E N V I R O N M E N T P R O T E C T I O N A U T H O R I T Y

Air Quality Monitoring for Sulphur Dioxide in Metropolitan Adelaide




Government of South Australia

EPA South Australia

AIR

Air Quality Monitoring for Sulfur Dioxide in Metropolitan Adelaide

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Definitions and abbreviations

Air NEPM	Ambient Air Quality National Environment Protection Measure
ambient air	the external air environment; does not include the air environment inside buildings or structures
EPA	Environment Protection Authority
EPHC	Environment Protection Heritage Council (now incorporates the NEPC)
DEH	Department for Environment and Heritage
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NO	nitric oxide
percentile	for example, the 98th percentile means 98% of the data are less than or equal to the given value
PMS	performance monitoring station
ppm	parts per million by volume
ppb	parts per billion by volume
PULP	Premium Unleaded Petrol
SO_2	sulfur dioxide
WHO	World Health Organization

SUMMARY

This report presents the available data for sulfur dioxide (SO_2) concentrations in ambient air in metropolitan Adelaide in order to assess the levels of sulfur dioxide present and make recommendations for future monitoring.

Globally, the main emission sources for sulfur dioxide are volcanoes and fossil fuels. In Adelaide the main emission sources are motor vehicles, energy production, shipping and boating, other fuel combustion and, until recently, petroleum refining.

Sulfur dioxide is widely monitored in urban areas because it is known that exposure to the pollutant irritates the respiratory system, which can cause bronchial restrictions leading to symptoms such as coughing, wheezing or shortness of breath.

Sulfur dioxide has been measured at one site in Adelaide, Christies Beach, since 1992, to monitor the effect of emissions from the Port Stanvac oil refinery. Nearly all exceedences of the National Environment Protection Measure (NEPM) criteria at this peak site can be attributed to performance issues within the refinery's sulfur recovery plant. The refinery closed indefinitely in July 2003, and since that time ambient levels of sulfur dioxide have been negligible.

In 2002 monitoring also began at Elizabeth (in May), Kensington (in August) and Northfield (in October) in accordance with the Ambient Air Quality Monitoring Plan for South Australia, endorsed by the National Environment Protection Council (NEPC) as the State's plan to implement the Ambient Air Quality NEPM (Air NEPM). A new instrument was installed at Elizabeth, with older monitors placed at the other two sites. Subsequent installation of new monitors at Kensington and Northfield in September–October 2003 is reflected in a small shift in the baseline of the data at each site.

Ambient sulfur dioxide levels at all these sites have been low, well below the 75% and 55% of the NEPM standards for sulfur dioxide, with both old and new instruments. NEPC endorsed a series of Technical Guidance Papers to aid implementation of the Air NEPM, and paper # 4, *Screening Procedures* (NEPC 2001), lists criteria by which measurement of a pollutant in a region can be screened out. The sulfur dioxide results for the Adelaide region meet those criteria, and current levels are not likely to have an adverse impact on either human health or vegetation in metropolitan Adelaide. Unless there is a change back to high-sulphur fuel use, the sulphur dioxide concentration in Adelaide should remain near the present levels.

INTRODUCTION

Sulfur dioxide (SO_2) is a colourless, non-flammable gas with a suffocating, choking odour. It is produced naturally through geothermal activity. However, about 99% of sulfur dioxide in the atmosphere has been artificially made (DEH nd). Anthropogenic sources include fossil-fuel (predominantly coal and petroleum) refining and burning, non-ferrous smelters, iron ore smelters, pulp and paper mills, transportation sources and steel mills. Area sources include residential, industrial and commercial space heating (e.g. coal used as a fuel in a home fireplace). In general, Australian cities do not have significant sulfur dioxide pollution (DEH 2004), primarily because fuels used are low in sulfur[1] and power stations are not located in urban areas. It has been reported (Baldasano et al. 2003) that Perth (as of 1995) ranks very low in sulfur dioxide pollution in comparison to other major world cities; as Adelaide is of similar size, geography and transport fuel composition, it is expected that it, also, would not have a problem with sulfur dioxide.

Currently, the EPA monitors ambient sulfur dioxide at four sites in metropolitan Adelaide: three residential sites (Kensington, Northfield and Elizabeth) and one peak site (Christies Beach) near the Port Stanvac oil refinery. This report provides an assessment of the currently available data on ambient levels of sulfur dioxide in metropolitan Adelaide, and examines the need for future monitoring in the Adelaide airshed.

[1] While fossil fuels, generally, contain sulfur in the range 0.1–3.0%, Australian fossil fuels are low in sulfur, typically about 0.5% (<*www.epa.nsw.gov.au/soe/97/ch1/6-10.htm*>).

SOURCES, EFFECTS AND NATURE OF SULFUR DIOXIDE

Sources of sulfur dioxide in Adelaide

In metropolitan Adelaide the second largest source of sulfur dioxide (after motor vehicles) was the Port Stanvac oil refinery (Cuik 2001) at Christies Beach. This has now been decommissioned (July 2003), removing 22% of the total mass emission of sulfur dioxide in Adelaide. As of 1 January 2004 the allowable sulfur in Adelaide's diesel fuel has been reduced from 1100 ppm to 500 ppm. In 2006 this will be further reduced to 50 ppm, and the limit for sulfur in premium unleaded petrol (PULP) will drop from 150 ppm to 50 ppm. Thus the major source of sulfur dioxide in Adelaide is diminishing.

The 2002–03 emission inventory of metropolitan Adelaide (Ng 2004) estimated the annual discharge of SO_2 to be approximately 1178 tonnes from anthropogenic sources (table 1). This low result is due to the predominance of low-sulfur fuel use in this region.

Table 1 The relative contribution of sources of sulfur dioxide, 2002–03

Source	Estimated emissions (t/yr)	% of total
Motor vehicles	666.7	56.60
Gaseous fuel burning (domestic)	1.7	0.14
Liquid fuel burning (domestic)	8.0	0.70
Commercial shipping/boating	216.2	18.35
Fuel combustion (sub reporting threshold facilities)	140.3	12.00
Solid fuel burning (domestic)	45.7	3.90
Recreational boating	0.2	0.02
Aeroplanes	39.2	3.33
Railways	10.1	0.90
Lawn mowing	50.0	4.23

Source: Ng 2004

Adverse effects

Health effects

Sulfur dioxide is widely monitored in urban areas because it is known to irritate mucous membranes, including the eyes and nasal passages, and cause bronchoconstriction in sensitive individuals. This is due to its property of being readily soluble in water, forming sulfurous and sulfuric acids. Sulfuric acid in the air forms small particles around particulate matter by the process of nucleation. This leads to the formation of larger particles which, being strongly hygroscopic, bond readily to the walls of the air passages of the nose, trachea and lungs (WHO air quality guidelines (WHO 2000)). Together, sulfur dioxide and particulate matter may exert synergistic toxic effects (USEPA 1995).

Respiration is the main route of exposure that leads to noticeable health effects from air pollution in general. Many studies show a relationship between air pollution and such

symptoms as impaired lung function, cough, heightened allergic reactions, asthma, chronic bronchitis and infections of the lower respiratory tract (Brunekreef and Holgate 2002; Devalia et al. 1996; Kagawa 2002). Asthmatics, children and the elderly are especially sensitive to its effects.

The most at-risk group for adverse health effects from sulfur dioxide are individuals with asthma, chronic obstructive pulmonary disease or cardiovascular diseases. Sulfur dioxide causes bronchoconstriction, involving probably both the neural and inflammatory pathways, resulting in coughing, chest tightness and wheezing. It appears that the effects are increased during exercise.

Some health impacts of sulfur dioxide are (WHO 2000):

- lung function reduction in groups at rest after 10 minutes' exposure at 4000–5000 ppb (4–5 ppm)
- lung function reduction with heavy exercise at concentrations of 600 ppb (0.6 ppm)
- lung function reduction with moderate to heavy exercise at concentrations of 500 ppb (0.5 ppm)

These findings are by no means conclusive and a large variation is apparent in results from human studies. More recent work has focused on cardiovascular effects, and it is suggested that levels as low as 200 ppb may alter heart rate variability. How this affects the wellbeing of an individual needs further investigation.

There are clearly gaps in the knowledge on the effects of sulfur dioxide, especially in short-term (<1 hour) epidemiological exposure studies. Further, defining a threshold value has also proven problematic, especially in the context of air-pollutant mixes found in different centres.

For a more extensive discussion on the health effects of sulfur dioxide, the reader's attention is drawn to the NEPM documents available on <*www.ephc.gov.au/nepms/air/air_nepm.html*>.

Effects on the ecosystem

Emissions of sulfur dioxide can lead to the deposition of acid rain over large distances—often more than 1000 kilometres from their source. Acid rain can damage ecosystems on a regional scale. It is a major problem in the northern hemisphere, where entire forests have suffered defoliation and dieback, and lakes and watercourses have lost the ability to support life due to changing acidity and mobilisation of certain minerals. Acid rain is not a problem in Australia; however, sulfur dioxide deposition can affect vegetation around large industrial discharges unless appropriate ambient concentrations are achieved through appropriate source management.

Effects on visibility

Sulfur dioxide can form secondary particles (sulfate) that cause haze and reduce visibility due to their high light-scattering ability. These sulfate particles have a modifying effect on enhanced greenhouse warming because they reflect incoming heat from the sun.

Dispersion of sulfur dioxide in the atmosphere

Sulfur dioxide gas can be carried long distances, but its concentration reduces with time due to its reactivity with other atmospheric components. It reacts with water, nitrates, oxygen, ozone and OH radicals to produce sulfuric acid, sulfurous acid (H_2SO_3) and various sulfates, some of which fall out as particulate matter.

In general, the maximum concentration of sulfur dioxide is in the vicinity of its source; the concentration decreases rapidly as the distance from the source increases, indicating a short tropospheric lifetime of typically a few days. Clean continental air contains less than 1 ppb sulfur dioxide (Eisinger and Burrows 1998).

Sulfur dioxide standards and monitoring requirements

Sulfur dioxide standard for ambient air

There are three National Environment Protection Measure (NEPM) standards for sulfur dioxide (table 2): an annual arithmetic average, a 24-hour (daily) average and an hourly average. The NEPM standards are met if the annual arithmetic average does not exceed 0.02 ppm in each year, the daily average does not exceed 0.08 ppm, and the hourly average does not exceed 0.20 ppm, each more than once per year.

Table 2 NEPM standards for sulfur dioxide

NEPM standard	Concentration	Allowed exceedences (NEPM goal)
One-hour standard	0.20 ppm	1 per year
One-day standard	0.08 ppm	1 per year
One-year standard	0.02 ppm	none

NEPM context for sulfur dioxide monitoring

The monitoring requirement for the Adelaide airshed, in accordance with NEPM Clause 14, is calculated from

$$1.5P + 0.5$$

where P is the population in millions, which translates to two performance monitoring stations (PMS)[2]. It may be demonstrated that fewer stations are needed for a particular pollutant under the National Environment Protection Council (NEPC) Peer Review Committee screening procedures (Technical Paper No. 4 (NEPC 2001)).

Under the Air NEPM, for a trend site[3] (for five or more years of data), 'if concentrations in excess of 75% of the standard for a pollutant are probable within a region, performance monitoring should occur' and 'the acceptance limit to be used is that of the standard which is most difficult to meet' (NEPC 2001). These criteria would apply to the monitoring site at Christies Beach (operational since 1992).

For campaign sites[4], which would include Elizabeth, Northfield and Kensington, the acceptance limit is 55% of the NEPM standard for one year, or 60% for two or more years, of data collection.

[2] A performance monitoring station (PMS) measures performance against national standards and is intended to remain in place over at least five years.

[3] A trend station aims to reveal trends over a set period.

[4] A campaign monitoring site is temporary (usually 12 months), to determine if ongoing monitoring is necessary for that site.

SAMPLING LOCATIONS AND MONITORING METHODS

Monitoring sites in metropolitan Adelaide

Sulfur dioxide is currently monitored at four sites in the Adelaide metropolitan area. The station at Christies Beach has been in place since 1992, in order to monitor air quality near the Port Stanvac oil refinery, which was a primary source of this air pollutant until its indefinite closure in July 2003. Monitors were installed in May 2002 at Elizabeth, in August 2002 at Kensington and in October 2002 at Northfield, all in residential areas with no major sources in the vicinity. Monitoring sites and the major emission sources are shown in figure 1 (see appendix A2 for site information).

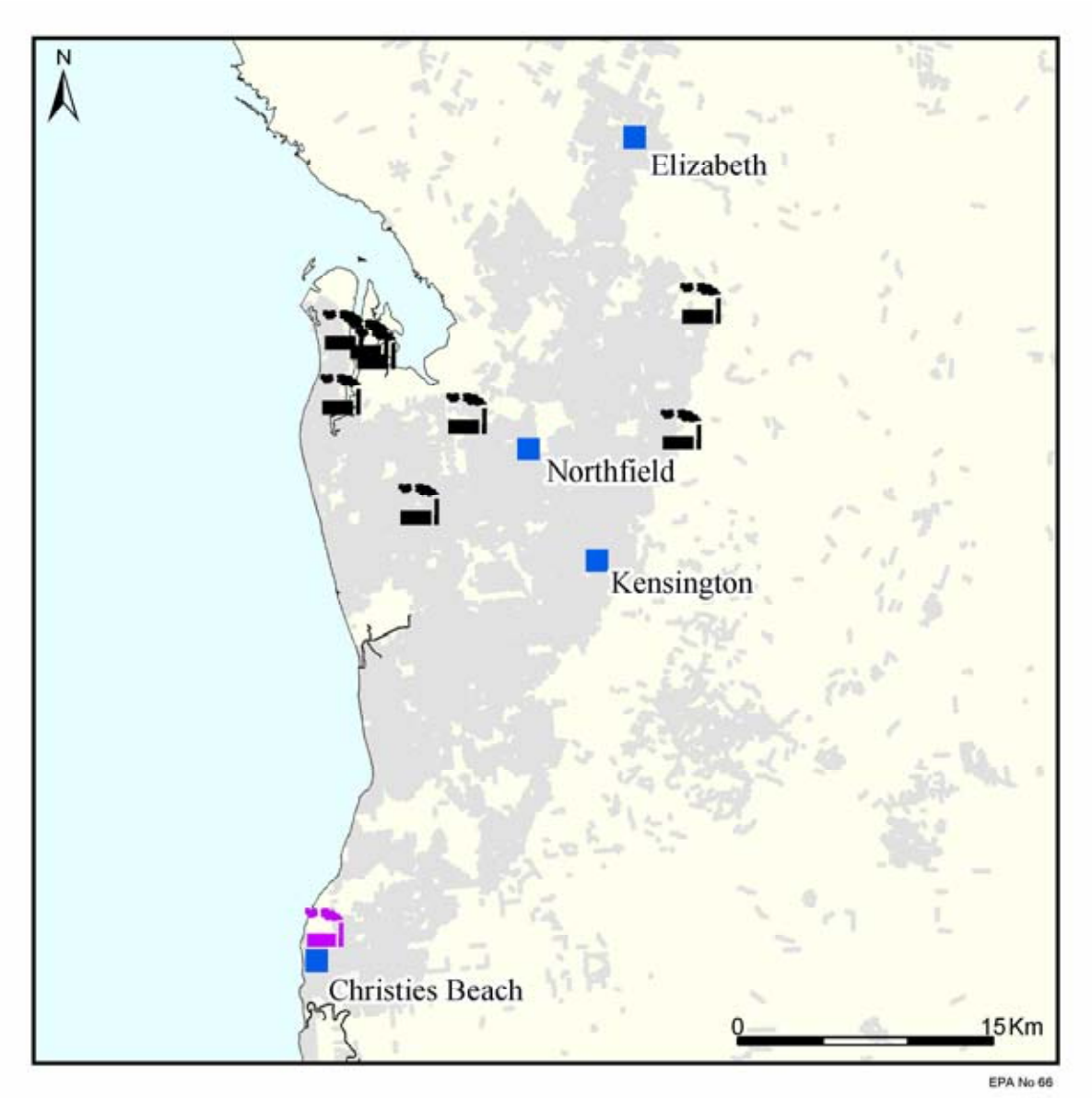

Figure 1 Location of SO_2 monitoring stations and major SO_2 emitters (EPA licensed industries that emit or have the potential to emit 1000 kg a year or more of SO_2) in metropolitan Adelaide

* Note that the refinery at Christies Beach is now closed.

Monitoring methods

Monitor type

In accordance with Schedule 3 of the Ambient Air Quality NEPM (Air NEPM) (NEPC 1998), the four sites in Adelaide use the direct reading instrumental method for monitoring sulfur dioxide, as outlined in AS3580.4.1-1990. The older units use pulsed UV fluorescence and the newer units continuous fluorescence (see appendix A3 for current monitoring specifications).

Measurement principle

Sulfur dioxide measurements are made by excitation of the SO_2 molecule in the presence of ultraviolet light, with a typical wavelength of 214 nm. When the molecule reverts to its normal energy state, light is emitted at a wavelength of 300–390 nm, in proportion with the sulfur dioxide concentration. A photomultiplier captures the photons, with the energy level being directly proportional to the sulfur dioxide concentration. A band pass filter on the photomultiplier reduces interference from nitric oxide (NO).

RESULTS AND DISCUSSION

Ambient sulfur dioxide measurements at the four sites in metropolitan Adelaide indicate that the NEPM one-hour standard has been exceeded only once since 1997, at the peak site at Christies Beach. Overall, ambient sulfur dioxide concentrations are negligible in the Adelaide airshed (DEH 2004).

It should be noted that, as the measured values for sulfur dioxide are so low, only some of the plots are on a scale that would allow comparison of measurements with the NEPM standards. The precision of the monitoring instrument is about ± 0.0005 ppm, indicating that no directly measured concentrations may be reported to more than four decimal places and must be taken as no more precise than ± 0.0005 ppm. All uncertainties in this report are the standard deviation of the data set.

Christies Beach

Sulfur dioxide has been monitored at Christies Beach since 1992 to help assess the impact of the Port Stanvac oil refinery. A new detection instrument was installed on 4 December 1999.

At Christies Beach in 2003, hourly averages of sulfur dioxide were within the range 0–0.059 ppm (table 3), with an average for the year of < 0.001 ppm. There were no exceedences of the NEPM standard (0.20 ppm as an hourly average) recorded in 2003, or to the end of April in 2004. Similarly, no exceedences have been measured for either the one-day (0.08 ppm) or one-year (0.02 ppm) NEPM criteria (figures 2, 3 and 4). The exceedences observed in 1996 and 2002 (table 3) were directly attributed to plant failure at the refinery and, specifically, to the sulfur recovery plant failures in 1996 and 2002. The maximum concentration recorded in 2003 (0.059 ppm, 74% lower than the previous year), may be attributed to the technological controls (e.g. successful operation of the sulfur recovery plant to reduce SO_2 emissions) by the industry.

According to the Peer Review Committee (PRC) screening procedure (NEPC 2001), the data for a long-term site should be less than 75% of the standard for five or more years. At Christies Beach the data from 1999 to 2003 has been consistently less than 0.15 ppm for hourly averages (75% of 0.20 ppm), with only one exceedence of this in 2002, when the sulfur recovery plant failed. The 99th percentile in 2002 was 0.049 ppm, which is 24.5% of the one-hour NEPM standard, and the maximum of 0.059 ppm in 2003 is 29.5%. The maximum so far in 2004 is 0.010 ppm (table 3, figures 4 and 5), which is 5% of the standard. As the oil refinery is no longer in operation, and levels of sulfur dioxide since that time have been negligible, it is expected that these criteria will continue to be met for the foreseeable future.

Table 3 Sulfur dioxide statistics at Christies Beach 1992–April 2004

Year	Number of exceedences of one-hour NEPM criterion for SO_2 (0.20 ppm)	Maximum concentration (ppm)	90th percentile (ppm)	99th percentile (ppm)	Data recovery (%)
1992	0	0.188	0.003	0.053	97
1993	7	0.319	0.002	0.038	96
1994	0	0.187	0.002	0.060	97
1995	8	0.349	0.002	0.065	98
1996	12	0.479	0.003	0.053	88
1997	0	0.134	0.002	0.033	75
1998	0	0.105	0.005	0.018	97
1999	0	0.076	0.003	0.024	86
2000	0	0.057	0.003	0.014	30*
2001	0	0.098	0.000	0.014	51*
2002	1	0.225	0.003	0.049	62
2003	0	0.059	0.001	0.006	84
2004	0	0.010	0.0003	0.004	29*

- Note that data was available for only part of these years.

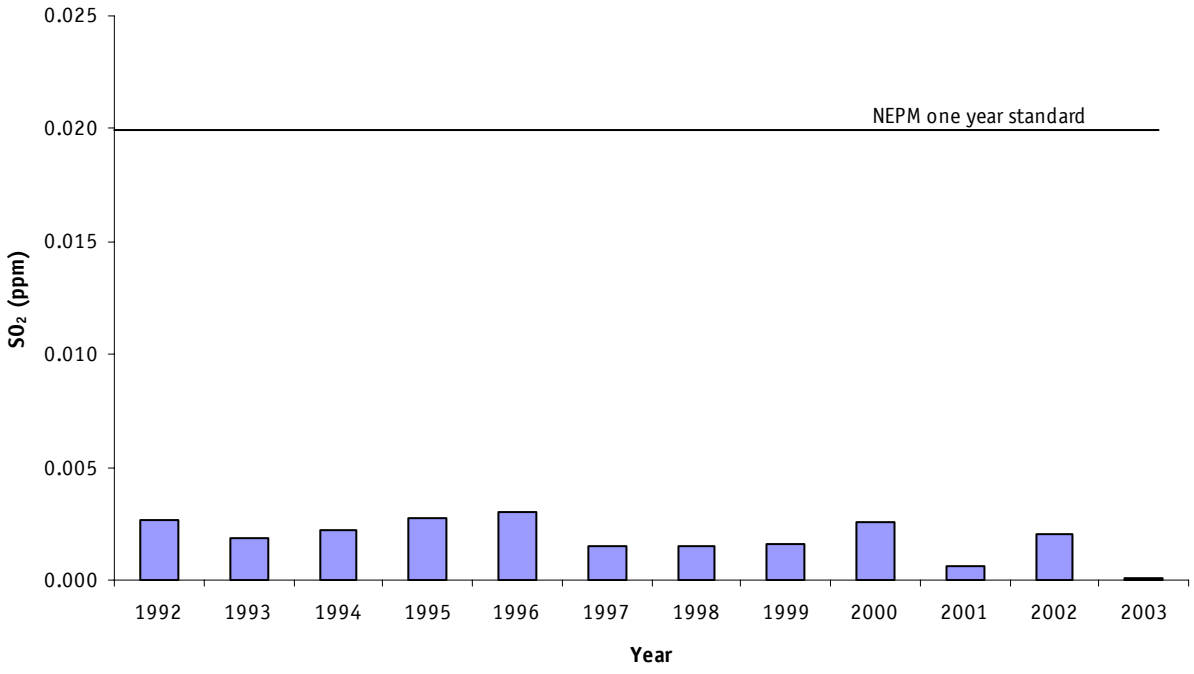

Figure 2 Sulfur dioxide in air at Christies Beach—annual hourly averages 1992–2003

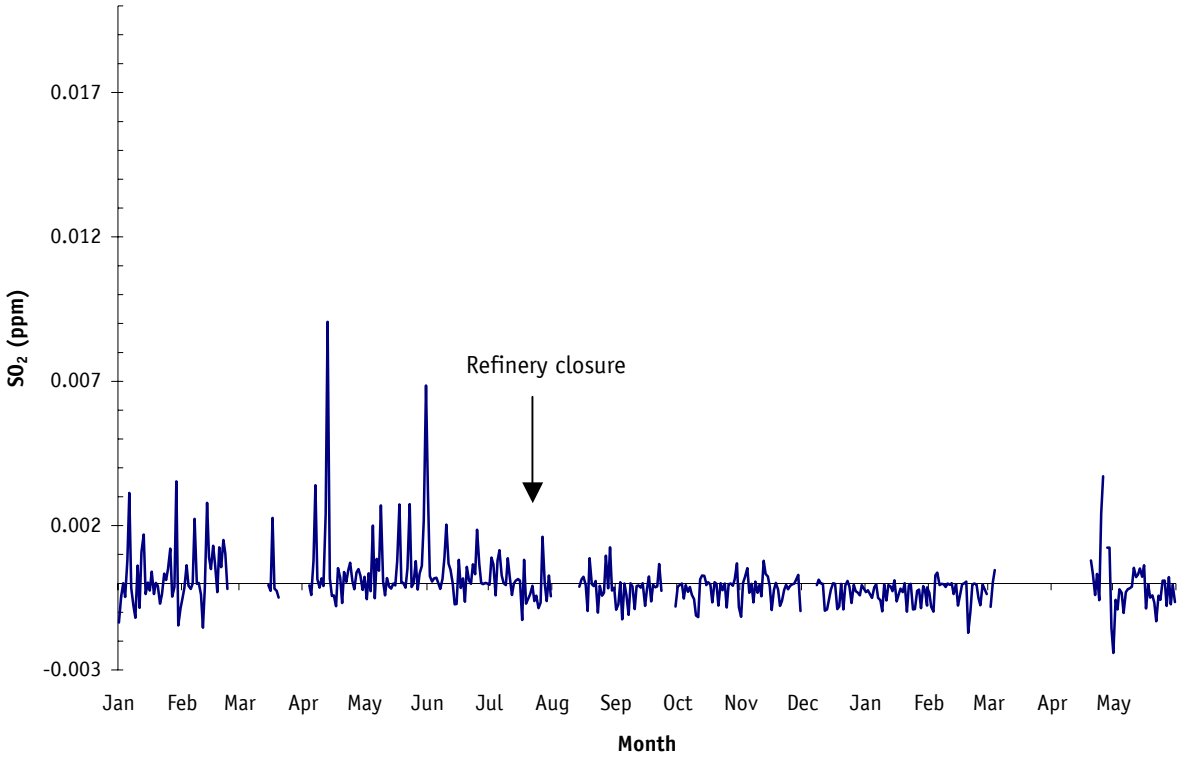

Figure 3 Daily averaged data for Christies Beach 2003–04

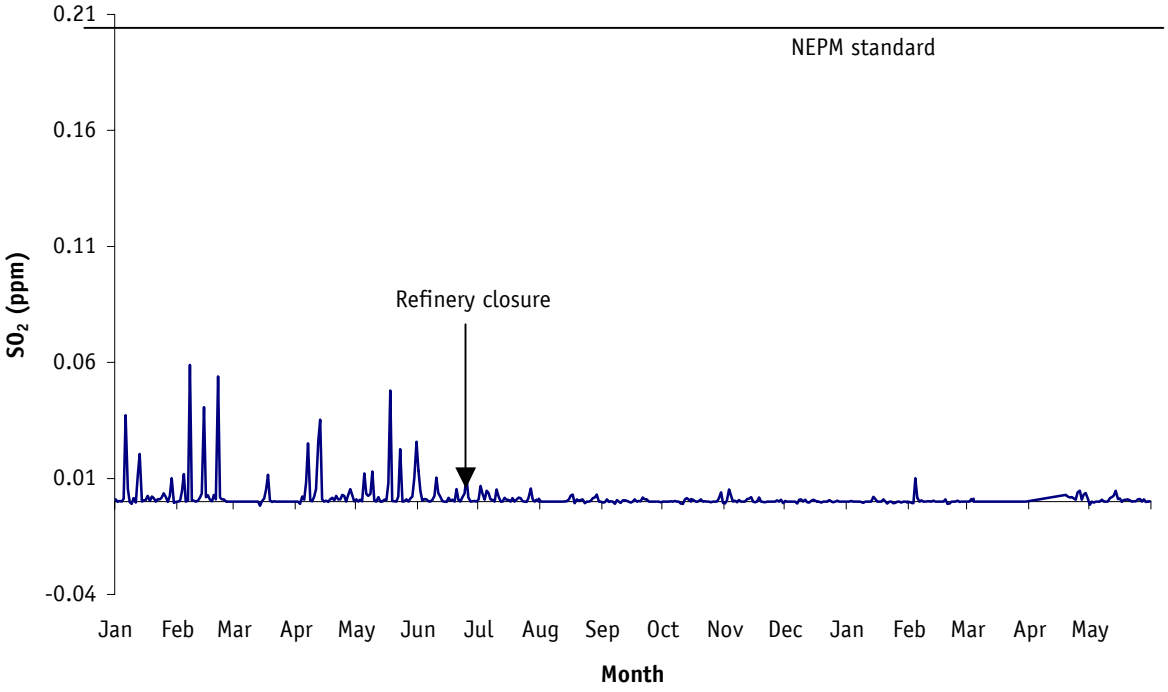

Figure 4 Daily maximum one-hour data for Christies Beach 2003–04

Elizabeth

At Elizabeth, from May to December 2002, hourly averages of sulfur dioxide were within the range 0–0.013 ppm, with an average for the year (from May) of 0.002 ± 0.001 ppm (table 4). There were no exceedences of the NEPM one-hour standard of 0.20 ppm and thus no exceedences of either the one-day (0.08 ppm) or one-year (0.02 ppm) NEPM criteria for that period (figures 5 and 6). There were also no exceedences in 2003, when the annual average was 0.0008 ± 0.001 ppm. New instruments were used at this site from the time of installation, with a routine changeover of instruments on 6 December 2002. The unit was removed in April 2004.

Table 4 Sulfur dioxide statistics at Elizabeth May 2002–March 2004

Year	Number of exceedences of one-hour NEPM criterion for SO_2 (0.20 ppm)	Maximum concentration (ppm)	90th percentile (ppm)	99th percentile (ppm)	Data recovery (%)
2002	0	0.013	0.004	0.006	48
2003	0	0.032	0.002	0.004	96
2004	0	0.008	0.003	0.004	24

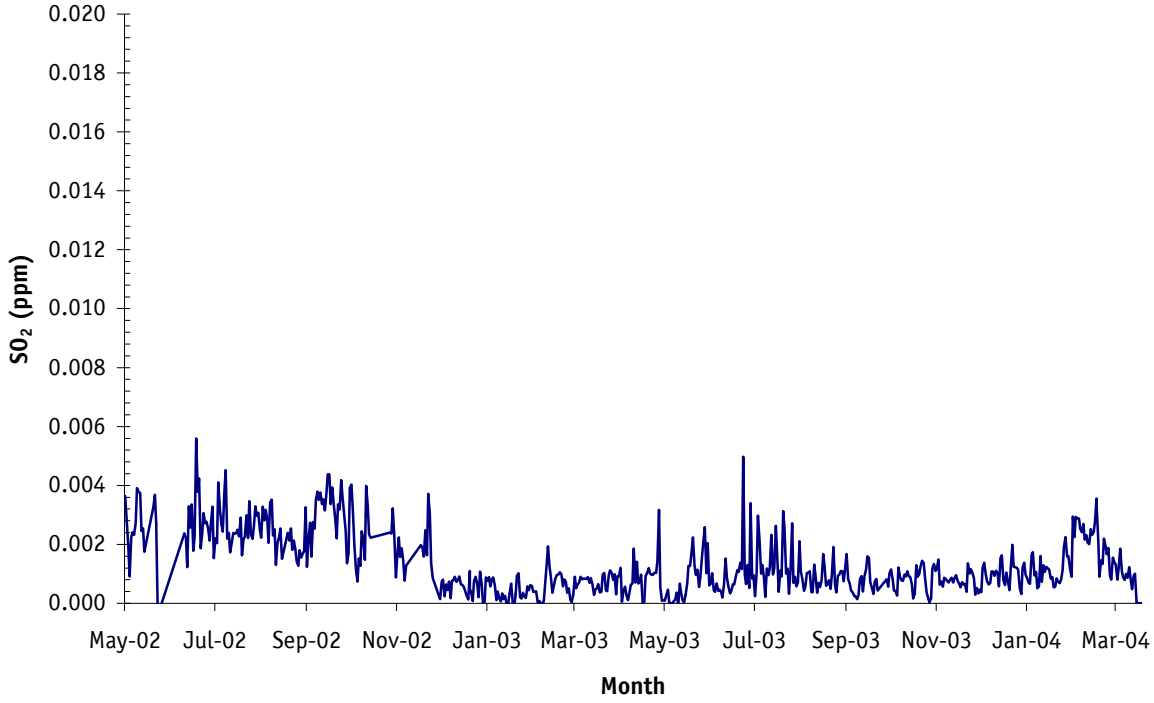

Figure 5 Daily averaged data for Elizabeth 2002–04

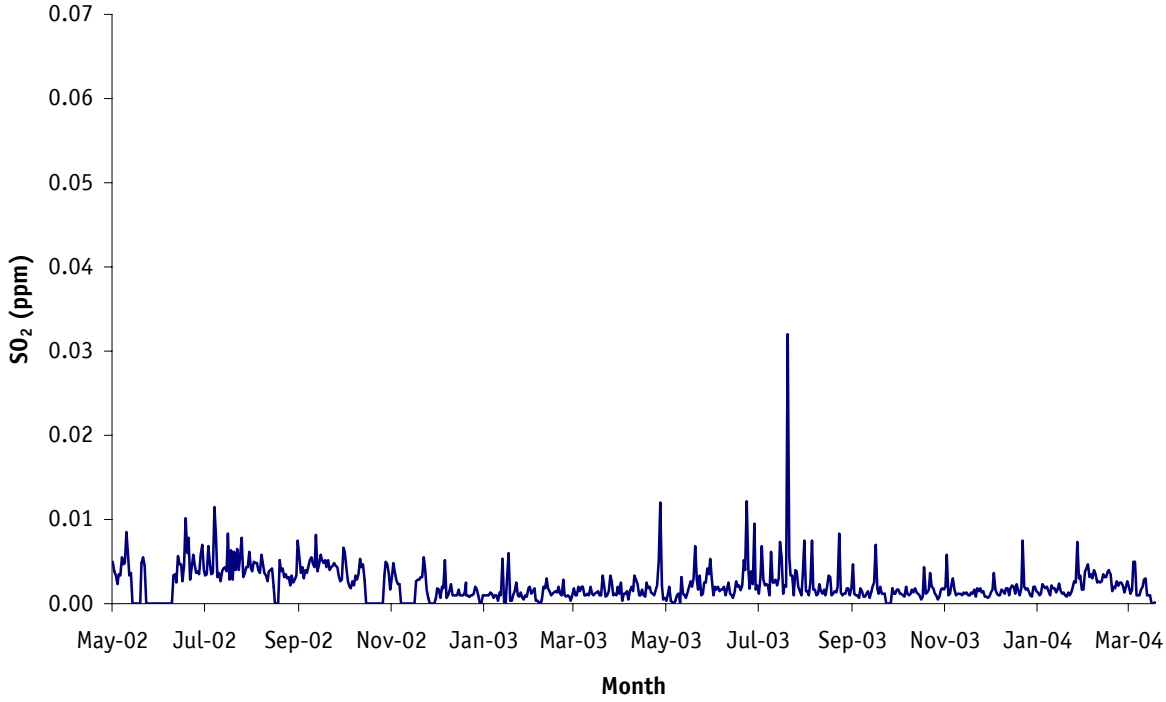

Figure 6 Daily maximum one-hour data for Elizabeth 2002–04

Northfield

Hourly averages of sulfur dioxide at Northfield from October to December 2002 were within the range 0–0.039 ppm (table 5), with an average for the period of 0.002 ± 0.004 ppm. There were no exceedences of either the one-hour NEPM criterion (0.20 ppm) or the one-day NEPM criterion (0.08 ppm) for that period (figures 7 and 8). There were also no exceedences in 2003, with the average over the year being <0.001 ppm. A new instrument was installed at Northfield in late September 2003, accounting for the change in the baseline of the data. The average to the end of April 2004 was <0.001 ppm.

For a campaign site, the acceptance limits for the PRC screening procedure (NEPC 2001) are 55% of the NEPM one-hour standard for one year, or 60% for two or more years, of data collection.

At Northfield there is only one complete year of data, that of 2003. The maximum hourly concentration for the year was 0.009 ppm, which is 0.045%* of the NEPM one-hour standard (i.e. 0.20 ppm), substantially less than 55% of the standard. Thus the station at Northfield meets the screening criteria.

Table 5 Sulfur dioxide statistics at Northfield October 2002–April 2004

Year	Number of exceedences of one-hour NEPM criterion for SO_2 (0.20 ppm)	Maximum concentration (ppm)	90th percentile (ppm)	99th percentile (ppm)	Data recovery (%)
2002	0	0.039	0.005	0.024	16
2003	0	0.009	0.002	0.004	95
2004	0	0.008	0.001	0.002	29

***Erratum: correct figure is '4.5%'**

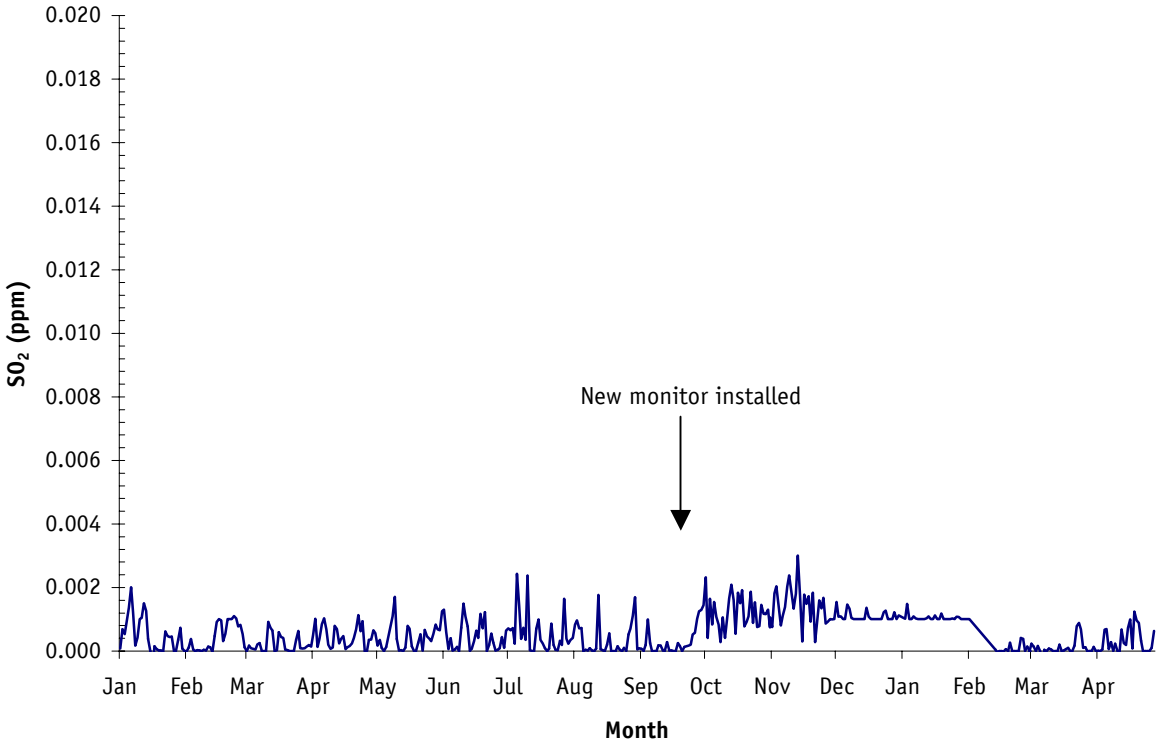

Figure 7 Daily averaged data for Northfield 2003–04

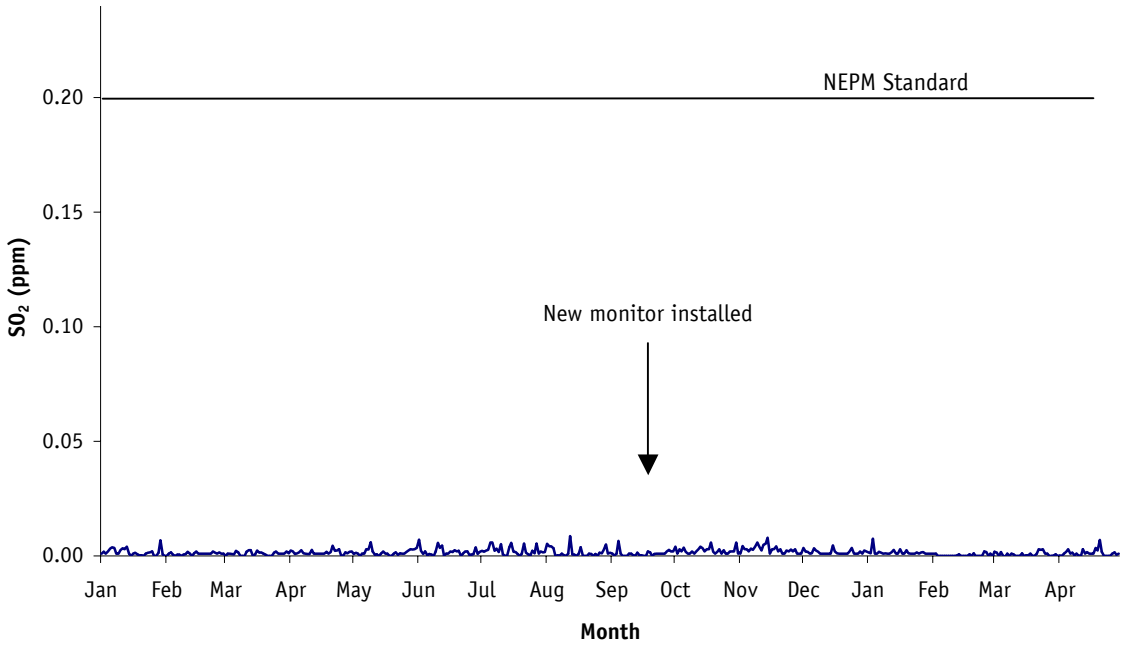

Figure 8 Daily maximum one-hour data for Northfield 2003–04

Kensington

Hourly averages of sulfur dioxide at Kensington from August 2002 were within the range 0–0.019 ppm (table 6), with an average for the period of 0.003 ± 0.002 ppm. There were no exceedences of the one-hour NEPM criterion (0.20 ppm) or the one-day NEPM criterion (0.08 ppm) for that period. The hourly annual average for 2003 was 0.002 ± 0.003 ppm. A new instrument was installed at Kensington in late September 2003, replacing one that was several decades old. The relatively high readings before this date can be attributed to noise (± 0.015 ppm), an increased detection limit (should be ~0.001 ppm, but changes with age of the instrument) and zero drift. It can be seen in figure 9 that, even before replacement with an updated monitor, the monitored levels of sulfur dioxide were well below the NEPM standard.

Kensington is classed as a campaign site. The acceptance limits for the PRC screening procedure (NEPC 2001) are 55% of the NEPM one-hour standard for one year, or 60% for two or more years, of data collection.

At Kensington there is only one complete year of data, that of 2003. The maximum hourly concentration for the year was 0.045 ppm, which is 0.225%* of the NEPM one-hour standard of 0.20 ppm and substantially less than 55% of the standard. Thus the station at Kensington also meets the screening criteria for a campaign site.

Table 6 Sulfur dioxide statistics at Kensington August 2002–April 2004

Year	Number of exceedences of one-hour NEPM criterion for SO_2 (0.20 ppm)	Maximum concentration (ppm)	90th percentile (ppm)	99th percentile (ppm)	Data recovery (%)
2002	0	0.019	0.005	0.007	37
2003	0	0.045	0.005	0.014	87
2004	0	0.009	0.0002	0.002	31

***Erratum: correct figure is 22.5%**

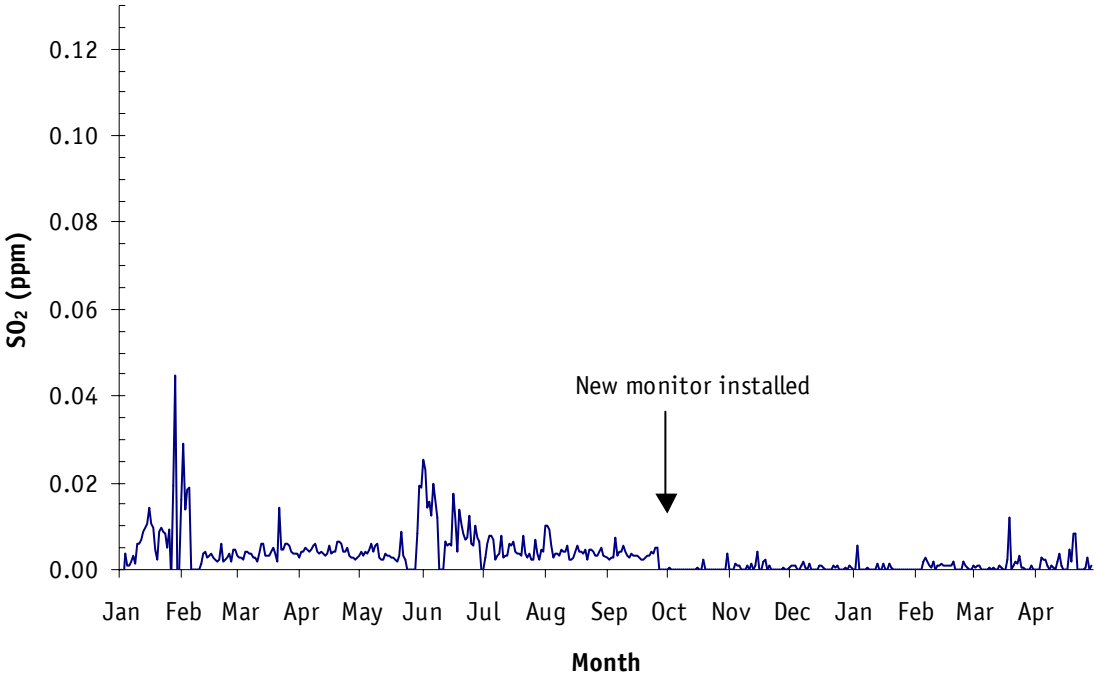

Figure 9 Daily maximum one-hour data for Kensington 2003–04

CONCLUSIONS

Sulfur dioxide levels detected in metropolitan Adelaide are very low, well below 75% (for trend sites) and 55% (for campaign sites) of the NEPM standards of 0.20 ppm over one hour, 0.08 ppm over one day and 0.02 ppm over one year. Even with old equipment, which incorporates a large 'noise' component, levels were still very low.

The average for the metropolitan Adelaide area in 2003 was 0.001 ± 0.0008 ppm. The maxima in Adelaide in 2004 were 0.010 ppm at Christies Beach, 0.008 ppm at Elizabeth, 0.008 ppm at Northfield and 0.009 ppm at Kensington. These figures are well below the required 75% and 55% of the standards and, in accordance with the screening procedure, monitoring may no longer be required at all sites.

The current sulfur dioxide levels are not likely to have an adverse impact on either human health or vegetation in the metropolitan Adelaide region. Measured concentrations are lower than those found to cause symptoms in most people (i.e. lung function reduction with heavy exercise at concentrations of 600 ppb) (WHO 2000). Unless there is an extremely unlikely change back to high-sulfur fuel use, the ambient sulfur dioxide concentration in the Adelaide region should remain near the present low levels until 2006, and then reduce even further with 10-fold decreases due to occur in vehicle-fuel sulfur levels.

BIBLIOGRAPHY

Baldasano, JM, Valera, E and Jiménez, P 2003, Air quality data from large cities, *The Science of the Total Environment*, 307, 141–165.

Brunekreef, B and Holgate, ST 2002, Air pollution and health, *The Lancet*, 360, 1233–1242.

Cuik, J 2001, *National pollutant inventory, aggregate air emissions study, 1998/1999*, Summary report, Adelaide and regional airsheds, South Australian Environment Protection Agency, Adelaide.

DEH 2004, *State of the air: National ambient air quality status and trends report, 1991-2001,* ISBN 0 642 54990 7, Department of the Environment and Heritage, Canberra.

ECOTECH 1999, ML®9850B Sulfur Dioxide Analyzer Operation Manual.

DEH nd, *Fact sheet – Sulfur dioxide,* Department of the Environment and Heritage, <*www.deh.gov.au/atmosphere/airquality/sulfurdioxide.html*>.

Devalia, JL, Rusznak, C, Wang, J, Khair, OA, Abdelaziz, MM, Calderón, MA and Davies, RJ 1996, Air pollutants and respiratory hypersensitivity, *Toxicology Letters*, 86, 169–176.

Eisinger, M and Burrows, JP 1998, Tropospheric SO_2 observed by the ERS-2 GOME Instrument, *Geophysical Research Letters*, 25(22), 4177–4180.

Kagawa, J 2002, Health effects of diesel exhaust emissions—a mixture of air pollutants of worldwide concern, *Toxicology*, 181–182, 349–353.

NEPC 1998, *Ambient air quality, National Environment Protection Measure for Ambient Air Quality,* National Environment Protection Council.

NEPC 2001, *Screening procedures, National Environment Protection (Ambient Air Quality) Measure*, Technical Paper No. 4, National Environment Protection Council, Peer Review Committee.

Ng, LY 2004, Update of South Australian aggregated emissions data, prepared by EPA Victoria for Environment Protection Authority of South Australia.

Tropospheric Emission Monitoring Internet Service (TEMIS) 2004, *Sulfur dioxide (SO_2) introduction,* <*www.temis.nl/products/so2.html*>.

USEPA 1995, *National air quality and emissions trends report 1994,* EPA 454/R-95-014, Office of air quality planning and standards, United States Environment Protection Authority, Research Triangle Park, North Carolina 27711.

Website nd, *Microscale gas chemistry: Sulfur dioxide information,* Creighton University, Omaha, Nebraska 68178 USA <*mattson.creighton.edu/SO2/SO2_Info.html*>.

Website nd, *Sulfur dioxide [SO_2] – properties, purity and packaging,* CFC Startec <*www.c-f-c.com/specgas_products/so2.htm*>.

WHO 2000, *Air quality guidelines for Europe (2nd edition)*, European Series No. 91. Chapter 7.4, Sulfur dioxide, <*www.euro.who.int/air/Activities/20020620_1*>.

APPENDIX A1

Data summary

Table A1.1 Frequency distribution data for all sites

Site	Averaging period	Frequency distribution (percentiles)								
		MIN	10	30	50	70	90	99	MAX	Data available (%)
Christies Beach	1 hr	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.006	0.059	84
	24 hr	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.003	0.009	84
Elizabeth	1 hr	<0.001	<0.001	<0.001	<0.001	0.001	0.002	0.004	0.032	96
	24 hr	0.001	<0.001	<0.001	<0.001	0.001	0.001	0.003	0.005	98
Northfield	1 hr	<0.001	<0.001	<0.001	<0.001	0.001	0.002	0.004	0.009	95
	24 hr	<0.001	<0.001	<0.001	<0.001	0.001	0.002	0.002	0.003	99
Kensington	1 hr	<0.001	<0.001	<0.001	0.002	0.003	0.005	0.014	0.045	87
	24 hr	<0.001	<0.001	<0.001	0.002	0.003	0.005	0.010	0.016	91

Table A1.2 Monthly averages for all sites, 2003

Site	Monthly means (ppm)												Annual mean	Standard deviation
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Christies Beach	0.0001	0.0004	>0.0001	0.0006	0.001	0.0004	>0.0001	>0.0001	-0.0003	-0.0002	-0.0002	-0.0003	0.0001	0.002
Elizabeth	0.0004	0.0005	0.001	0.0007	0.0006	0.001	0.001	0.001	0.0008	0.0008	0.0008	0.0009	0.0008	0.001
Northfield	0.0005	0.0004	0.0002	0.0005	0.0004	0.0005	0.0006	0.0003	0.0003	0.001	0.001	0.001	0.0006	0.001
Kensington	0.003	0.003	0.002	0.003	0.003	0.006	0.002	0.003	0.002	>0.0001	0.0001	>0.0001	0.002	0.003

APPENDIX A2

Site information

Table A2.1 Site information for sulfur dioxide monitoring

Site	Location	Start dates	EPA site #	Amg zone	Easting	Northing	Latitude	Longitude
Christies Beach	Winnerah Rd, Christies Beach	22/04/1992	0148	54	270244	6109682	138.478475	-35.129523
Elizabeth	Heard St, Elizabeth Downs	12/05/2002	0175	54	288946	6157975	138.695764	-34.698489
Kensington	East Tce, Kensington	13/08/2002	0178	54	286713	6133184	138.665116	-34.921403
Northfield	Royal Adelaide Hospital, Northfield	15/10/2002	0111	54	282704	6139680	138.622946	-34.862022

APPENDIX A3

Instrument specifications

This model is used at the currently operating sites in metropolitan Adelaide (i.e. Christies Beach, Elizabeth, Northfield and Kensington).

(All specifications for STP [standard temperature and pressure] from Operation Manual (ECOTECH 1999))

Instrument	ML ® 9850B SO_2 Sulfur Dioxide Analyzer by ECOTECH
Description	an ultraviolet (UV) fluorescence spectrometer comprising an optical sensor assembly, an analog electronic signal preprocessor module, microprocessor-based control and computation electronics, a pneumatic system that samples ambient air by point monitoring and a charcoal scrubber to provide SO_2-free reference air as a background
Range	0–20 ± 0.001 ppm
Noise (RMS)	during measurement – 0.25 ppb or 0.1% of concentration reading, whichever is greater; analog output – 0.5 ppb or 0.2% of analog output full scale, whichever is greater
Detection limit	during measurement – <0.5 ppb or 0.2% of concentration reading, whichever is greater; analog output – 0.5 ppb or 0.2% of analog output full scale, whichever is greater
Zero drift	Temperature – 0.1 ppb per ^oC; time (at fixed temperature) – <1.0 ppb over 24 hours, <1.0 ppb over 30 days
Span drift	Temperature – 0.1% per ^oC; time (at fixed temperature) – 0.5% of reading over 24 hours, 0.5% of reading over 30 days
Lag time	<20 seconds
Precision	0.5 ppb or 1% of reading, whichever is greater
Sample flow rate	0.65 slpm (standard litres per minute)
Pressure dependence	1% change in reading over 5% change in pressure
Operating temperature range	5^o C – 40^o C
Weight	21.3 kg
Analog output	0–5 volts