
Stack diameter	6.1	m
Exit velocity	40	m/s
Exit temperature	833	K
Exit pressure	1.022	bar
Exit mass flow	520	kg/s
Density	1.2	kg/m³
Sulphur dioxide emission rate (assuming S = 0.001% weight)	10.4	g/s
Nitrogen dioxide emission rate (165 mg/Nm³)	82.7	g/s
Nitrogen dioxide emission rate (600 mg/Nm³)	300.74	g/s
Particulate matter emission rate (assuming 50 mg/Nm³)	21.67	g/s
Particulate matter emission rate (using NPi emission factors)	2.31	g/s
Carbon monoxide emission rate	15.66	g/s

4.2 Dispersion Simulations

The same methodology was used as discussed in section 3.4.

All the concentration plots are provided in Appendix C and a summary of the results is given in Table 4-2 (operating 2 hours per day) and 4-3 (operating 6 hours per day).

Table 4-2: Maximum predicted concentrations at the Eskom power station and at both the Eskom power station (operating 2 hours per day) and the PetroSA Refinery (Scenarios 1 and 2).

Pollutant	Impact Period	Guideline/ Standard (µg/m³)[3]	Maximum impact at the Power station		Maximum cumulative impact	
			Conc. (µg/m³)	% of Guideline/ Standard	Conc. (µg/m³)	% of Guideline/ Standard
PM10[1]	Highest Daily	75[4]	0.22[6] (0.023)[7]	<1 (<1)	1.22[6] (1.21)[7]	1.6 (1.6)
	Annual	40[4]	0.01[6] (0.001)[7]	<1 (<1)	0.19[6] (0.184)[7]	<1 (<1)
SO_2[1]	Highest Hourly	350[5]	2.52	<1	2.52	<1
	Highest Daily	125[4]	0.11	<1	0.11	<1
	Annual	50[4]	0.005	<1	0.005	<1
CO[1]	Hourly	30 000[4]	3.79	<1	75	<1
NO_2[1] (165 mg/Nm³)	Highest Hourly	200[4]	20.01	10	172	86
	Highest Daily	150[5]	0.83	<1	30.78	21
	Annual	40[4]	0.04	<1	4.67	12
NO_2[2] (600 mg/Nm³)	Highest Hourly	200[4]	73	37	172	86
	Highest Daily	150[4]	3	2	30.82	21
	Annual	40[4]	0.15	<1	4.68	12

Notes:
(1) Scenario 1.
(2) Scenario 2.
(3) Although the threshold levels to be selected for the proposed South Africa air quality standards are not currently known it is expected that such thresholds will be more stringent than the current DEAT guidelines and more in line with the SANS limits. Therefore comparison was made to the stricter SANS limits as a conservative approach.
(4) South African limit values, reference: SANS 1929 - Ambient air quality - Limits for common pollutants.
(5) WHO 2000.
(6) Predicted ground level concentration assuming PM10 of 50mg/Nm³ emitted from turbine.
(7) Predicted ground level concentration assuming PM10 of 2.31g/s emitted from turbine.

Table 4-3: Maximum predicted concentrations at the Eskom power station and at both the Eskom power station (operating 6 hours per day) and the PetroSA Refinery (Scenarios 3 and 4).

Pollutant	Impact Period	Guideline/ Standard (µg/m³)[3]	Maximum impact at the Power station		Maximum cumulative impact	
			Conc. (µg/m³)	% of Guideline/ Standard	Conc. (µg/m³)	% of Guideline/ Standard
PM10[1]	Highest Daily	75[4]	0.48[6] (0.052)[7]	<1 (<1)	1.22[6] (1.21)[7]	1.6 (1.6)
	Annual	40[4]	0.025[6] (0.003)[7]	<1 (<1)	0.19[6] (0.184)[7]	<1 (<1)
SO_2[1]	Highest Hourly	350[5]	2.541	<1	2.545	<1
	Highest Daily	125[4]	0.228	<1	0.229	<1
	Annual	50[4]	0.012	<1	0.012	<1
CO[1]	Hourly	30 000[4]	3.83	<1	75	<1
NO_2[1] (165 mg/Nm³)	Highest Hourly	200[4]	20.21	10.1	172	86
	Highest Daily	150[5]	1.81	1.2	30.79	21
	Annual	40[4]	0.09	<1	4.68	12
NO_2[2] (600 mg/Nm³)	Highest Hourly	200[4]	73.47	37	172	86
	Highest Daily	150[4]	6.59	4	30.88	21
	Annual	40[4]	0.34	<1	4.74	12

Notes: [1] Scenario 3.
[2] Scenario 4.
[3] Although the threshold levels to be selected for the proposed South Africa air quality standards are not currently known it is expected that such thresholds will be more stringent than the current DEAT guidelines and more in line with the SANS limits. Therefore comparison was made to the stricter SANS limits as a conservative approach.
[4] South African limit values, reference: SANS 1929 - Ambient air quality - Limits for common pollutants.
[5] WHO 2000.
[6] Predicted ground level concentration assuming PM10 of 50mg/Nm³ emitted from turbine.
[7] Predicted ground level concentration assuming PM10 of 2.31g/s emitted from turbine.

4.3 Impact Assessment

4.3.1 Inhalable particulates (PM10)

The daily and annual average concentration plots are shown in Appendix C figures C-1 to C-6. The predicted results from simulations were very low when compared to the current DEAT guideline as well as the proposed SA limit and target values at both the power station and the cumulative scenario. The impacts did not exceed the SANS limits for highest daily (75 $\mu g/m^3$) and the annual (40 $\mu g/m^3$) averaging periods and were less than 1% of the respective guidelines. The Eskom power station contributes 5% to the predicted cumulative annual average ground level concentrations for operating 2 hours per day, and 13% for operating 6 hours per day. The predicted concentrations for the 6 hour scenario are 2.2 (daily) and 2.5 (annual) times higher than for the 2 hour scenario.

4.3.2 Sulphur dioxide (SO_2)

The hourly, daily and annual average concentration plots are shown in Appendix C, figures C-7 to C-15. The DEAT has no hourly average guideline for SO_2 and only stipulates a guideline for instantaneous (10-minute) concentrations of 500 $\mu g/m^3$. The dispersion model can only simulate for an hourly averaging period (shortest averaging period), and therefore the European Community (EC) guideline for hourly averages are used (see Table 2.1).

The EC hourly guideline (350 $\mu g/m^3$) and the DEAT daily and annual guideline (125 $\mu g/m^3$ and 50 $\mu g/m^3$) are not exceeded for the power station. The highest hourly predicted ground level concentration for the power station is less than 1% of the EC limit (350 $\mu g/m^3$). The predicted ground level concentrations for the highest daily and annual averaging periods are also less than 1% of the DEAT guidelines. The power station is the main contributor of SO_2 as there is little or no sulphur present in the PetroSA fuel gas. The predicted concentrations for the 6 hour scenario are 2.1 (daily) and 2.4 (annual) times higher than for the 2 hour scenario, while the predicted ground level concentration for the highest hourly stays similar for both scenarios.

4.3.3 Nitrogen dioxide (NO_2) (165 mg/Nm^3)

The hourly, daily and annual average concentration plots are given in Appendix C, figures C-16 to C-24. The hourly (200 $\mu g/m^3$), daily (150 $\mu g/m^3$) and annual (40 ug/m^3) SANS standards (hourly and annual) and WHO guidelines (daily) are not exceeded at either the power station or for the cumulative scenario. The highest hourly, daily and annual ground level concentrations for the cumulative scenario were 86%, 21% and 12% of the standards, respectively. The predicted ground level concentrations at the power station for the highest daily and annual averaging periods are less than 1% of the SANS limits, while the predicted concentration for the highest hourly averaging period was 10% of the limit of 200 $\mu g/m^3$. The Eskom power station contributes 2% for the predicted cumulative annual average ground level concentrations (for the 6 hour scenario). The predicted concentrations for the 6 hour scenario are 2.2 (daily) and 2.3 (annual) times higher than for the 2 hour scenario, while the predicted ground level concentration for the highest hourly stays similar for both scenarios.

4.3.4 Nitrogen dioxide (NO_2) (600 mg/Nm³)

The hourly (200 μg/m^3), daily (150 μg/m^3) and annual (40 ug/m^3) SANS standards (hourly and annual) and WHO guidelines (daily) are not exceeded at either the power station or for the cumulative scenario. The highest hourly, daily and annual ground level concentrations for the cumulative scenario were 86%, 21% and 12% of the standards, respectively. The predicted ground level concentrations at the power station for the annual averaging periods is less than 1% of the SANS limits, while the predicted concentration for the highest hourly averaging period was 37% of the limit of 200 μg/m³. The Eskom power station contributes 7% for the predicted cumulative annual average ground level concentrations (for the 6 hour scenario). The predicted concentrations for the 6 hour scenario are 2.2 (daily) and 2.3 (annual) times higher than for the 2 hour scenario, while the predicted ground level concentration for the highest hourly stays similar for both scenarios.

4.3.5 Carbon monoxide (CO)

The highest predicted hourly CO concentration is 3.8 μg/m^3 and 75 μg/m^3 at the power station and the cumulative scenario, respectively (as shown in figure C-25 and figure C-26 in Appendix C); which is less than 1% of the SANS limit.

5. CONCLUSIONS AND RECOMMENDATIONS

The main aim of this study was to determine the impacts associated with the proposed OCGT power station. All sources of pollutants were identified and emission rates quantified. Dispersion simulations were undertaken to reflect ambient air concentrations and the results thereof were compared to local and international guidelines and standards.

5.1 Conclusions

Scenario 1

- The OCGT contributes <1 % to the cumulative predicted annual average NO_2 ground level concentrations due to the power station and the PetroSA refinery.

- The OCGT is the main source of sulphur dioxide; however the predicted concentrations are well below the standards (less than 1%).

- The nitrogen dioxide concentrations did not exceed the guidelines for the hourly, daily or annual averaging periods and were 10%, <1% and <1% of the guidelines and standards, respectively for the power station, and 86%, 21% and 12% for the cumulative scenario. Given that these emissions were all assumed to be NO_2, when it may only be as little as10% of the total NOx emissions, it can be concluded that NO_2 would be further below the respective guidelines and standards.

- The inhalable particulates and carbon monoxide concentrations also did not exceed the respective standards (less than 1%).

Scenario 2

- The OCGT contributes 3 % to the cumulative predicted annual average NO_2 ground level concentrations due to the power station and the PetroSA refinery.

- The nitrogen dioxide concentrations did not exceed the guidelines for the hourly, daily or annual averaging periods and were 37%, 2% and <1% of the guidelines and standards, respectively for the power station, and 86%, 21% and 12% for the cumulative scenario.

- The predicted ground level concentrations are 3.6 times higher for the NOx at 600 mg/Nm^3 scenario compared to the NOx at 165 mg/Nm^3 scenario.

Scenario 3

- For an increase in operating hours from 2 hours per day to six hours per day, predicted highest hourly ground level concentrations stay similar, whereas highest daily and annual average concentrations are approximately 2.2 and 2.4 times higher respectively.

Scenario 4

- The OCGT contributes 7 % to the cumulative predicted annual average NO_2 ground level concentrations due to the power station and the PetroSA refinery.

- The nitrogen dioxide concentrations did not exceed the guidelines for the hourly, daily or annual averaging periods and were 37%, 4% and <1% of the guidelines and standards, respectively for the power station, and 86%, 21% and 12% for the cumulative scenario.

5.2 Recommendations

- Even for the worst case scenario (operating 6 hours per day and NOx at 600 mg/Nm³) the Eskom power station contributes only 7 % to the cumulative predicted annual average concentrations, and exceeds none of the standards or guidelines. Additionally, given that the emissions were all assumed to be NO_2, when it may only be as little as 10% of the total NOx emissions, a conservative approach has been adopted and levels may be even lower than predicted. Therefore NOx concentrations could be up to 600 mg/Nm³ and the plant could operate for 6 hours per day without exceeding any guidelines or standards.

- It is recommended that once the power station is operational the emissions concentrations for NO_2 be verified.

- The predicted ground level concentrations are based on the assumption that the open cycle gas turbines will operate a maximum of 6 hours per day. If operating hours increase, especially operating during the night-time which is associated with calm conditions and unfavourable dispersion, the predicted ground level concentrations would increase and additional simulations would have to be performed.

6. REFFERENCES

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APPENDIX A

AMBIENT AIR QUALITY EVALUATION CRITERIA

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

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

A.1 Ambient Air Quality Criteria for Suspended Particulates

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

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

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

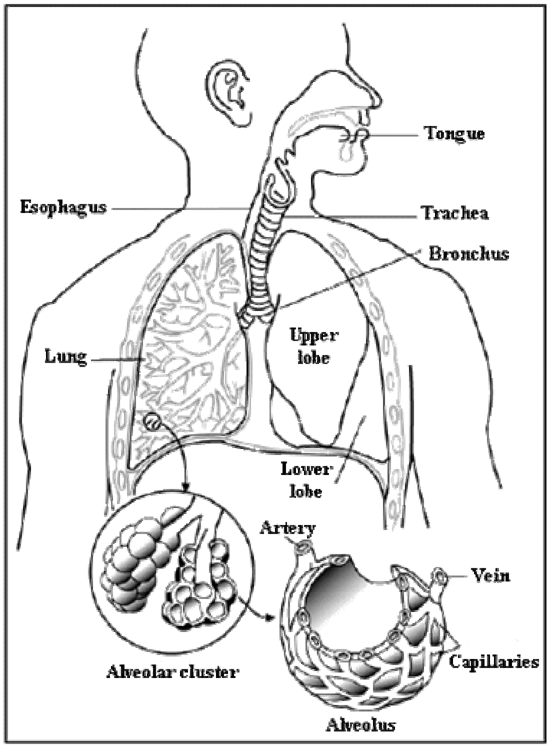

Figure A-1: Schematic diagram indicating the trachea, bronchus and alveolar regions (NCOH, 1992).

A.1.1 Air Quality Guidelines and Standards for Suspended Particulates

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

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

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

Maximum 24 hr average	-	65 µg/m^3
Annual average	-	15 µg/m^3

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

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

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

Notes:

(1) Not to be exceeded more than three times per year.
(2) Represents the arithmetic mean.
(3) Not to be exceeded more than once per year.
(4) Requires that the *three-year* annual average concentration be less than this limit.
(5) Compliance by 1 January 2005. Not to be exceeded more than 25 times per calendar year. (By 1 January 2010, no violations of more than 7 times per year will be permitted.)
(6) Compliance by 1 January 2005.
(7) Compliance by 1 January 2010.
(8) 24-hour mean, not to be exceeded more than 35 times a year. Compliance by 31 December 2004.
(9) Annual mean, with compliance required by 31 December 2004.
(10) Pollutant concentration limit at property boundary (World Bank 1998).
(11) South African limit values, reference: *SANS 1929 - Ambient air quality - Limits for common pollutants.*
(12) South African target values, reference: *SANS 1929 - Ambient air quality - Limits for common pollutants.*

A.1.2 Dose Response Relationships for Suspended Particulate Exposures

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

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

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

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

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

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

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

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

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

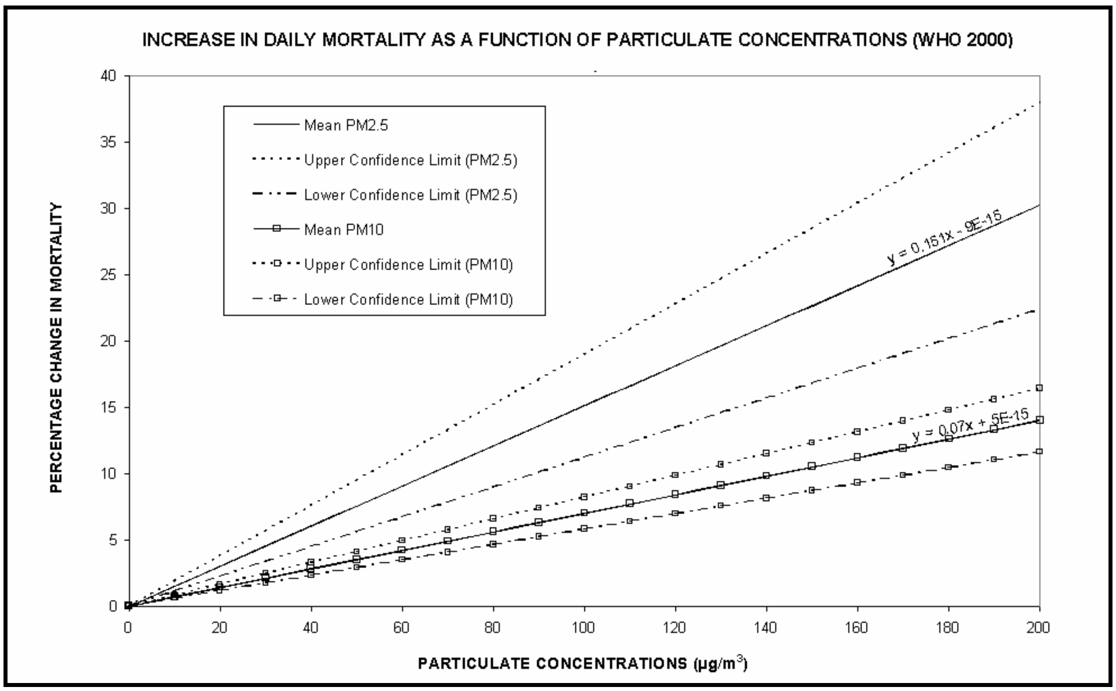

Figure A-2: Increases in daily mortality as a function of increases in PM10 and PM2.5 concentrations (after WHO, 2000).

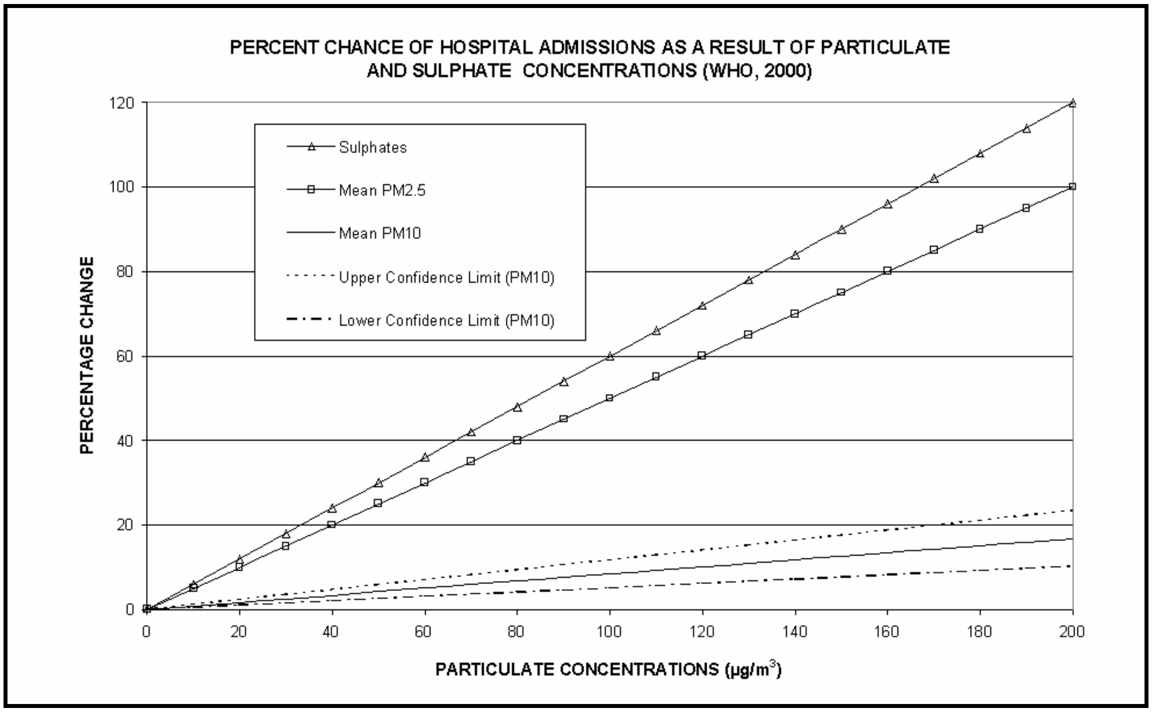

Figure A-3: Increases in hospital admissions as a result of increased PM10, PM2.5 and sulphate concentrations (WHO, 2000).

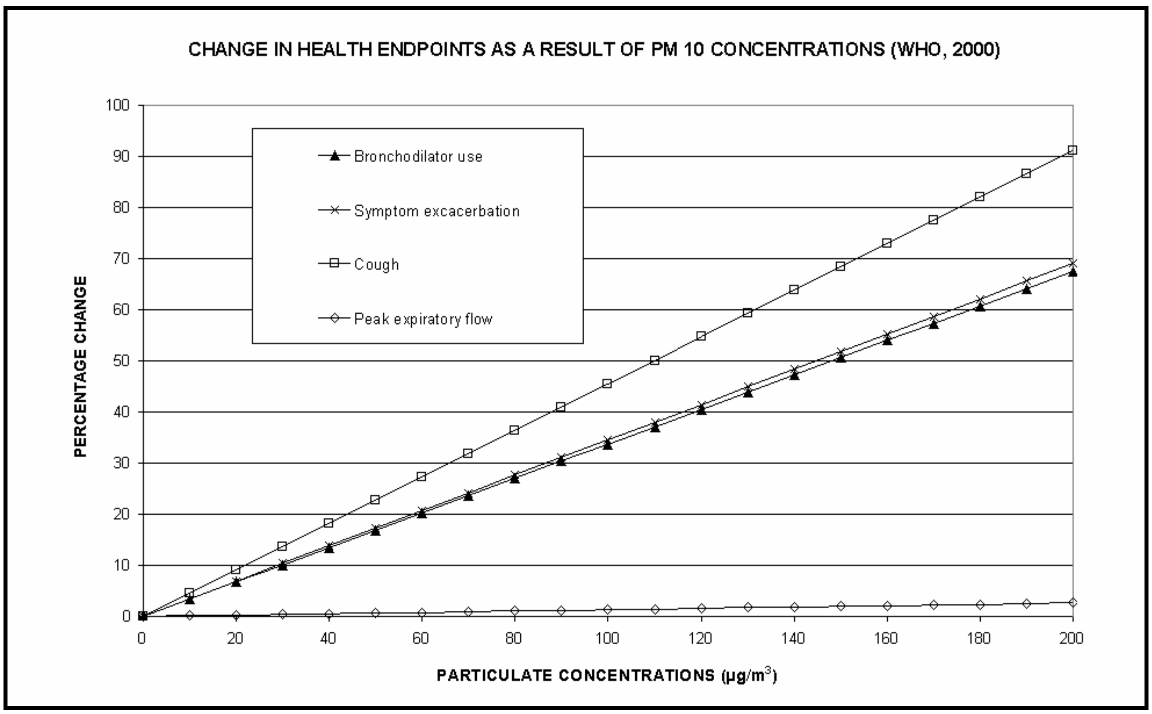

Figure A-4: Percentage change in the occurrence of various health endpoints as a result of changes in ambient PM10 concentrations (WHO, 2000).

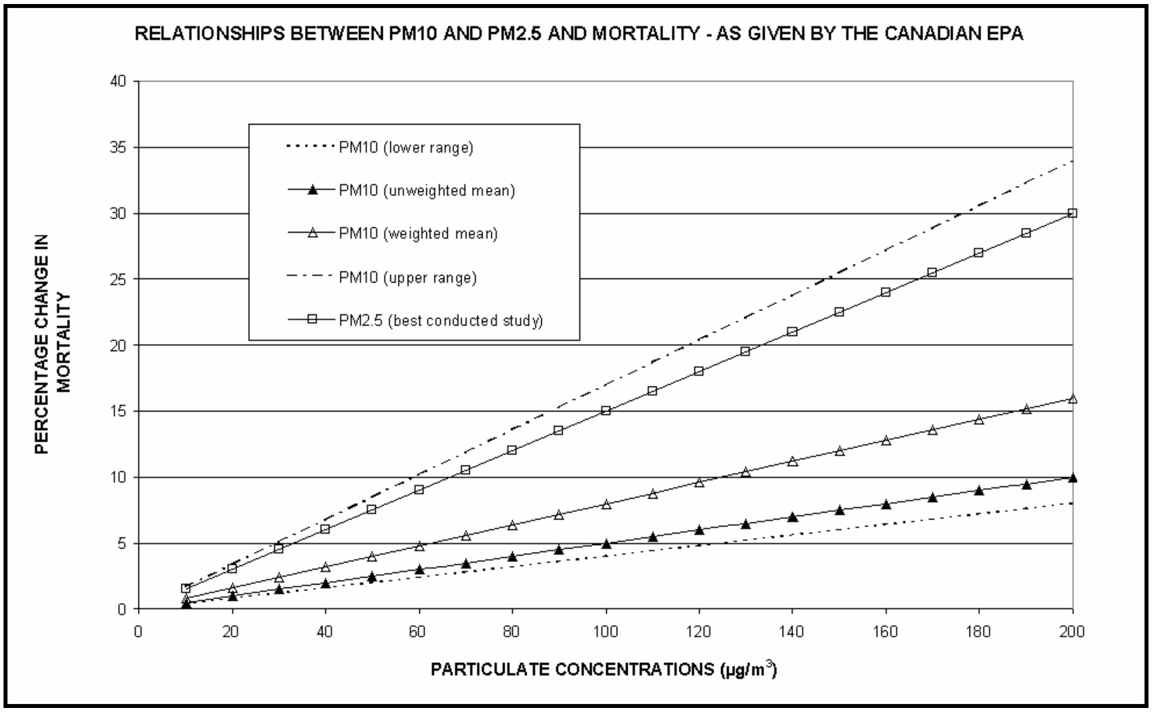

Figure A-5: Relationships between PM10 and PM2.5 and mortality indicated by the Canadian EPA (CEPA/FPAC Working Group, 1998).

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

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

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

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

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

- *There is no effect of concern on pulmonary function in normal healthy individuals at concentrations of acidic aerosols as high as 1000 μg/m³. Effects that may have biological significance may occur at concentrations below 100 μg/m³ in the most sensitive asthmatic individuals.*

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

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

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

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

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

Health Outcome:		**Dose-Response Coefficient:**
Deaths brought forward (all causes)	-	+0.75% per 10 μg/m³ (24 hr mean)
Respiratory hospital admissions	-	+0.8% per 10 μg/m³ (24 hr mean)

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

< 50 μg/m³	=	Low
50 – 74 μg/m³	=	Moderate

75 – 99 μg/m^3 = High
> 100 μg/m^3 = Very high

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

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

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

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

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

A.2 Ambient Air Quality Criteria for Gaseous Pollutants

A.2.1 Sulphur Dioxide (SO_2)

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

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

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

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

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

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

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

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

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

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

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

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

Notes:

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

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

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

A.2.2 Oxides of Nitrogen

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

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

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

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

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

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

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

Table A-6: South African DEAT air quality guidelines for oxides of nitrogen(1)

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

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

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

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

A.2.3 Carbon Monoxide

Carbon monoxide absorbed through the lungs reduces the blood's capacity to transport available oxygen to the tissues. Approximately 80-90 % of the absorbed CO binds with haemoglobin to form carboxyhaemoglobin (COHb), which lowers the oxygen level in blood. Since more blood is needed to supply the same amount of oxygen, the heart needs to work harder. These are the main causes of tissue hypoxia produced by CO at low exposure levels. At higher concentrations, the rest of the absorbed CO binds with other heme proteins such as myoglobin and with cytochrome oxidase and cytochrome P-450.

CO uptake impairs perception and thinking, slows reflexes, and may cause drowsiness, angina, unconsciousness, or death. An exposure to concentrations of 45 mg/m^3 for more than two hours adversely affects a person's ability to make judgements. Two to four hours of exposure at 200 mg/m^3 raises the COHb level in the blood to 10-30 % and increases the possibility of headaches. Exposure to 1 000 mg/m^3 raises the COHb level in the blood to 30 % and causes a rapid increase in pulse rate leading to coma and convulsions. One to two hours of exposure at 1 830 mg/m^3 results in 40 % COHb in blood, which may cause death (MARC 1991). Endogenous production of CO results in COHb levels of 0.4-0.7% in healthy subjects (WHO 2000). During pregnancy, elevated maternal COHb levels of 0.7-2.5% have been reported, mainly due to increased endogenous production. The COHb levels in non-smoking general populations are usually 0.5-1.5% due to endogenous production and environmental exposures. Non-smoking people in certain occupations (car drivers, policemen, traffic wardens, garage and tunnel workers, firemen etc.) can have long-term COHb levels up to 5%, and heavy cigarette smokers have COHb levels up to 10%. Well-trained subjects engaging in heavy exercise in polluted indoor environments can increase their COHb levels quickly up to 10-20%. Epidemic CO poisonings in indoor ice arenas have been reported. To protect non-smoking, middle-aged and elderly population groups with documented or latent coronary artery disease from acute ischemic heart attacks, and to protect fetuses of non-smoking pregnant mothers from untoward hypoxic effects, a COHb level of 2.5% should not be exceeded (WHO 2000).

The guideline values, and periods of time-weighted average exposures, have been determined in such a way that the COHb level of 2.5% is not exceeded, even when a normal subject engages in light or moderate exercise. The guideline values for CO are 100 mg/m^3 for 15 minutes, 60 mg/m^3 for 30 minutes, 30 mg/m^3 for 1 hour, and 10 mg/m^3 for 8 hours (WHO 2000). These ambient air quality guidelines and other standards issued for various countries and organisations for carbon monoxide are given in Table A-7.

Table A-7: Ambient air quality guidelines and standards for carbon monoxide

Averaging Period	South Africa		UK		World Health Organisation		US-EPA	
	µg/m^3	ppm	µg/m^3	ppm	µg/m^3	ppm	µg/m^3	ppm
Max. 8-hour Ave	10 000	9	11 600(a)	10(a)	10 000	9	10 000	9
Max. 1-hour Ave	40 000(b) 30 000(c)	35(b) 26(c)	-	-	30 000	26	40 000	35

Notes:
(a) Running 8-hour mean to be achieved by 31 December 2003.
(b) Current SA guidelines.
(c) South African limit values, reference: *SANS 1929 - Ambient air quality - Limits for common pollutants.*

APPENDIX B

REGIONAL CLIMATE AND ATMOSPHERIC DISPERSION POTENTIAL

B.1. Regional Atmospheric Dispersion Potential

The macro-ventilation characteristics of the region are determined by the nature of the synoptic systems, which dominate the circulation of the region, and the nature and frequency of occurrence of alternative systems and weather perturbations over the region. Meso-scale processes affecting the dispersion potential include thermo-topographically induced circulations, the development and dissipation of surface inversions, and the modification of the low-level windfield and stability regime by urban areas.

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

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

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

Anticyclones situated over the subcontinent are associated with convergence in the upper levels of the troposphere, strong subsidence throughout the troposphere, and divergence in the near-surface wind field. Subsidence inversions, fine conditions with little or no rainfall, and light variable winds occur as a result of such widespread anticyclonic subsidence.

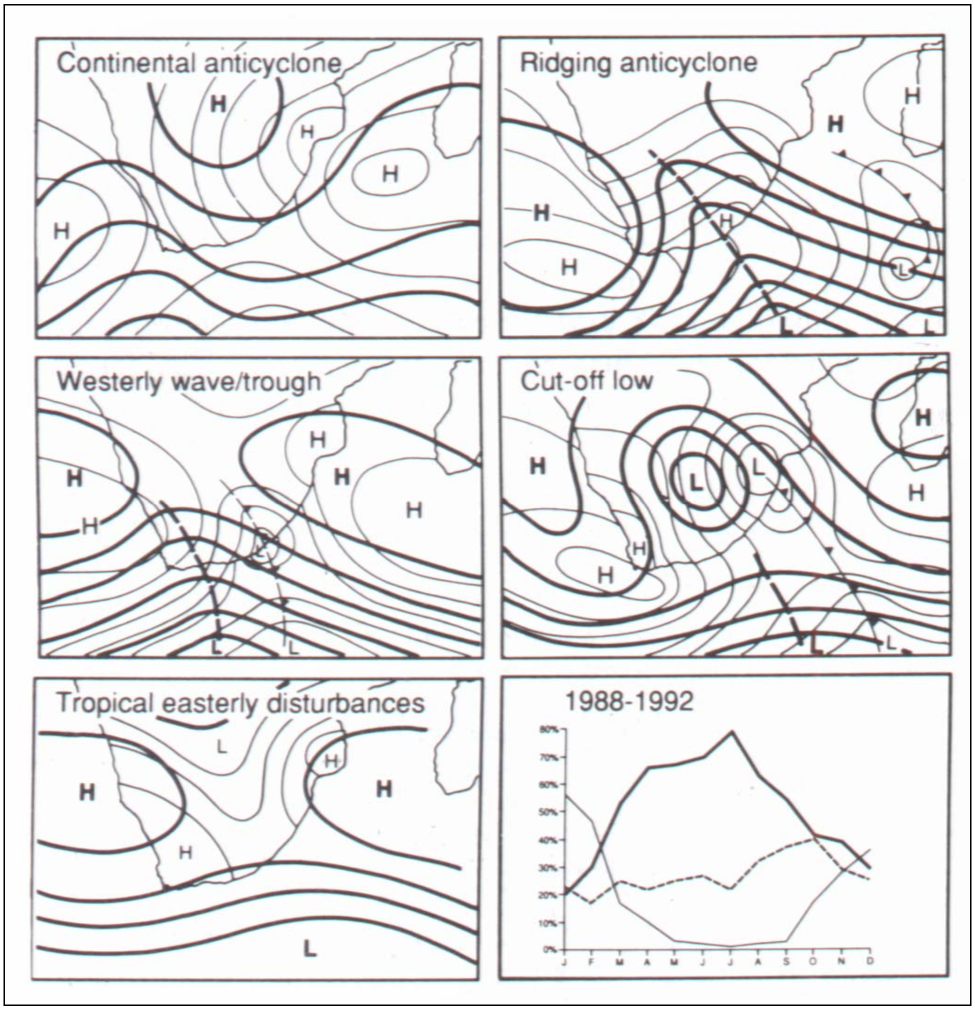

Figure B-1 Major synoptic circulation types affecting southern Africa and their monthly frequencies of occurrence over a five-year period (after Preston-Whyte and Tyson, 1988 and Garstang *et al.,* 1996a).

Anticyclones occur most frequently over the interior during winter months, with a maximum frequency of occurrence of 79 percent in June and July. During December such anticyclones only occur 11 percent of the time. Although widespread subsidence dominates the winter months, weather occurs as a result of uplift produced by localized systems.

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

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

B.2. Elevated Inversions And Stable Layers

The various synoptic systems and weather disturbances each affect the height and persistence of elevated inversions. Temperature inversions are important in that they represent sharp discontinuities in temperature, humidity and airflow profiles, with the atmosphere above the inversion being decoupled from conditions in the lower atmosphere. Inversions are therefore observed by Theron and Harrison (1991) to be dynamic and thermodynamic interfaces demarcating various levels at which airflow directions reverse. Elevated inversions limit the depth to which pollutants are able to mix thus resulting in higher ambient air pollutant concentrations than which may have occurred in their absence.

Multiple elevated inversions occur in the middle to upper troposphere as a result of large-scale anticyclonic subsidence. Three distinct elevated inversions, situated at altitudes of approximately 700 hPa (~3 km), 500 hPa (~5 km) and 300 hPa (~7 km), were identified over the southern Africa plateau (Preston-Whyte et al., 1977; Cosijn, 1996). The height and persistence of such elevated inversions vary with latitudinal and longitudinal position.

Over the west coast, a persistent low-level subsidence inversion with its base at approximately 500 m and a depth of ~600 m is evident. This inversion is due to the predominance of the South Atlantic HP system, and represents the boundary between the dry, subsided upper air and the moist influx of maritime air. The height of this inversion layer is related to the depth of the sea breeze system and the intensity of subsidence in the upper air. The strength of the inversion has been shown to vary between an average of 7°C in summer and 5.2°C in winter (Preston-Whyte et al., 1977). The sub-escarpment inversion is stronger and occurs more frequent during summer (51% frequency) due to the South Atlantic HP reaching is most easterly position during December. This inversion occurs for ~30% of the time during winter months.

In contrast to anticyclonic circulation, convective activity associated with westerly wave disturbances hinders the formation of inversions. Cyclonic disturbances, which are associated with strong winds and upward vertical air motion, may destroy, weaken, or increase the altitude of, elevated inversions. Although cyclonic disturbances are generally associated with the dissipation of inversions, pre-frontal conditions tend to lower the base of the elevated inversion, so reducing the mixing depth. Pre-frontal conditions are also characterised by relatively calm winds. Following the passage of the front, an increase in the mixing depth occurs (Cosijn, 1996; Preston-Whyte and Tyson, 1989).

The subsidence inversion over the west coast only rarely breaks up. The passages of cold fronts across the west coast do not necessarily result in the dissipation of the low level inversion. The presence of the subsistence inversion is often clearly discernible by the distinct differences in moisture content and temperatures of the upper and lower atmosphere. On occasion the subsidence inversion may extent to ground; this lowering of the base appears to coincide with the movement of a coastal low along the coast (Scorgie, 1999).

An occasion on which the subsidence inversion over the west coast does dissipate coincides with the occurrence of certain bergwind conditions. Berg winds generated by the pressure gradient between the continental HP over the interior and a weak low pressure off the west coast give rise to high temperatures and low relative humidity's occur throughout a large section of the atmosphere, indicating the dissipation of the characteristic subsidence inversions. Bergwind conditions arising from pre-frontal divergence seldomly, however, coincide with the dissipation of the low-level subsidence inversions (Scorgie, 1999). High temperatures and low relative humidity's are therefore confined to the lower atmosphere.

B.3. Mixing Height and Atmospheric Stability

The vertical component of dispersion is a function of the extent of thermal turbulence and the depth of the surface mixing layer. Unfortunately, the mixing layer is not easily measured, and must therefore often be estimated using prognostic models that derive the thickness from some of the other parameters that are routinely measured, e.g. solar radiation and temperature. During the daytime, the atmospheric boundary layer is characterised by thermal turbulence due to the heating of the earth's surface and the extension of the mixing layer to the lowest elevated inversion. Radiative flux divergence during the night usually results in the establishment of ground based inversions and the erosion of the mixing layer. Day-time mixing heights were calculated with the prognostic equations of Batchvarova and Gryning (1990), while night-time boundary layer heights were calculated from various diagnostic approaches for stable and neutral conditions.

Atmospheric stability is frequently categorised into one of six stability classes. These are briefly described in Table B-1.

Table B-1: Atmospheric stability classes.

A	very unstable	calm wind, clear skies, hot daytime conditions
B	moderately unstable	clear skies, daytime conditions
C	unstable	moderate wind, slightly overcast daytime conditions
D	neutral	high winds or cloudy days and nights
E	stable	moderate wind, slightly overcast night-time conditions
F	very stable	low winds, clear skies, cold night-time conditions

The atmospheric boundary layer is normally unstable during the day as a result of the turbulence due to the sun's heating effect on the earth's surface. The thickness of this mixing layer depends predominantly on the extent of solar radiation, growing gradually from sunrise to reach a maximum at about 5-6 hours after sunrise. This situation is more pronounced during the winter months due to strong night-time inversions and a slower developing mixing layer. During the night a stable layer, with limited vertical mixing, exists. During windy and/or cloudy conditions, the atmosphere is normally neutral.

For elevated releases, the highest ground level concentrations would occur during unstable, daytime conditions. The wind speed resulting in the highest ground level concentration depends on the plume buoyancy. If the plume is considerably buoyant (high exit gas velocity and temperature) together with a low wind, the plume will reach the ground relatively far downwind. With stronger wind speeds, on the other hand, the plume may reach the ground closer, but due to the increased ventilation, it would be more diluted. A wind speed between these extremes would therefore be responsible for the highest ground level concentrations. The highest concentrations for low level releases would occur during weak wind speeds and stable (night-time) atmospheric conditions. Air pollution episodes frequently occur just prior to the passage of a frontal system which is characterised by calm winds and stable conditions.

APPENDIX C

DISPERSION SIMULATION RESULTS

Table C-1: Concentration Plots for the Impact Assessment.

Pollutant	Scenario	Averaging Period	Guideline (µg/m³)	Figure No.
PM10	Power station	Highest daily	75	C-1
		Annual average	40	C-2
	Baseline	Highest daily	75	C-3
		Annual average	40	C-4
	Cumulative	Highest daily	75	C-5
		Annual average	40	C6
SO_2	Power station	Highest hourly	350	C-7
		Highest daily	125	C-8
		Annual average	50	C-9
	Baseline	Highest hourly	350	C-10
		Highest daily	125	C-11
		Annual average	50	C-12
	Cumulative	Highest hourly	350	C-13
		Highest daily	125	C-14
		Annual average	50	C-15
NO_2	Power station	Highest hourly	200	C-16
		Highest daily	150	C-17
		Annual average	40	C-18
	Baseline	Highest hourly	200	C-19
		Highest daily	150	C-20
		Annual average	40	C-21
	Cumulative	Highest hourly	200	C-22
		Highest daily	150	C-23
		Annual average	40	C-24
CO	Power station	Highest hourly	30 000	C-25
	Baseline	Highest hourly	30 000	C-26
	Cumulative	Highest hourly	30 000	C-27

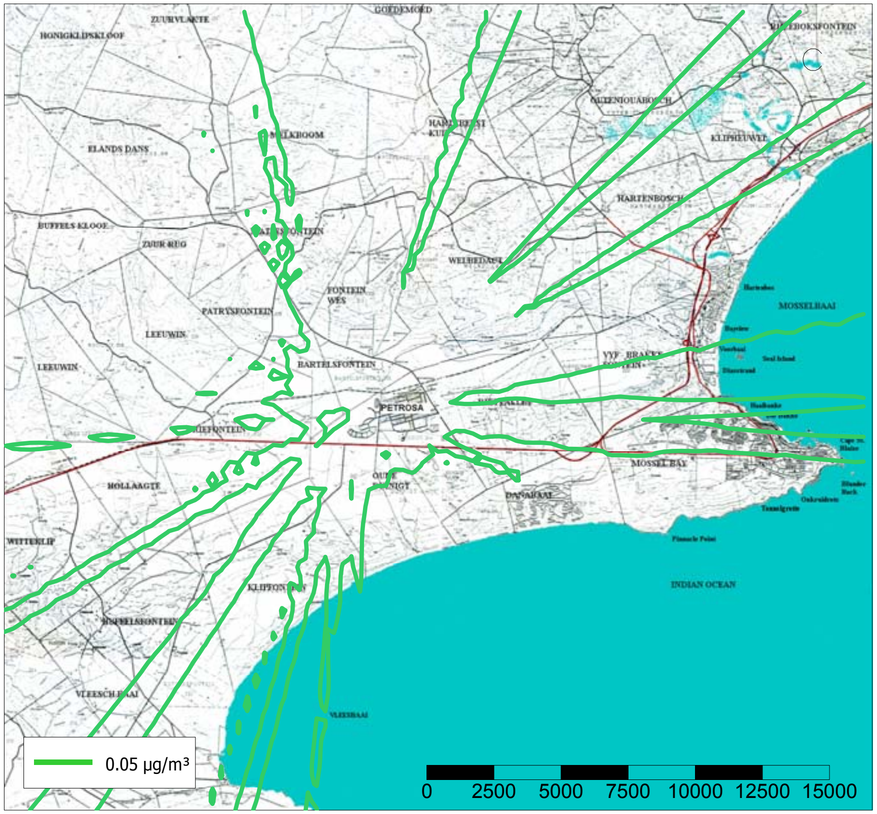

Figure C-1 Highest daily predicted PM10 ground level concentrations ($\mu g/m^3$) for the power station.

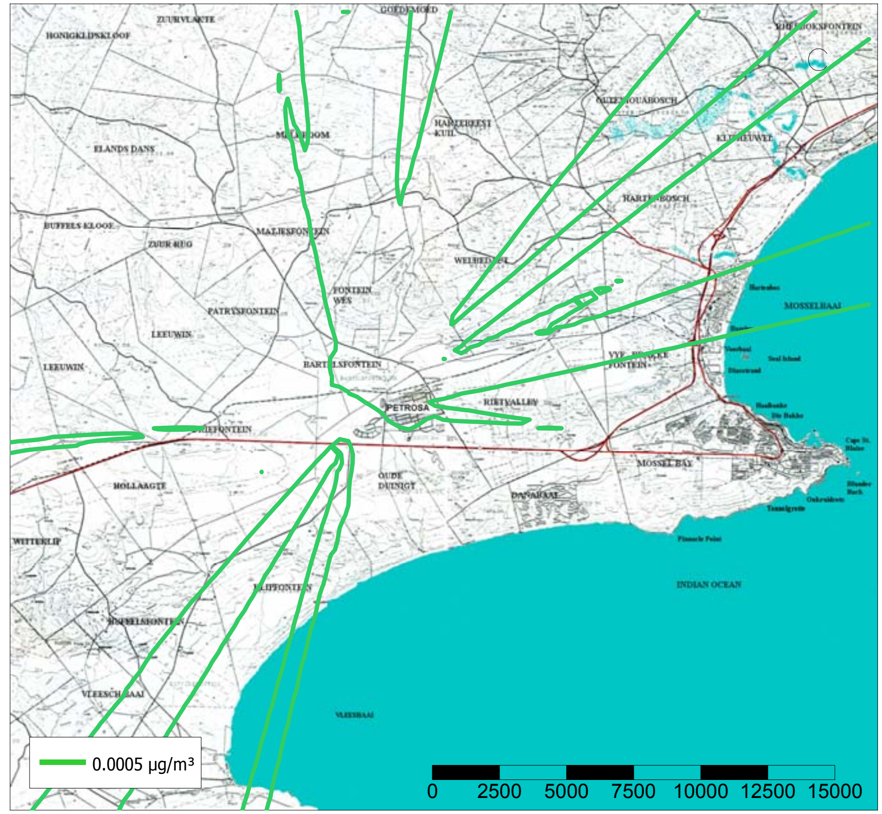

Figure C-2 Annual average predicted PM10 ground level concentrations ($\mu g/m^3$) for the power station.

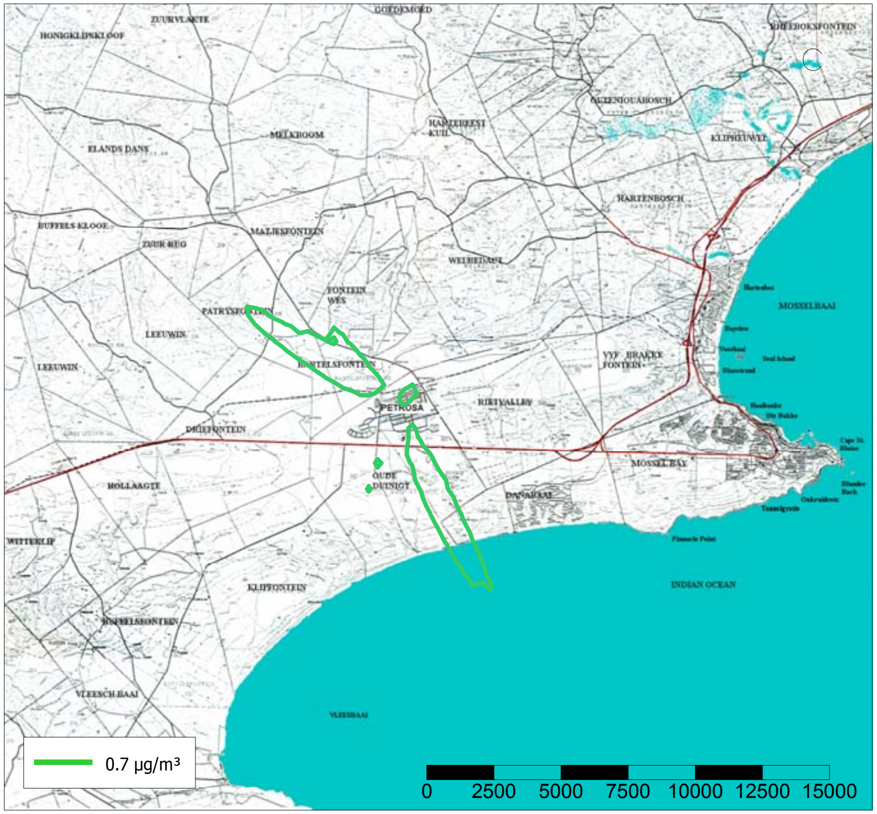

Figure C-3 Highest daily predicted PM10 ground level concentrations ($\mu g/m^3$) for the PetroSA refinery (baseline).

Figure C-4 Annual average predicted PM10 ground level concentrations ($\mu g/m^3$) for the PetroSA refinery (baseline).

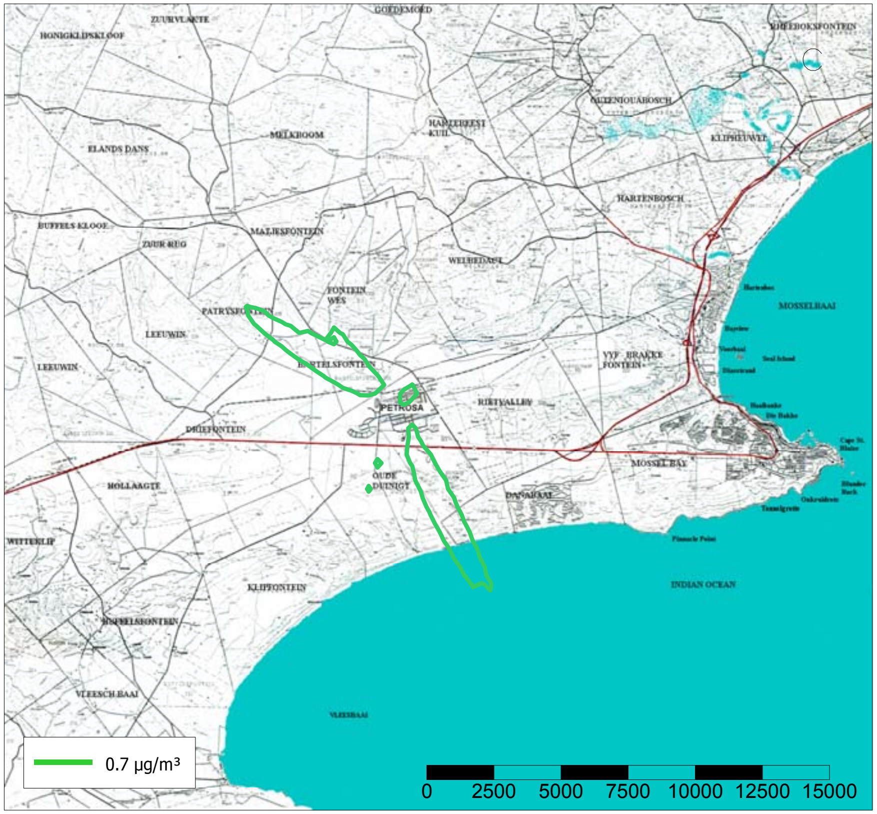

Figure C-5 Highest daily predicted PM10 ground level concentrations ($\mu g/m^3$) for all sources.

Figure C-6 Annual average predicted PM10 ground level concentrations ($\mu g/m^3$) for all sources.

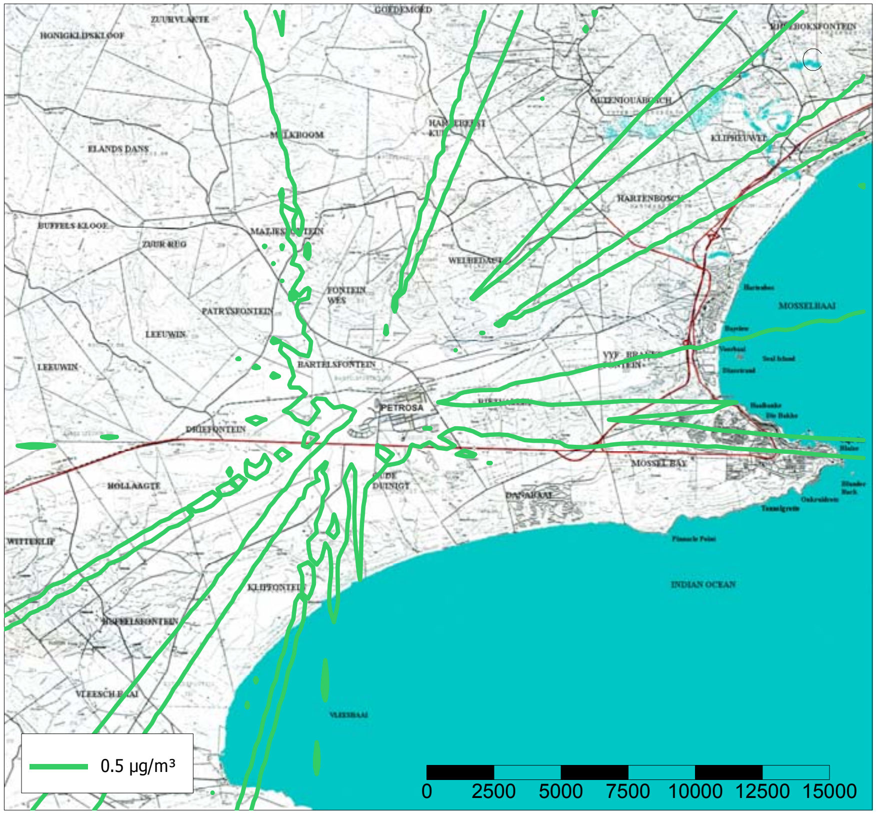

Figure C-7 Highest hourly predicted SO_2 ground level concentrations (µg/m³) for the power station.

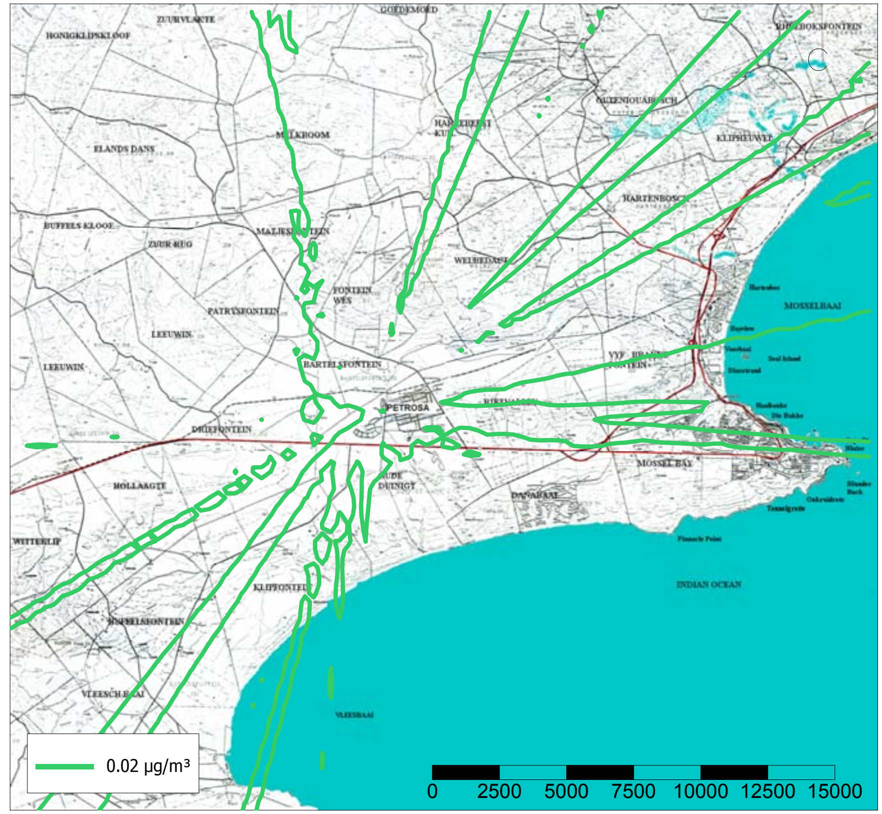

Figure C-8 Highest daily predicted SO_2 ground level concentrations (µg/m³) for the power station.

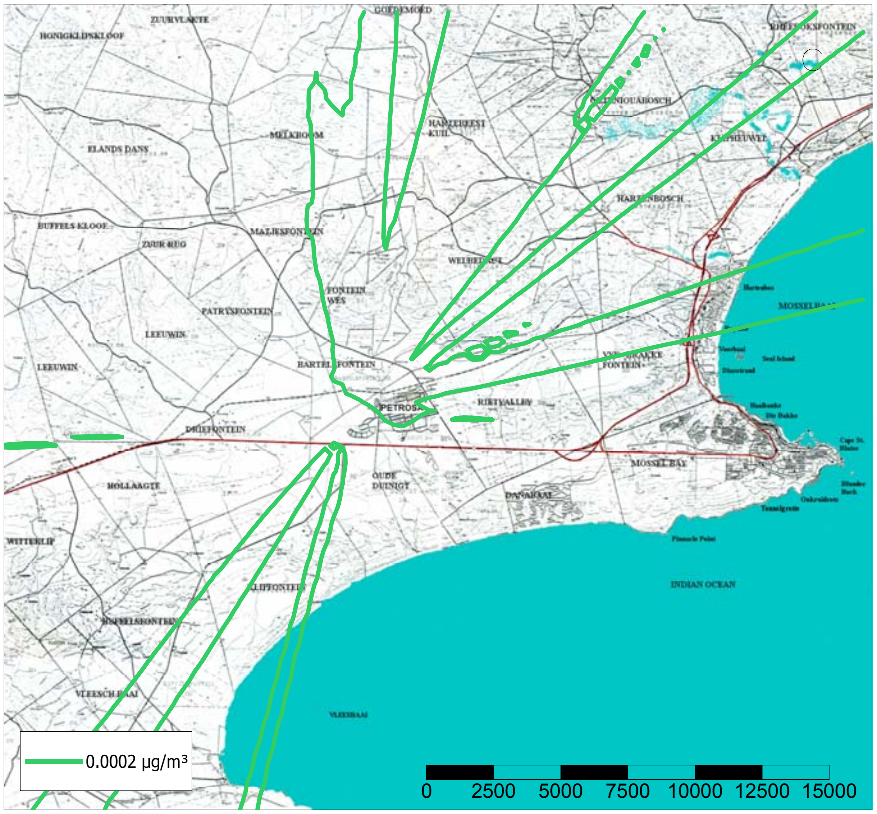

Figure C-9 Annual average predicted SO_2 ground level concentrations (µg/m³) for the power station.

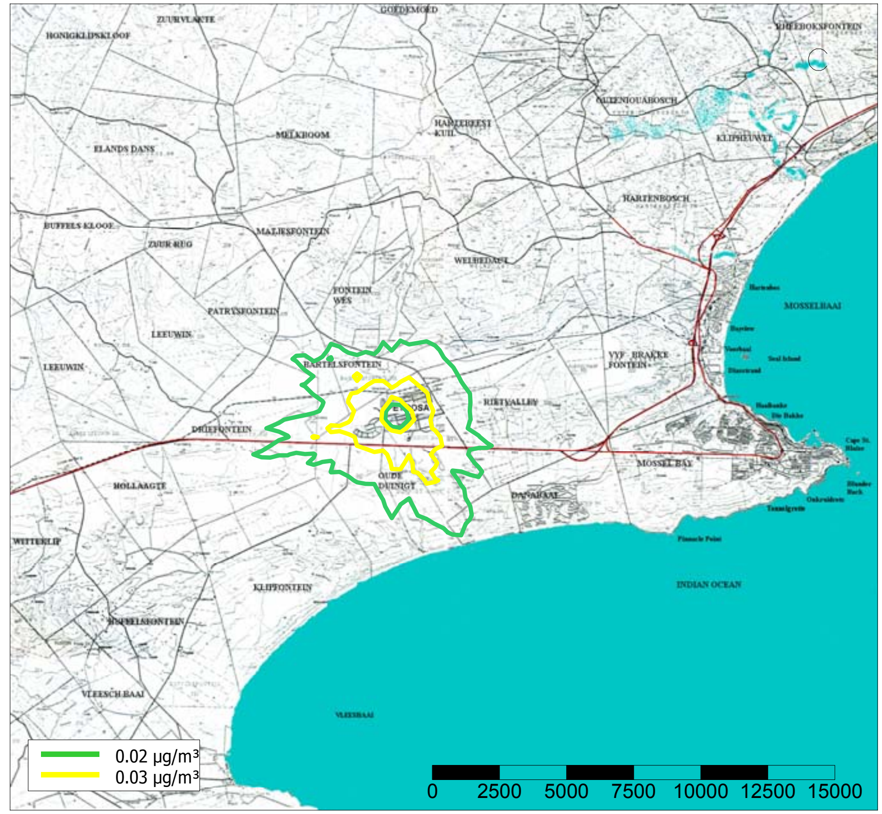

Figure C-10 Highest hourly predicted SO_2 ground level concentrations (µg/m³) for the PetroSA refinery (baseline).

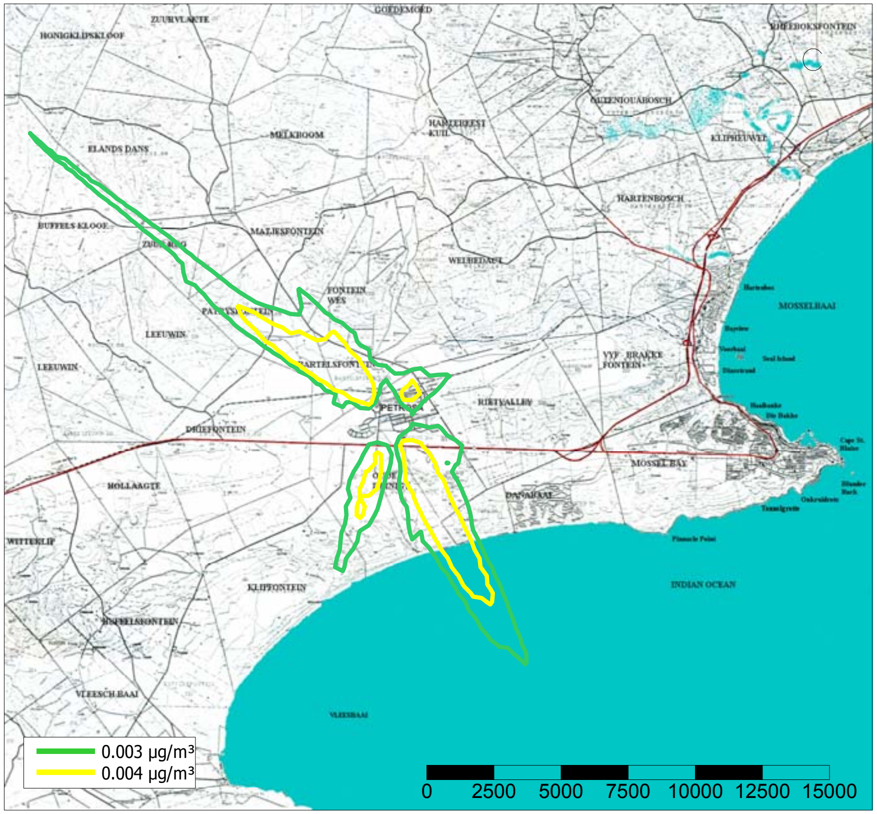

Figure C-11 Highest daily predicted SO_2 ground level concentrations (µg/m³) for the PetroSA refinery (baseline).

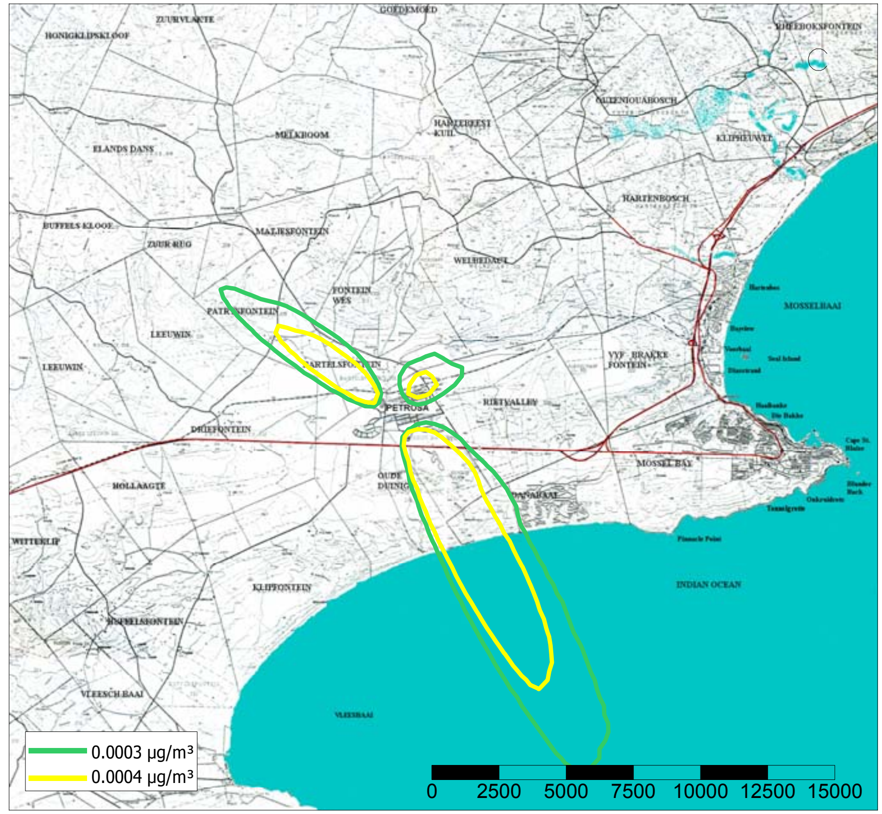

Figure C-12 Annual average predicted SO_2 ground level concentrations (µg/m³) for the PetroSA refinery (baseline).

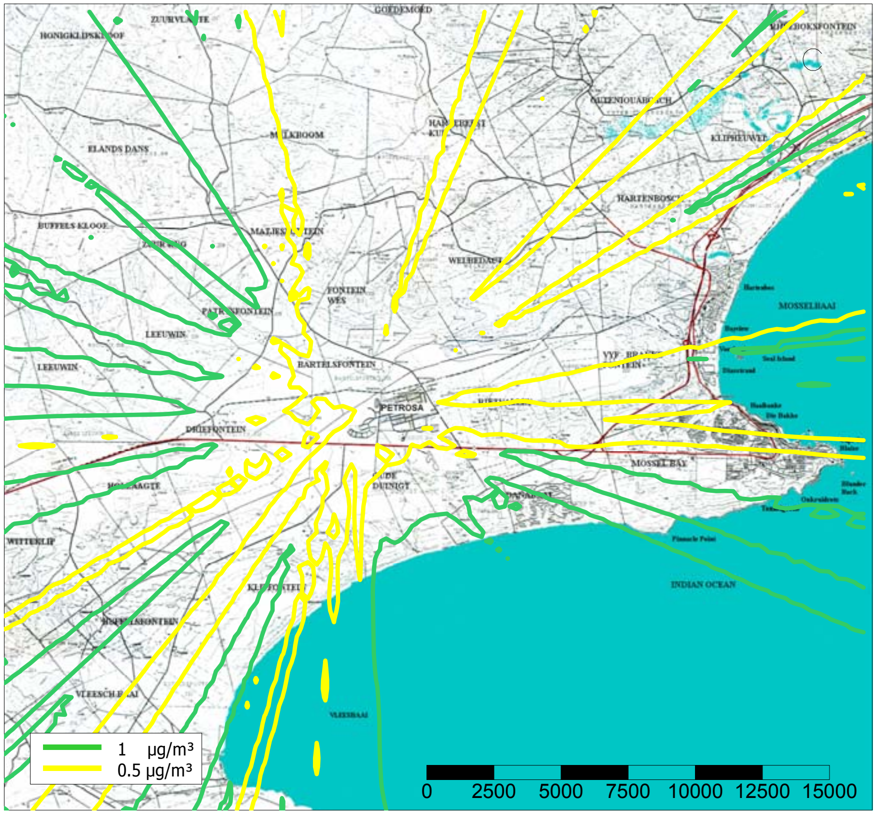

Figure C-13 Highest hourly predicted SO_2 ground level concentrations (µg/m³) for all sources.

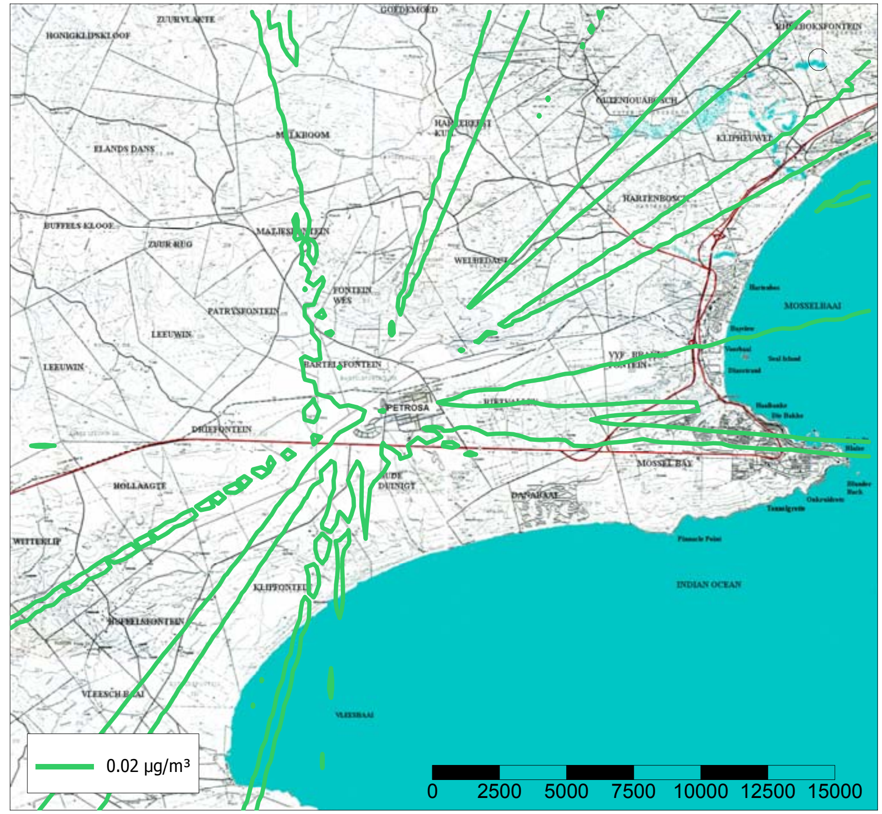

Figure C-14 Highest daily predicted SO_2 ground level concentrations (µg/m³) for all sources.

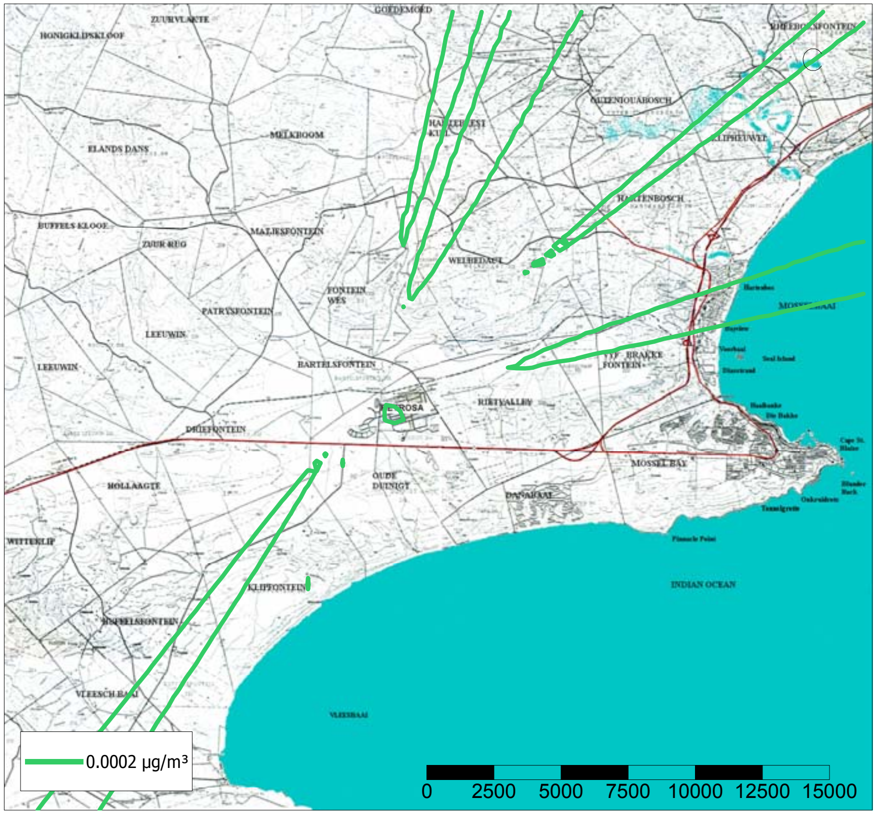

Figure C-15 Annual average predicted SO_2 ground level concentrations (µg/m³) for all sources.

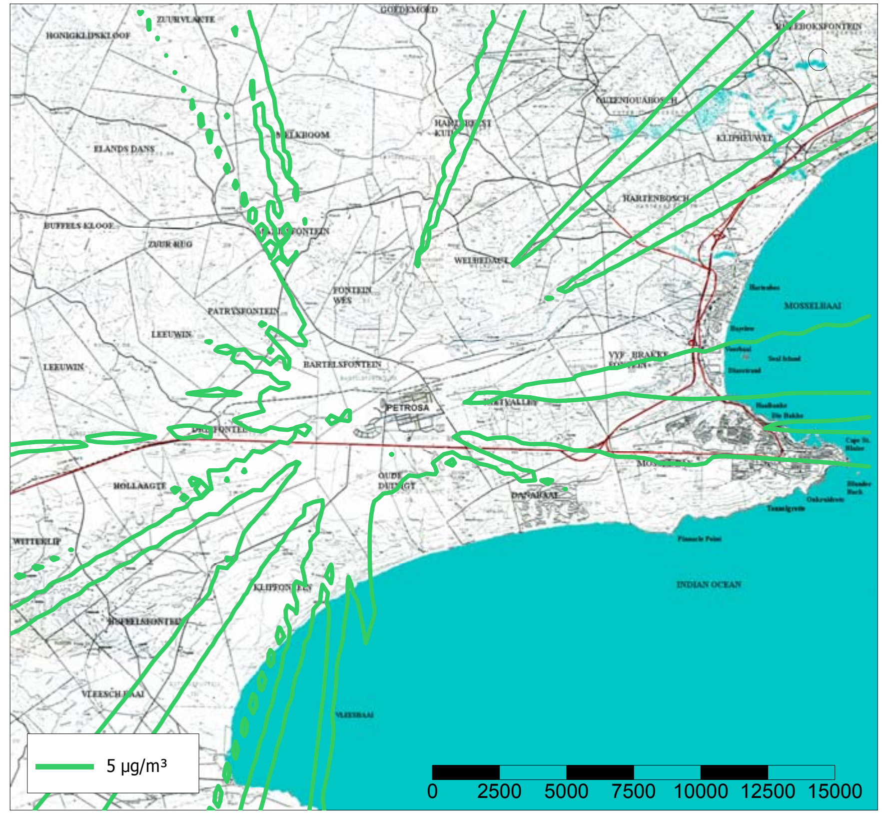

Figure C-16 Highest hourly predicted NO_2 ground level concentrations (µg/m³) for the power station.

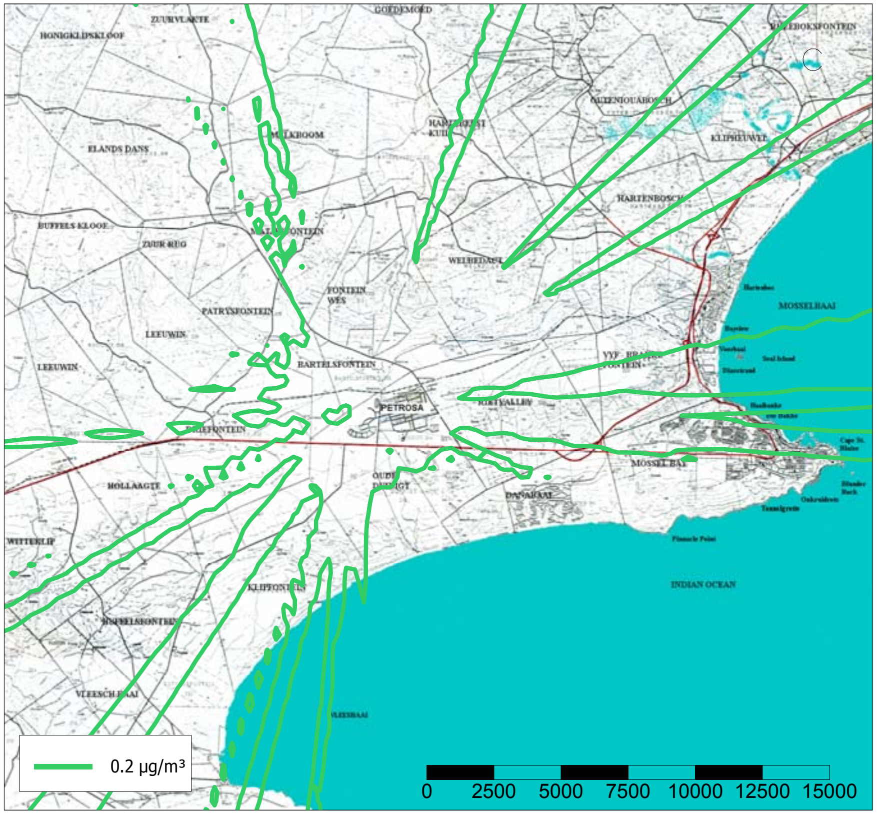

Figure C-17 Highest daily predicted NO_2 ground level concentrations (µg/m³) for the power station.

Figure C-18 Annual average predicted NO_2 ground level concentrations (µg/m³) for the power station.

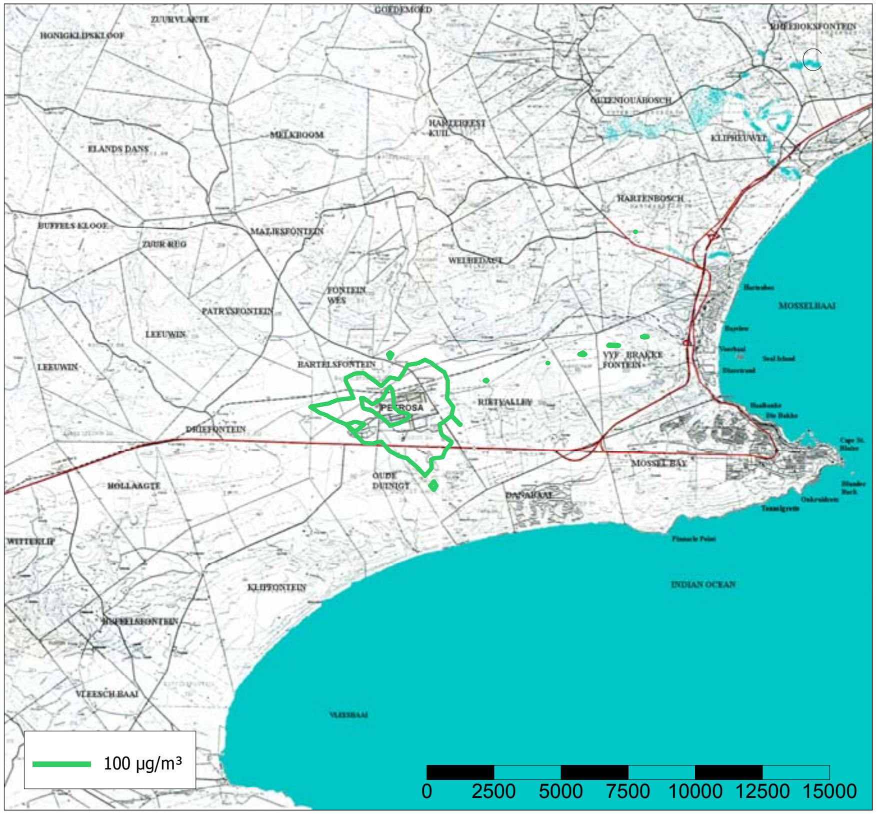

Figure C-19 Highest hourly predicted NO_2 ground level concentrations (µg/m³) for the PetroSA refinery (baseline).

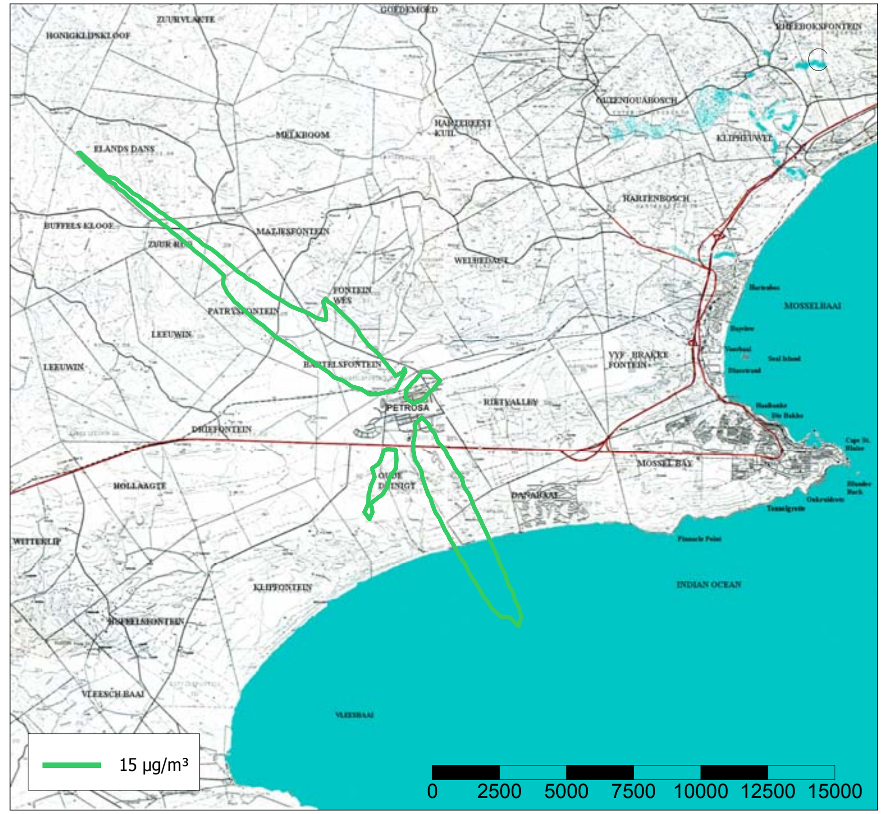

Figure C-20 Highest daily predicted NO_2 ground level concentrations (µg/m³) for the PetroSA refinery (baseline).

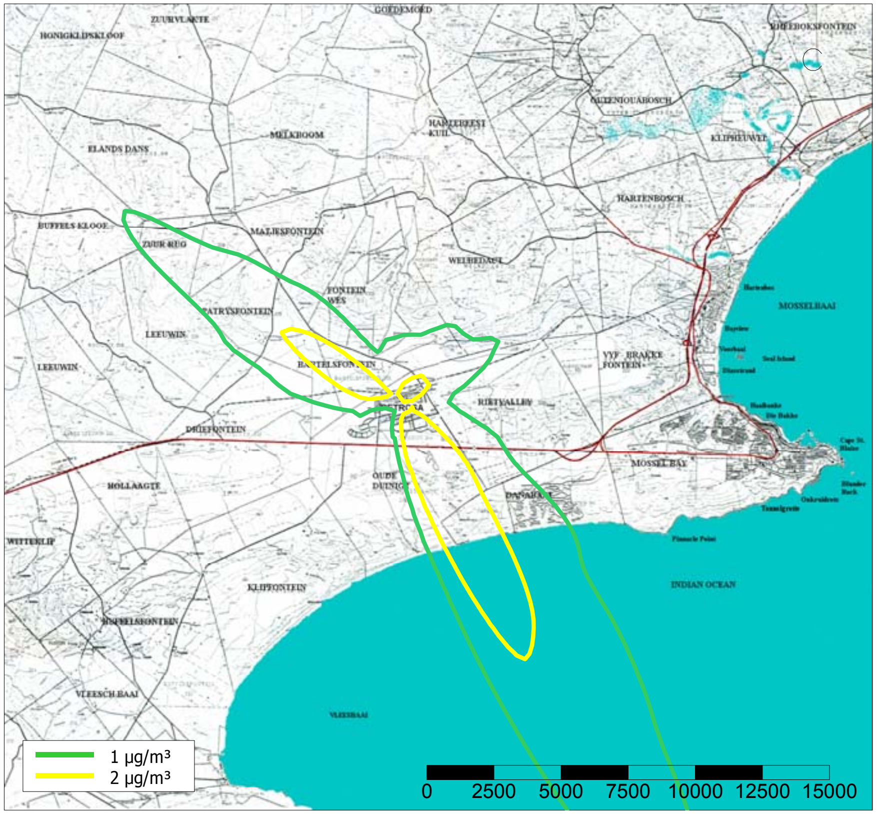

Figure C-21 Annual average predicted NO_2 ground level concentrations (µg/m³) for the PetroSA refinery (baseline).

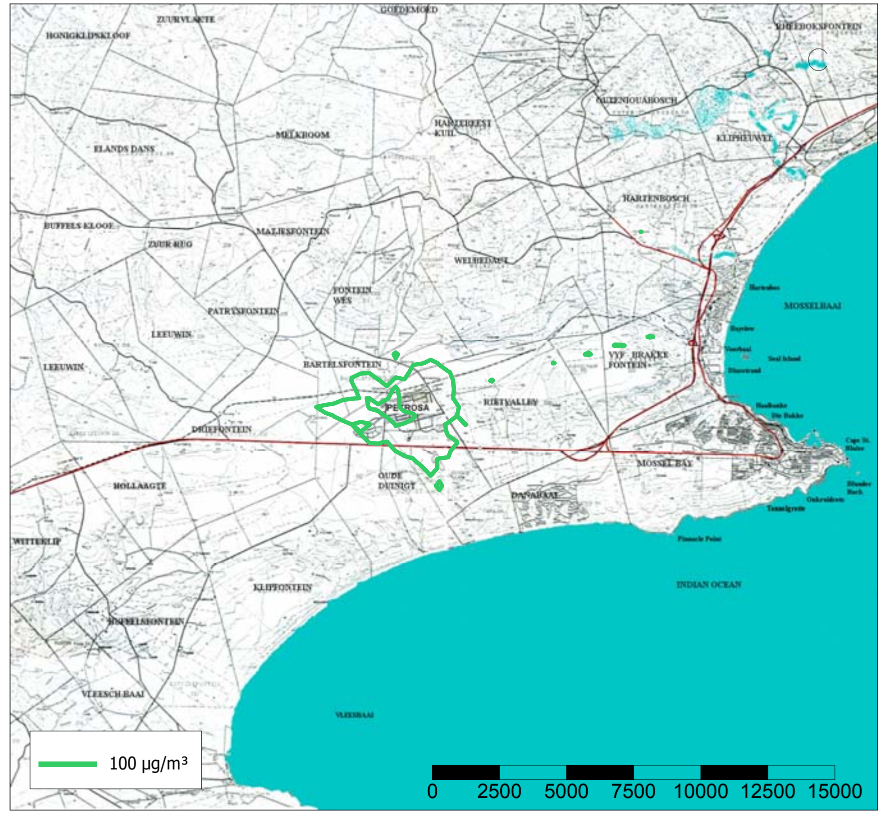

Figure C-22 Highest hourly predicted NO_2 ground level concentrations (µg/m³) for all sources.

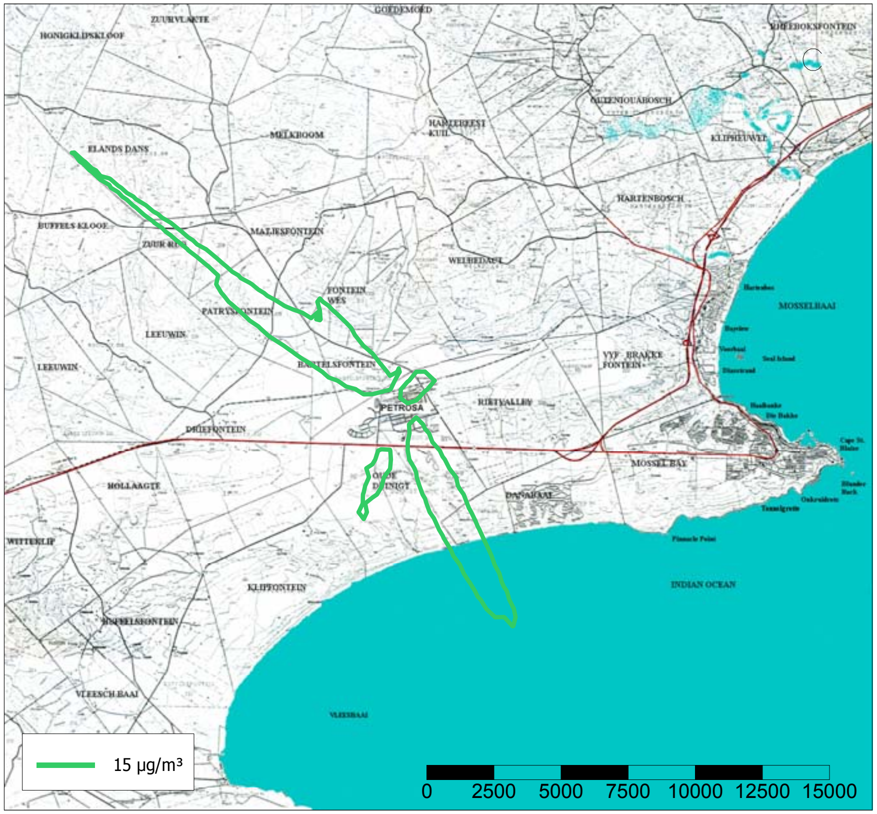

Figure C-23 Highest daily predicted NO_2 ground level concentrations (µg/m³) for all sources.

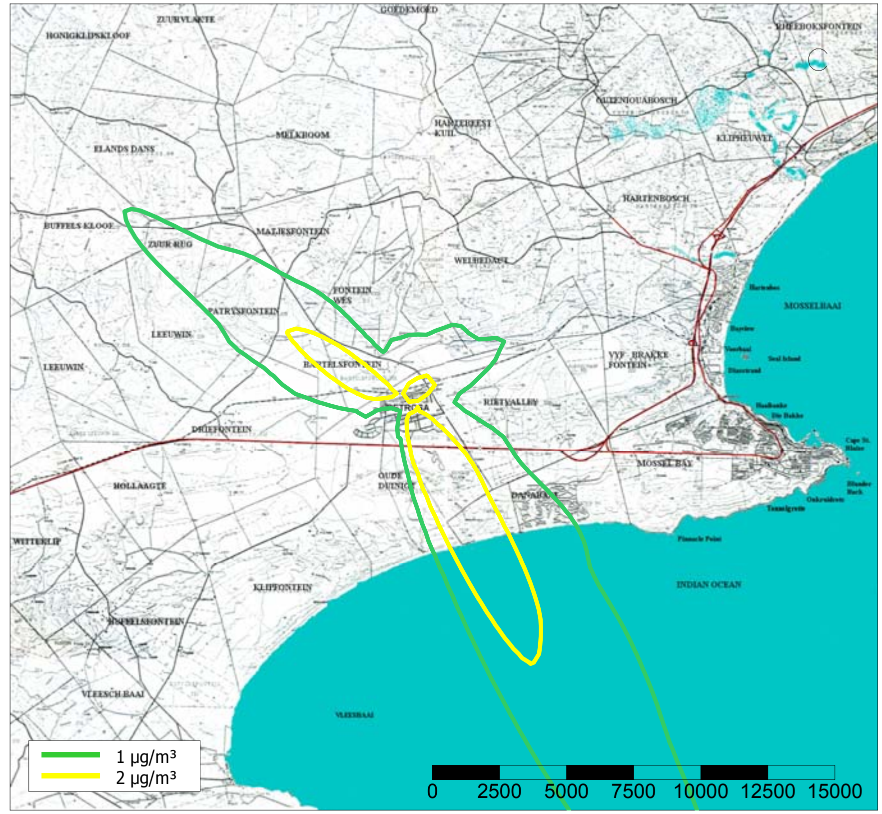

Figure C-24 Annual average predicted NO_2 ground level concentrations (µg/m³) for all sources.

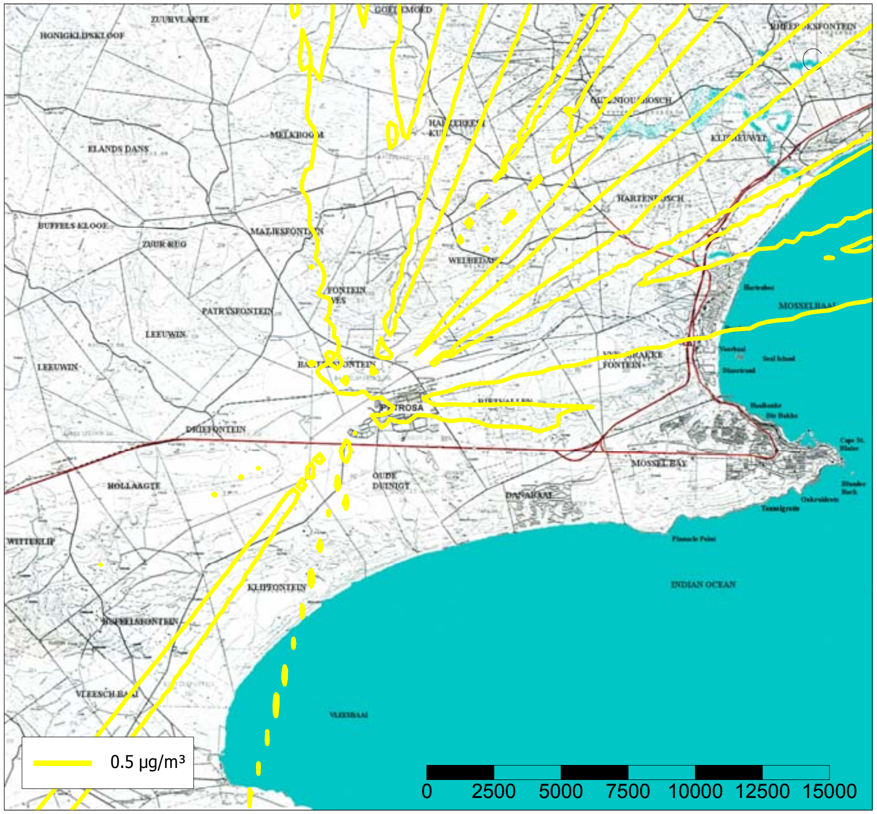

Figure C-25 Highest hourly predicted CO ground level concentrations (µg/m³) for the power station.

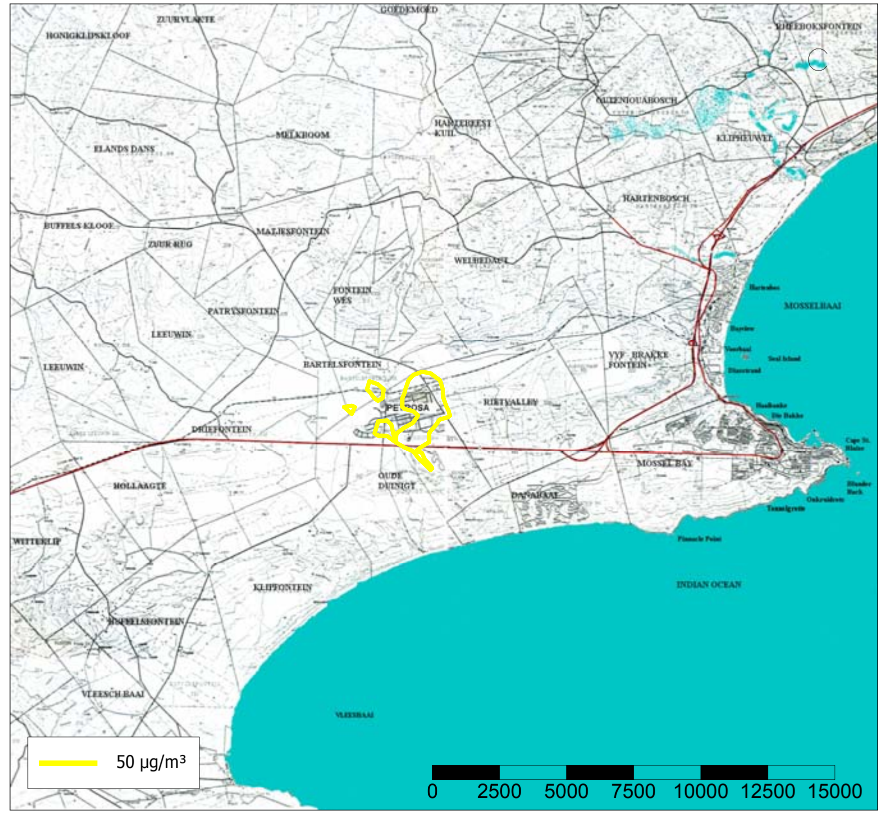

Figure C-26 Highest hourly predicted CO ground level concentrations (µg/m³) for the PetroSA refinery (baseline).

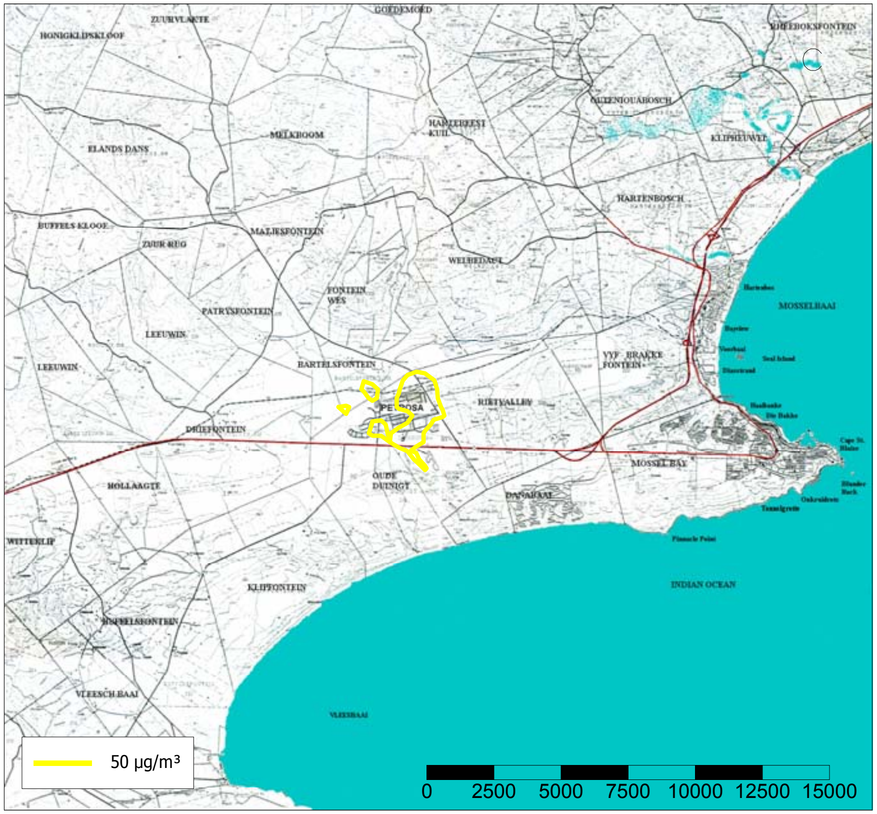

Figure C-27 Highest hourly predicted CO ground level concentrations (µg/m³) for all sources.

ANNEXURE H:

PIPELINE RISK STUDY

PROJECT DONE ON BEHALF OF
NINHAM SHAND

HAZARDS OF TRANSPORTATION OF FLAMMABLE LIQUIDS VIA OVERLAND PIPELINE FROM THE PETROSA REFINERY TO THE PROPOSED POWER STATION AT MOSSEL BAY

Report No.: IR/05/NIN-01 Rev 1

August 2005

M P Oberholzer

Ilitha
RisCom (Pty)Ltd

P O Box 336
Wierda Park 0149
Tel: +27 (0) 12 668 1075
fax: +27 (0) 12 668 1828
e-mail: jhbsales@ilitha.com

EXECUTIVE SUMMARY

Pipelines are the safest method of transporting flammable liquids. Despite the good safety record of pipelines, the loss of containment of the pipelines does occur. Without ignition, the spilt material can result in an environmental problem. With ignition the flammable material can burn or explode resulting in injury to people or damage to equipment. The extent of the hazard must be evaluated using the specific conditions of the system. For the proposed pipeline from the PetroSA refinery to the Power Station, a loss of containment from a leak or rupture could form a flammable pool with an area of 3000 m^2 and have a venerable zone of 40 m or more from the pipeline.

The likelihood of a loss of containment from a pipeline is derived from historical data and would be influenced by the design codes, materials of construction and the environment of the pipeline such as waterways, steep terrains, corrosion etc.

From a town planning prospect, development would be not be allowed in the vulnerable zone. High density residential and developments such as hospitals, schools and old age homes may be would only be allowed as a distance from the pipeline that has been deemed to have acceptable risks and could be at a distance of 100m or more from the pipeline.

The distances indicated in the report are preliminary and based on a large fire. Mitigation can be implemented to reduce the impact of the fires and can only be analysed with a more detailed design. It is however advisable to conduct hazard identification methods such as Hazop Studies at an early stage as changes to the design later on may be costly and time consuming.

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HAZARDS OF TRANSPORTATION OF FALMMABLE LIQUIDS VIA OVERLAND PIPELINE FROM THE PETROSA REFINERY TO THE PROPOSED POWER STATION AT MOSSEL BAY

1 INTRODUCTION

The proposed Power Station at Mosselbay will be powered by fuel transported overland via a pipeline from PetroSA. The pipeline is expected to be either a 4" or 6" NB, above ground mild steel pipeline designed to ANSI 16.5. The pipeline will be installed above ground and operate at a pressure of 10 bar gauge.

The risks from pipelines depend on the potential consequences as well as the frequency of the occurrence. For emergency planning only the consequence is considered with vulnerable zones being identified. Town planning criteria takes the likelihood of the event into account to determine the acceptability of the installation. The likelihood of the event will take historical failures, design specifications and terrain into account. It is thus important to consider both consequences and likelihood of the event.

2 CONSEQUENCES FROM A LOSS OF CONTAINMENT OF AN OVERLAND PIPRLINE

The loss of containment of flammable or combustible liquids below their normal boiling points in the proposed pipeline could result in a number of hazards. The material could have a direst ignition and will consume the spilt material at a rate equal or less than the release flow rate. If no immediate ignition occurs, the material may for a pool of liquid that evaporates at a rate primarily dependant on the surface area and ambient temperature. The evaporated liquid can form a flammable cloud. In the event of ignition the flammable mass in the cloud will ignite resulting in a fire ball with an associated overpressure. This is normally of short duration, but can result in injuries and property damage. After the flammable gaseous mass has been consumed, a pool fire will form where the evaporation rate is replaced by the burning rate. The flame characteristics will depend on the physical properties of the material and atmospheric conditions. The flame length will depend primarily on the fire diameter with the flame tilt depending on the wind speed.

The radiation from the flames decreases rapidly from the flame, but with large fires this may extend some distances. With a loss of containment of pipelines, it would not be uncommon to have a pool area of 3000m^2 and a vulnerable zone of 40m and more from the pipeline. More precise numbers would have to be established using more detailed modeling. The size of the pool will depend on the hole size and the time taken to identify the leak with appropriate measures to stop the flow. In the worst case of a pipe rupture, the flow rate will be determined by the maximum pumping rate plus the backflow of material in the pipe upstream of the break.

A small leak on the pipeline can also result in a fire directly under the pipeline. Under certain conditions, the fire will produce high intensity fames that can damage the pipeline with a secondary event of a larger loss of containment ultimately resulting in a large fire.

Preliminary calculations of a large hydrocarbon fire along the proposed pipeline at Mossel Bay indicate that there could be damage to equipment and buildings at a distance of 40 m from the pipeline, combustion of vegetation up to 80 m from the pipeline and secondary degree burns at 120 m from the pipeline. Under such circumstances, it would be likely that no residential developments would be allowed closer than 100-120 m from the pipeline.

Distances can be reduced with engineering designs and considerations such as placing the pipeline underground, introducing methods to detect leaks and take quick action etc.

3 FAILURE FREQUENCIES OF PIPELINES

A number of reason have been identified for the reason of pipe failures and these are discussed in more detail in Appendix A. Some of these reasons are:

i Natural causes such as earthquakes, landslides, floods etc;
ii Mechanical failure such as poor welding, metal fatigue etc;
iii Operational such as operating the pipeline beyond its design duty;
iii Corrosion; and
iv Third party interference of an outside party deliberately or otherwise damaging the pipeline.

For a large hydrocarbon spill on the proposed pipeline at Mossel Bay, acceptable risks for land development could be as far as 100-120 m from the pipeline.

Risks can be reduced by reducing the quantity of material spilt, as described above, as well as the pipeline design such as design and construction to the proposed code, prevention of liquid hammer, provision for thermal expansion of the liquid and pipeline, adequate protection from corrosion etc.

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5 APPENDIX A: HISTORICAL TRENDS AND FAILURES OF OVERLAND PIPELINES

Pipeline failures have, for many years, been reported either by law and made public, as in the USA, or by law, but under conditions of confidentiality, as in some European countries. The US Department of Transport (DOT) regularly publishes statistics of oil and gas pipeline failures. Two groups, namely the European Gas Pipeline Incident Group (EGIG) and the European oil companies (CONCAWE), record the European experiences. These results are summarised below, with the addition of incident statistics in Australia.

It is known that transport through pipelines has created the safest mode of transportation today, surpassing road, rail, air and water. Figure 5-1 is a clear illustration of this situation in the USA. This record has been achieved and maintained with the use of redundant safety systems, round-the-clock monitoring and extensive inspection and maintenance to keep the pipelines operating in top condition.

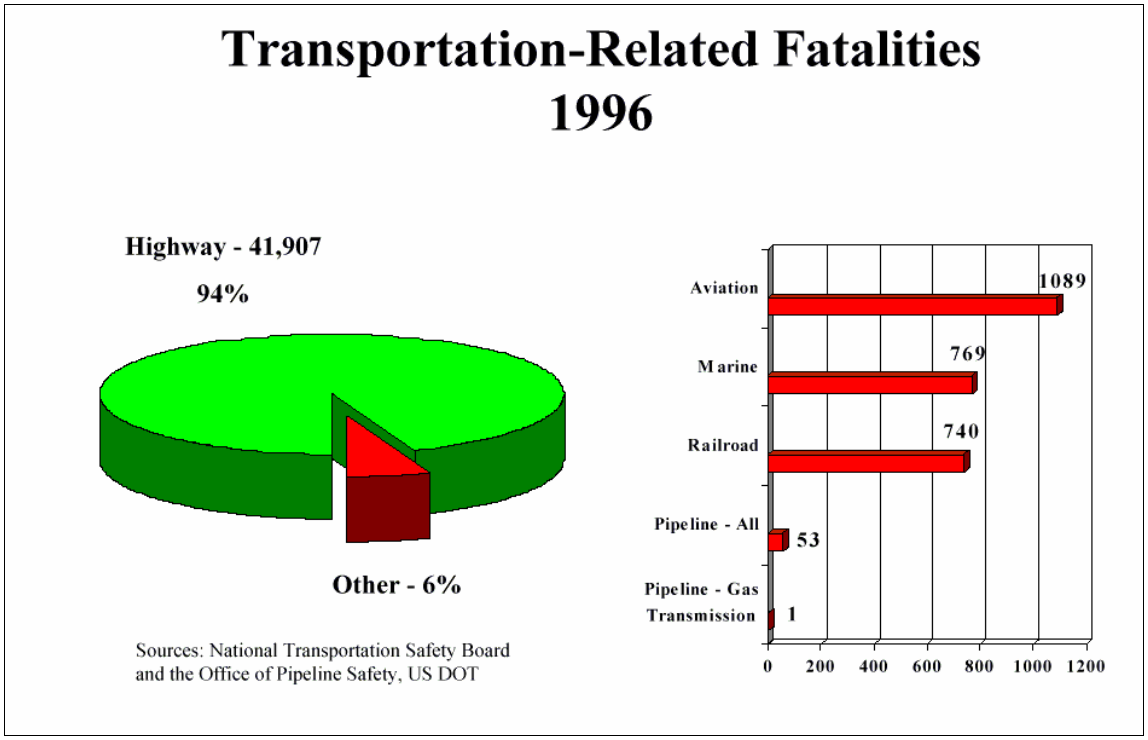

Figure 5-1: Statistical comparison of transportation fatalities in the USA (Sources: National Transportation Safety Board and Office of Pipeline Safety, United States Department of Transport).

In this investigation, a review of historical pipeline spillage records from the USA, Europe, Australia and New Zealand forms the basis for establishing generic accidents and failure rates. The leak and spill history for these pipelines will be discussed in the following section. For the purposes of risk assessment, both USA and European pipeline accident databases were consulted for the development of historical pipeline failure rates, including the event frequency data and causes of leaks and spills.

Most studies of pipeline failures have identified a range of causes and possible hole sizes. A failure occurs when there is a loss in the integrity in the pipeline, either in the pipe wall itself or in a weld where sections of the pipeline have been joined together. Damage may be due to corrosion or mechanical impact damage, whilst more severe failures may occur due to ground movement, over-pressurisation of the pipe or construction faults.

The European Gas Pipeline Incident Data Group, comprising gas institutions from nine European countries has collected data since 1970 about the performance of onshore transmission gas pipelines in Western Europe. The data have been analysed (EGIG 1999) to record the reported-on pipeline system development over time, quantify environmental performance and reveal trends in causes of spillages. The two most important causes of spillages are third party accidents and mechanical failure, with corrosion in third place and operational and natural hazards making minor contributions.

Third party interference is the most important mechanism of pipeline damage in terms of likelihood and volume spilled. This term means that someone other than the pipeline operator (a 'third-party') damages the pipeline. This type of accident is normally a consequence of digging operations with mechanical diggers or, occasionally, by driving metal or wooden stakes into the ground. The result may be an immediate leak or a weakened part in the pipeline that might fail at some point in the future.

Mechanical failures are essentially unrehearsed failures of the pipe wall or welds. This may, for example, occur when the pipeline is used continuously at a pressure considerably higher than the designed specification; this may lead to material fatigue. Alternatively, a weld may split open at a weak point (e.g. inclusion of a piece of slag or simply a thin portion). Although very uncommon, a pipe may fail due to stress on the steel, which would typically occur as a result of an incorrect installation.

Corrosion of a pipeline can be either external or internal. Where the pipe wall or a weld has been corroded away, the corrosion usually forms a very small hole, or pinhole. Corrosion can be a result of electrochemical differences between the soil and pipeline surface, or an existing weak point on the pipe or weld. This is generally difficult to predict or pinpoint since large holes from corrosion are very rare.

Natural hazards include flooding, landslides, earthquakes and sinkholes (undermining). The latter event is possibly the only significant natural hazard anticipated along the proposed pipeline route.

Operation failures cover operator error and malfunction of the pressure control and protection systems.

The best collection of cross-country pipeline performance data in the European petrochemical industry is that compiled by the CONCAWE Oil Pipeline Management group (Berry *et al*, 1999). Although this information may not strictly be regarded for the transport of gas, the results are relevant for the principles are the same. Furthermore, gas transportation often requires more strict design codes, and hence the CONCAWE findings may be regarded to be more conservative.

According to the 1998 statistical summary of reported spillages by the CONCAWE Oil Pipeline Management group, there were nine incidents recorded in which reportable spillages occurred. In total, 680 million m^3 of crude oil and refined products were transported through the pipeline system, resulting in a total traffic volume of 123 00 million m^3 – km. The occurrence of these spillages amount to approximately 0.29 spills per year per 1 000 km. There were no associated fires or injuries reported.

In the preceding report, covering a period over 25-years, CONCAWE (Lyons, 1998) reported three incidents, between 1971 and 1996, which resulted in fatal injuries. A total of 12 fatalities resulted after being caught up in fires following the spillage. In all of these cases the ignition was a delayed event, hours or days after the detection and demarcation of the spillage area had taken place.

Comparing the results for 1998 with the 25-year performance statistics, significant progress on pipeline spillage performance in the oil industry was illustrated. Figure 5-2 demonstrates the reduction of the spillage frequency per unit length of pipeline over the time. The figure shows the overall frequency trend, broken down into the major cause categories and projected as pipeline spills per 1 000 km by year. The frequency of spillages has been progressively reduced from about 1.2 per year per 1 000 km to about 0.4 over the 25 years, resulting in a reduction of approximately two thirds of what it started out in 1970. As a further comparison, the spillage occurrence in 1998 amount to approximately 0.29 spills per year per 1 000 km.

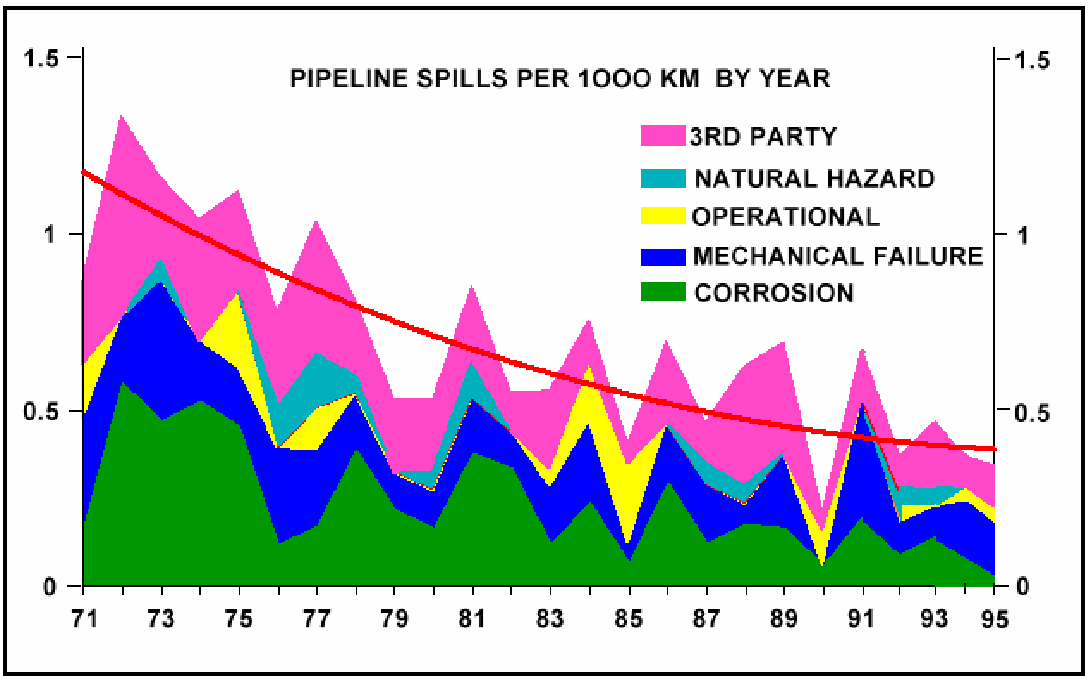

Figure 5-2: Oil spillage frequency trend by major cause category (Lyons, 1998)

The causes of spills were grouped into one of five categories and summarised in Figure 5-3.

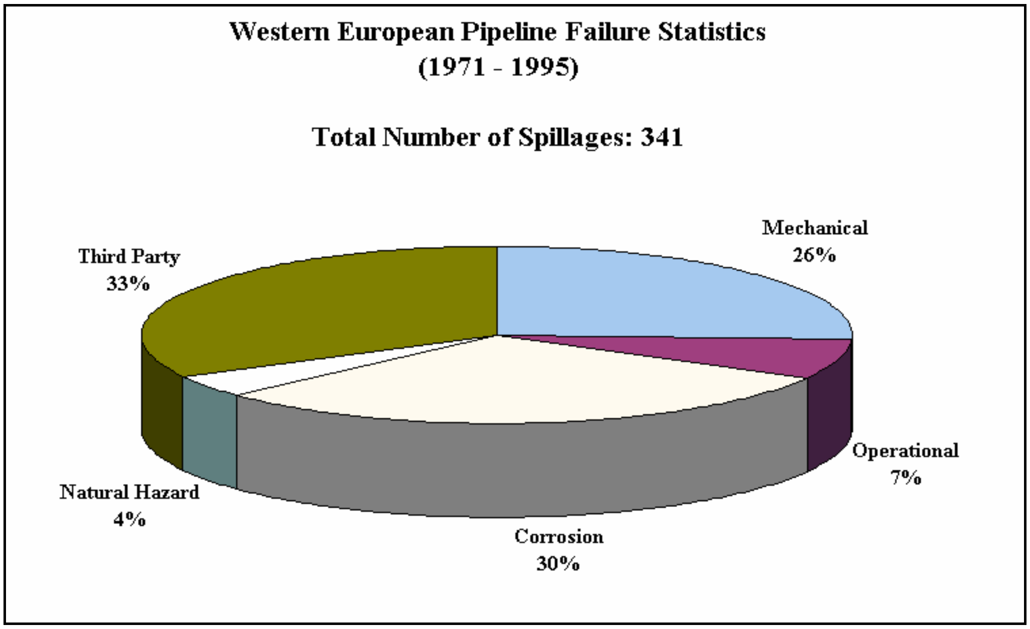

Figure 5-3: Oil spillage frequency by major cause category (Lyons, 1998)

Most studies of pipeline failures have identified a range of possible hole sizes. It is typical to categorise these sizes into *Small Leaks*, *Significant Leaks*, *Large Leaks* and *Full Bore Ruptures*. Small leaks are normally due to corrosion, and have a nominal hole diameter of 6 mm and less. Significant leaks would typically result from excavation work. A nominal size of 12 mm represents the lower end and, 50 mm the upper end of such leaks. Catastrophic pipe failures are considered as full bore ruptures. Table 12.1 is a summary of release frequencies as estimated from the data compiled by CONCAWE.

Table *5-1*: Oil spillage frequencies (per million km-years) determined from European experience (CONCAWE 1998).

CAUSE	SMALL LEAK	SIGNIFICANT LEAK	RUPTURE
Third Party	32.0	79.9	22.8
Mechanical Failure	111.2	47.7	8.0
Corrosion	81.8	1.6	0
Other	35.3	8.1	1.5
TOTAL	260.3	137.3	32.3

The CONCAWE study also found a direct relationship between pipeline diameter and spillage occurrence - smaller pipeline diameters were found to be strongly correlated to higher vulnerability (Figure 5-4).

Pipe sizes below 8” are approximately 2.5 times more vulnerable than the average, whilst pipes larger than 30” sustained only about one tenth of the average frequency of incidents. Unfortunately, inadequate data prevented an estimate of the risk reduction by deeper coverage - it is not recorded if larger pipelines have greater coverage than small ones.

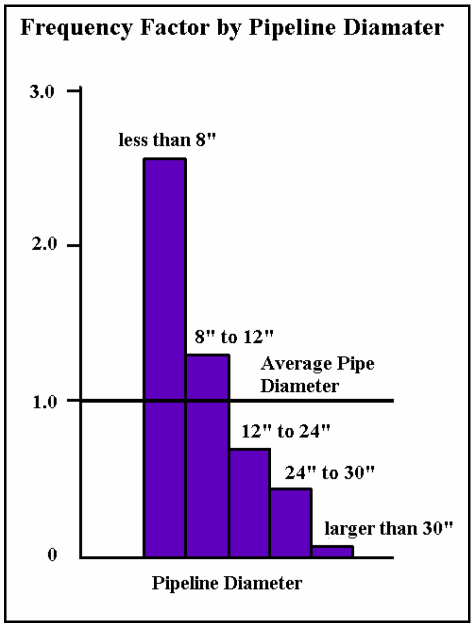

Figure *5-4*: Third party accidental spillages: measure of the vulnerability as a function of pipeline size (Lyons, 1998).

The European Gas Pipeline Incident Group (EGIG) collects incidents with gas releases from high-pressure, on-shore natural gas pipelines, meeting the following criteria:

- Steel pipelines;
- Design pressure greater than 15 bar;
- Outside fences of installations; and,
- Excluding associated equipment (e.g. valves, compressors) or parts other than the pipeline itself.

Considering the number of participants, the extent of the pipeline systems and the exposure period involved (from 1970 onwards for most of the companies), the EGIG database is a valuable and reliable source of information. The total length of the pipeline system of all the participating companies in the 1970 to 1998 period is 2.09 million kilometres-years.

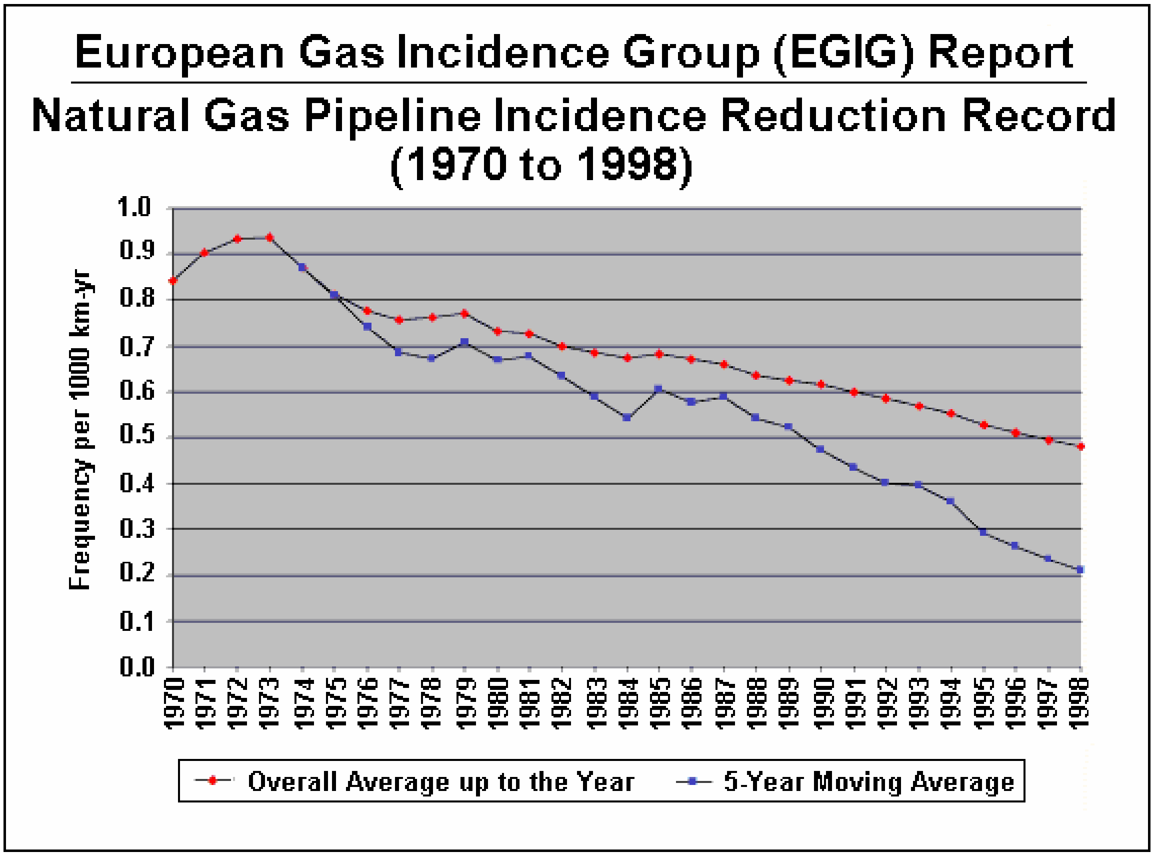

Figure 5-5 Natural gas incident frequency reduction trend from 1970 to 1998 (EGIG, 2000).

Figure 5-6 is a summary of the incident data for this period. An analysis of the most recent EGIG findings led to the following results:

- Over the period 1970 - 1998 there has been no fatal accident involving inhabitants. The overall incident frequency with an unintentional gas release over the period 1970 to 1998 is 480 incidents per year per million km pipeline years. However, the value over the past 5 years is significantly lower, i.e. 211 incidents per year per million km pipeline years. (An overview of the development of the safety performance over the years is given in Figure 5-5);
- External interference remains the main cause of gas pipeline incidents involving gas leakage. An average of 239 incidents per year per million km pipeline years was recorded for the period 1970 to 1998. However, an improvement in the incident frequency has been observed in more recent years: over the past 5 years the figure is 87 incidents per year per million km pipeline years;
- For the incident causes 'corrosion' and 'construction defects/material failures' no ageing could be demonstrated;
- There is a trend to use larger diameter pipelines in combination with a higher grade of material;

- A greater depth of cover significantly reduces the frequency for failures caused by third parties; and,
- In only a small minority of the incidents did the leak lead to ignition (3.8% average).

The distribution of the incident causes and type of leak for the period 1970 to 1996 is given Figure 5-6. A similar breakdown is also given in Table 5-2. However, this information reflects a relatively pessimistic picture when taking cognisance of the incident trend shown in Figure 5-6. The overall incident frequency in the table is about 480 incidents per million km pipeline years, compared to the most recent, 5-year moving average of 211 incidents per year per million km pipeline years (
Table *5-3*).

Table *5-2* Natural gas incident frequencies (per million km-years), as provided by the European Gas Incident Group for the period 1970 to 1998 (EGIG 2000).

Cause	Pinhole	Hole	Rupture
External Interference	60.3	127.2	51.5
Construction Defect/Material Failure	56.6	23.0	6.4
Corrosion	70.0	0.0	1.7
Ground Movements	7.7	8.9	12.1
Hot-Tap Made by Error	18.0	5.9	0.0
Other	28.2	0.5	0.0
TOTAL	**240.8**	**165.5**	**71.8**

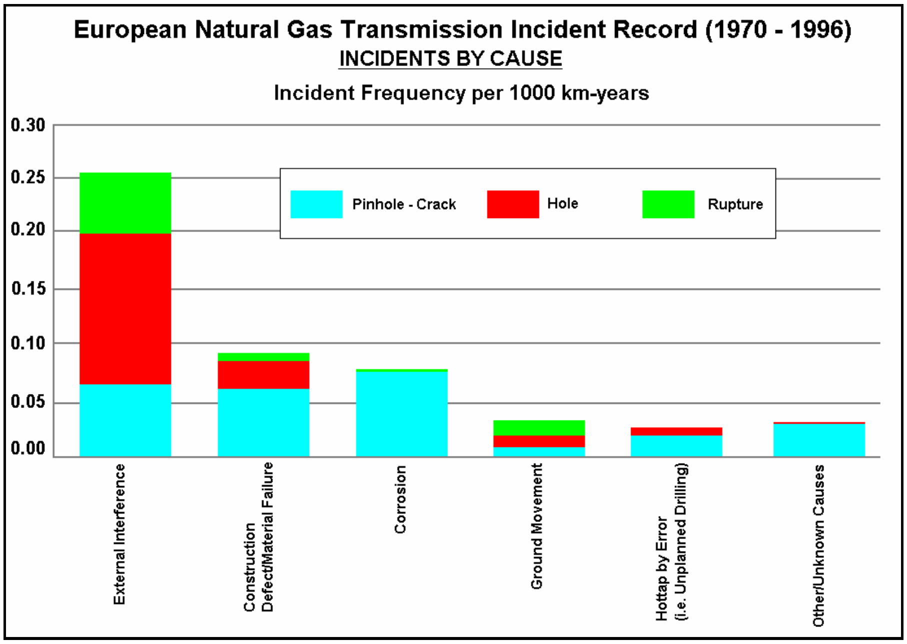

Figure 5-6 Natural gas incident frequency by major cause category (EGIG, 1998).

Table *5-3* Natural gas incident frequencies (per million km-years), as provided by the European Gas Incident Group for the period 1994 to 1998 (EGIG 2000).

Cause	Pinhole	Hole	Rupture
External Interference	22.1	46.6	18.9
Construction Defect/Material Failure	21.2	8.6	2.4
Corrosion	35.0	0.0	0.9
Ground Movements	5.1	5.9	8.1
Hot-Tap Made by Error	11.7	3.8	0.0
Other	23.1	0.4	0.0
TOTAL	**118.2**	**65.4**	**30.2**

From either of these tables, it can be concluded that third party damage has a higher probability of producing a significant leak than for a pinhole crack or a rupture. The most dangerous activities are digging the ground by excavators (42%) followed by ground works carried by drainage machines and ploughs (9%) and public works using bulldozers and shovels (8%).

The EGIG database also indicates a significant reduction in incidents with increasing diameter. The frequency of incidents caused by external (third party) interference for pipe diameters larger than 30" is approximately 15 per million km-years – representing about 5.8 % of the total given in Table 5-2 – and approximately per million km-years for pipelines 24 to 28". Although there is no direct relationship between external interference and pipeline diameters, the main factors that may influence the relationship are:

Smaller diameter pipelines are more exposed to external interference;

Smaller diameter pipelines can easily be hooked up during ground works;

Small diameter pipelines have, in general, less wall thickness than large diameter pipelines; and,

Small diameter pipelines have, in general, a lower grade of material than large diameter pipelines.

As expected, a greater depth of cover will reduce the occurrence of external interference faults. Approximately a 40% reduction in incidents can be achieved when the pipeline is at 1 m or deeper.

Similar statistical results were obtained in the USA. The data for buried, natural gas pipelines in the USA include a distance of approximately 200 000 km, over an operation period of 14 years (1970 to 1984). The USA pipeline failure frequency is estimated to be 568 per million-km years. This is similar to the value produced from the 1970-1984 EGIG data, i.e. 522 per million km-years (all incidents). The data for 1984 to 2000 indicated a lower failure frequency of about 41 per million km-years, which is similar to the latest EGIG, 5-year moving average of 211 incidents per year per million-km pipeline years (all incidents).

Bartenev *et al* (1996) determined the frequency of leaks from natural gas pipelines by a comprehensive review of incident statistics for Australasia. Most of the cross-country pipelines are installed to a minimum standard depth of 750 mm. The review indicated the following spillages during the equivalent of over 221 600 pipeline-years:

1 failure due to land subsidence (Natural Hazard);
1 pinhole leak due to weld fault (Mechanical Failure);
1 pinhole leak due to corrosion (Corrosion Failure);
3 failures due to excavation (Third Party);
1 failure due to stress corrosion cracking (Corrosion Failure);
1 incident due to land movement (Natural Hazard);
Various incidental small leaks at fittings (Mechanical Failure); and,
Small leaks due to corrosion (Corrosion Failure).

If the minor pinhole leaks are ignored, since it will have inconsequential impact, the frequency of serious leaks was estimated at 22.5 per million km-years (i.e. five significant leaks in 221 600-pipeline km-years). Alternatively, if the combined proportion of pinhole leaks was taken to be roughly equivalent to the sum of the other, more substantial leaks, the frequency become 45 per million km-years. The New South Wales Department of Urban Affairs and Planning (NSW 1996) sited the same order of magnitude, namely 31.6 per million km-years (or 64 per million km-years, when smaller leaks are included).

The apportionment for the failures of different hole sizes is as follows:

50% may be represented by minor holes of size 6 mm;
30% may be represented by significant holes of size 12 mm;
15% may be represented by a large hole of 50 mm; and,
5% may be represented by a full-bore rupture.